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GAC-MAC-IAH-CNC-CSPG 2022 Halifax Meeting: Abstracts, Volume 45

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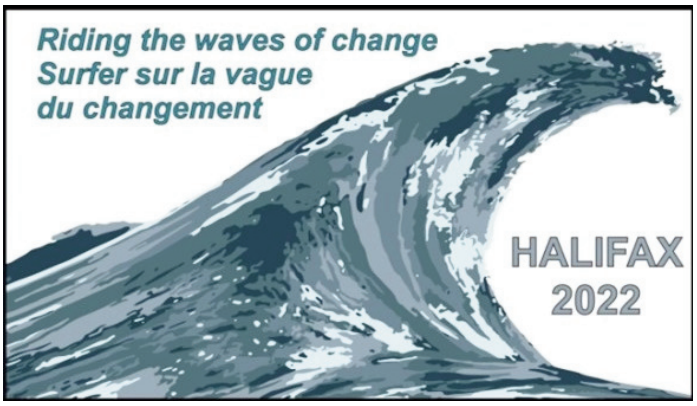
ABSTRACTS

GAC-MAC-IAH-CNC-CSPG 2022 Halifax Meeting: Abstracts, Volume 45



Introduction

First and foremost, thank you to all who authored and co-authored the abstracts assembled here. Without your participation, no Halifax 2022 conference could have happened. Seven years ago when the Atlantic Geoscience Society* agreed to host the conference as the centrepiece for the celebration of its 50th anniversary, the aim was to develop a diverse meeting – in terms of both the breadth of geoscience covered and the level of national and international participation. These abstracts demonstrate that both of those goals were achieved. We welcomed delegates (both in person and virtually) to Nova Scotia for this meeting that brought together the Geological Association of Canada (GAC), the Mineralogical Association of Canada (MAC), the Canadian Society of Petroleum Geologists (CSPG), and the Canadian National Chapter of the International Association of Hydrogeologists (IAH-CNC) and also included participation from members of the Canadian College and University Environmental Network. The preceding two years of largely virtual conferences provided us with new mechanisms for communication and resulted in a virtual component that no doubt will continue to be present at future meetings. We tried to develop an affordable hybrid model that retains the in-person experience while enabling meaningful participation by those unable to attend in person for a wide variety of reasons. The Halifax 2022 conference theme of "*Riding the Waves of Change*" was selected long before anyone had ever heard of COVID19. How appropriate that theme turned out to be – just as no one has been immune to the changes in our lifestyles over the past two years, so no earth scientist is immune from the changes in our science – the awareness of "critical elements", the urgent need to address climate change, plastic pollution and responsible mineral development, the advances in analytical techniques and the new discoveries they bring. Those changes are reflected in the abstracts for the conference, and in the wide range of associated short courses, workshops, field trips, and outreach events. I take this opportunity to personally thank the hard-working and dedicated members of the organizing committee for Halifax 2022, fondly known as the "LOC". This diverse group of individuals representing not only the scientific organizations involved in the conference, but also universities, federal and provincial governments, geoscience-related companies throughout Atlantic Canada and beyond volunteered many, many hours to pulling this event together. Without them, it would not have happened. I am especially grateful to my LOC co-chair, Rob Raeside, and GAC president Deanne van Rooyen, whose combined wisdom and hard work resulted in a "GAC-MAC meeting" unlike any before it and perhaps created a viable model for those that follow it.

Sandra Barr, Co-Chair and GAC representative
Halifax 2022 Organizing Committee

*The Atlantic Geoscience Society (AGS) brings together scientists interested in all aspects of earth science from universities, government institutions, and the mining, petroleum, and offshore exploration industries in the Atlantic Provinces. The AGS is active in public outreach and education, and the conference was a focus for the release of new publications including the second edition of *The Last Billion Years – A Geological History of the Maritime Provinces*, the new map *Journey Through Time: Places of Geological Significance in New Brunswick and Prince Edward Island*, a new brochure on *Nova Scotia Minerals and Gems*, and a new video release on Joggins and Arisaig. Visit https://atlanticgeosciencesociety.ca/ for more details on how to obtain these and other AGS products, and for more information about AGS activities. Everyone is welcome.

Introduction

Tout d'abord, merci à tous ceux qui ont écrit et co-écrit les résumés rassemblés ici. Sans votre participation, la conférence Halifax 2022 n'aurait pu avoir lieu. Il y a sept ans, lorsque la

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Société géoscientifique de l'Atlantique* a accepté d'accueillir la conférence en tant qu'élément central de la célébration de son 50e anniversaire, l'objectif était de développer une réunion diversifiée - à la fois par l'étendue des sujet géoscientifiques abordés et par le niveau de participation nationale et internationale. Ces résumés démontrent que ces deux objectifs ont été atteints. Nous avons accueilli des congressistes (en personne et virtuellement) en Nouvelle-Écosse pour cette conférence qui a réuni l'Association géologique du Canada (AGC), l'Association minéralogique du Canada (AMC), la Société canadienne des géologues pétroliers (SCGP) et Section nationale canadienne de l'Association internationale des hydrogéologues (AIH-SNC) et comprenait également la participation de membres du Réseau canadien des collèges et des universités en environnement. Les deux années précédentes de conférences essentiellement virtuelles nous ont fourni de nouveaux mécanismes de communication et ont abouti à une composante virtuelle qui continuera sans aucun doute d'être présente lors de futures réunions. Nous avons essayé de développer un modèle hybride abordable qui conserve l'expérience en personne tout en permettant une participation significative de ceux qui ne peuvent pas assister en personne pour des raisons très diverses. Le thème de la conférence Halifax 2022, « Surfer sur la vague du changement », a été choisi bien avant que quiconque n'ait jamais entendu parler de la COVID 19. À quel point ce thème s'est avéré approprié – tout comme personne n'a été à l'abri des changements dans nos modes de vie au cours des deux dernières années, aucun scientifique de la terre n'est à l'abri des changements de notre science – la prise de conscience d' « éléments cruciaux », l'urgence d'aborder les changement climatiques, la pollution plastique et le développement minéral responsable, les progrès des techniques analytiques et les nouvelles découvertes qu'ils apportent. Ces changements se reflètent dans les résumés de la conférence et dans le large éventail de cours et ateliers de courte durée associés, de visites sur le terrain et d'activités de sensibilisation. Je profite de l'occasion pour remercier personnellement les membres du comité organisateur de Halifax 2022, affectueusement surnommé le « LOC », qui n'ont pas ménagé leurs efforts et se sont dévoués à la tâche. Ce groupe diversifié de personnes représentant non seulement les organisations scientifiques impliquées dans la conférence, mais aussi les universités, les gouvernements fédéral et provinciaux, les entreprises liées aux géosciences à travers le Canada atlantique et au-delà, a consacré de très nombreuses heures à organiser cet événement. Sans eux, rien ne serait arrivé. Je suis particulièrement reconnaissante envers mon coprésident du LOC, Rob Raeside, et à la présidente de l'AGC, Deanne van Rooyen, dont la sagesse et le travail acharné ont abouti à une "réunion AGC-AMC" sans précédent et ont peut-être créé un modèle viable pour celles qui suivront.

Sandra Barr, coprésidente et représentante de l'AGC
Comité organisateur d'Halifax 2022

* La Société géoscientifique de l'Atlantique (SGA) regroupe des scientifiques intéressés par tous les aspects des sciences de la Terre, membres d'universités, d'institutions gouvernementales et des industries minières, pétrolières et d'exploration extracôtière des provinces de l'Atlantique. La SGA est active dans la sensibilisation et l'éducation du public, et la conférence a permis de mettre l'accent sur la parution de nouvelles publications, dont la deuxième édition de *The Last Billion Years – A Geological History of the Maritime Provinces*, la nouvelle carte *Journey Through Time: Places of Geological Significance in New Brunswick and Prince Edward Island*, une nouvelle brochure *Nova Scotia Minerals and Gems*, et une nouvelle vidéo sur Joggins et Arisaig. Visitez https://atlanticgeosciencesociety.ca/ pour plus de détails sur la façon d'obtenir ces produits et d'autres produits de l'AGS, et pour plus d'informations sur les activités de l'AGS. L'invitation s'adresse à tout le monde.

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CNC - SNC
International Association of Hydrogeologists
Association Internationale des Hydrogéologues

CSPG
Canada's Energy Geoscientists

ATLANTIC GEOSCIENCE SOCIETY

ALPHABETICAL LISTING OF ABSTRACTS

VIRTUAL FIELD TRIP: STRUCTURAL RECORD OF TERRANE ACCRETION IN THE SW IBERIAN MASSIF

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The southwestern Iberian Massif (Variscan Orogen) attests to the accretion of three continental terranes in the Late Paleozoic; they are, from north to south, the Central-Iberian Zone (CIZ), the Ossa-Morena Zone (OMZ), and the South-Portuguese Zone (SPZ), separated by orogenic sutures. The collision of these terranes had a marked left-lateral oblique component. The southern CIZ contains a variably folded Ediacaran–Early Carboniferous succession and seems to represent the northern edge of the Gondwana continent. The OMZ is also a northern Gondwanan continental piece, but separated from the CIZ by the so-called Badajoz-Córdoba Shear Zone, which includes retroeclogitic amphibolite bodies of Early Paleozoic age. The OMZ is characterized by a Late Proterozoic–Early Carboniferous succession. A continental rifting event stands out in the Early Paleozoic (pre-Variscan) and another one in the Early Carboniferous (intra-Variscan). The main deformation is Devonian in age and developed large-scale SW-vergent recumbent folds rooted in the Badajoz-Córdoba Shear Zone. The Early Carboniferous sedimentary rocks are associated with significant magmatism, and were in turn deformed in the Upper Carboniferous. The SPZ is interpreted as a portion of Avalonia, with outcrops of Devonian and Carboniferous rocks deformed by SW-vergent folds and thrusts during the Carboniferous collision with the OMZ. Three units crop out in the OMZ-SPZ boundary: (1) the allochthonous Cubito-Moura (rocks with high-pressure metamorphism and mafic rocks with oceanic affinity); (2) the Beja-Acebuches Amphibolite; and (3) the metasedimentary Pulo do Lobo. This boundary is considered part of the Rheic Ocean suture and had a complex evolution. The itinerary in this field trip guide traverses the three zones (terranes) of SW Iberia and focuses mainly on the boundaries between them. A total of 8 stops (some of them include multiple outcrops) are described from the SPZ to the southern CIZ.

VIRTUAL FIELD TRIP: THE EO-VARISCAN STRUCTURES OF THE EASTERN MOROCCAN MESETA

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The deformed Paleozoic sequence of the eastern Moroccan Meseta is exposed in relatively small and isolated outcrops. This field trip is focused on two of the largest Paleozoic inliers: Debdou and Mekkam. They are characterized by a monotonous sequence of slates and greywackes (Debdou-Mekkam metasedimentary units, DMMS). Recent U–Pb data on detrital zircon grains suggest a Late Devonian maximal depositional age for these rocks. The sequence is deformed by at least two folding events associated with low- to very low-grade metamorphic conditions. The first eo-Variscan phase (D1) is characterized by overturned to recumbent, tight to isoclinal, multi-kilometre-scale folds with SE-vergence and pervasive axial-planar cleavage. This tectonic event is related to the collision of an Avalonian promontory with the northern margin of Gondwana, as suggested by the presence of Avalonian-sourced detrital zircon grains in the DMMS. Furthermore, the DMMS are unconformably overlaid by a Late Visean volcano-sedimentary sequence, which is not deformed by the D1 event. Therefore, this eo-Variscan event must have occurred during Early Carboniferous time (Tournaisian–Early Visean). Later Variscan events (Dc) of likely Late Carboniferous age are characterized by variably oriented open folds, mainly with kink-band or chevron geometry, developing a locally intense spaced crenulation cleavage. This field trip has 10 stops through the Debdou-Mekkam inliers to observe the alternation of normal and inverse limbs of the multi-kilometre-scale D1 folds.

EASTWARD DISPLACEMENT OF THE OSSA-MORENA ZONE IN LATE CAMBRIAN–EARLY ORDOVICIAN TIME ALONG THE NORTHEASTERN GONDWANA MARGIN

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The Ossa-Morena Zone (OMZ), in SW Iberia, has generally been interpreted as being attached to the West African Craton (WAC) in Ediacaran–early Paleozoic times. Nevertheless, its early Paleozoic paleogeographic position is a matter of debate among those who propose an eastern location, close to the Tuareg Shield, and those who suggest that the OMZ never drifted too far away from the WAC. In this study, we analyze U–Pb detrital zircon geochronological data from 22 Ediacaran–Early Devonian samples from the OMZ. All the Ediacaran and Cambrian samples are characterized by a prevalent late Tonian–Ediacaran detrital zircon population (ca. 850–540 Ma, 45–90% of the data), a secondary Paleoproterozoic (ca. 2.2–1.7 Ga) peak, some Archean (ca. 2.8–2.5 Ga) grains, and the systematic lack of Mesoproterozoic (ca. 1.7–1.1 Ga) ages. These characteristics are usually considered to be the typical WAC signature. On the contrary, the Middle Ordovician–Early Devonian samples always contain an important and systematic Stenian–early Tonian detrital zircon population (ca. 1.1–0.85 Ga, ca. 20% of the data). This population is almost absent in older Ediacaran–Early Cambrian rocks (only 4–8% in 5 of 16 samples; probably recycled), in accordance with previous data. Sources of around 1 Ga can be found in NE African regions (e.g. Sahara Metacraton and/or Arabian-Nubian Shield). Based on these new data, we interpret the OMZ as having been attached to WAC until at least Mid-Cambrian time. During Late Cambrian–Early Ordovician time, dextral strike-slip movements along the northern margin of Gondwana would have displaced the OMZ eastwards, perhaps favoured by a very oblique tectonic setting during the Rheic Ocean opening. Since Middle Ordovician time, the sediments deposited in the OMZ were sourced from the Sahara Metacraton, which would have provided detrital zircon age populations similar to the ones fed from the WAC (late Tonian–Ediacaran, Paleoproterozoic, and Archean), plus the important Stenian–early Tonian population observed in our Ordovician–Early Devonian samples.

ON RHYTHMIC ZONATION IN IGNEOUS Ti–ANDRADITE GARNET FROM THE CROWSNEST FORMATION, CANADA

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Titanian andradite crystal clasts are diagnostic of pyroclastic deposits of the lower member of the Crowsnest Formation in southwestern Alberta, Canada. These deposits were erupted from a trachyte-phonolite magma during late Albian time.

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The garnets are euhedral and exhibit complex zonation patterns that are apparent in thin section (plain polarized light) and in μXRF mapping. These analytical techniques are too coarse to provide detailed analyses of zonation features. Titanian andradite is not amenable to cathodoluminescence mapping due to the high Fe content and another approach is needed. SEM backscatter electron imaging is used in conjunction with photographic enhancement techniques to create vivid images of zonation in grey scale from polished sections. Macroscale and microscale variations are clearly visible, reflecting atomic mass variation of the constituent elements within well-defined zonation regions. To investigate quantitative variation, EPMA traverses with 2 μm point spacing are used for detailed investigation whereas 50 μm spacing is used to investigate variation across an entire garnet. The images and EPMA data are combined in a non-earth coordinate system using MapInfo GIS software where thematic mapping using inverse distance squared analyses of element and element ratios is applied with accurate special resolution. Rhythmically zoned rims comprise between 60% and 85% of the garnet cross section surrounding a garnet core. Zonation occurs as concentric macro bands (100 to 500 μm wide) of elevated Fe and Ti versus bands of elevated Si and Al. Within the latter, thin micro-intervals between 4 and 40 μm are characteristic, whereas within the Fe- and Ti-enriched regions, thicker internal intervals between 20 and 70 μm are typical. Interval boundaries are both sharp and diffuse. We interpret the banding as the result of cyclic crystallization in an open system in which turbulence in the magma chamber is indicated. Crystallization occurred in cycles of silica saturation and silica undersaturation with titanium incorporation as a potential indicator. Coupled substitutions (Al-Fe^{3+}, Si-Ti, Ca-Mn, Mg-Fe^{2+}) have been demonstrated by previous studies. In context, we demonstrate that studied zonation and related substitutions have a distortive effect on the crystal lattice as demonstrated by cleavage in broken garnets that mimics the zonation pattern. This study has implications for determining optimal regions for application of radiogenic isotope systems and isotope tracer studies related to Fe-rich garnet. Furthermore, micro analyses can support investigations into the incorporation of REE, Y and U in such garnets facilitated by lattice strain due to substitutions, particularly Ti.

IGCP'S OUTREACH FOR 50 YEARS: EVOLUTION FROM EAST-WEST MALE RESEARCHER COLLABORATION TO GLOBAL OUTREACH WITH GENDER EQUALITY AND A PERSPECTIVE FOR A SUSTAINABLE FUTURE FOR OUR PLANET

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The International Geoscience Program (IGCP) is the oldest and most successful example of a scientific partnership between a non-governmental organization (the International Union of Geological Sciences; IUGS) and an intergovernmental organization (UNESCO). The IGCP projects have always been delivered through international collaboration but in the early years of the Program, projects leaders consisted mostly of male geologists from western and eastern hemispheres with projects having co-leaders from less than five countries. Since its 40th anniversary in 2012, IGCP carried out extensive outreach initiatives to improve global participation and gender equality with an important focus on developing countries around the world and north-south hemisphere collaboration. Earth sciences are still largely represented by male scientists but, as a result of a strong prioritization on the participation of female scientists, in particular of young female scientists from developing countries, in 2021, 40% of the active project leaders and 46% of participants were female geologists, and early career (42%) and developing world (47%) participations continued to increase from a 25% ratio in 2012. In 2021, more than 6000 participants from 126 countries worked together to deliver the objectives of 57 (22 in 2015) active IGCP projects led by 326 project leaders (168 in 2015) from 92 (53 in 2015) countries. Today, IGCP projects are being delivered by up to 18 project leaders from more than 15 different countries. For 50 years, IGCP adapted global requirements and recently focused on responsible and environmental resource extraction, natural hazard resilience and preparedness, as well as adaptability in an era of changing climate. Collaborative projects with a special emphasis on the benefit to society, capacity-building, and the advancement and sharing of knowledge among earth scientists are currently being prioritized by the IGCP Council. In addition to five main themes (geohazards, geodynamics, earth resources, global change, hydrogeology), IGCP launched special calls for proposals related to Geoheritage, Geoparks, Geodiversity, Anthropocene, and Artificial Intelligence (AI) applications in the Geosciences, as well as enhancing societal acceptance of the Sustainable Development of Earth's Geological Resources. Geoscience is paramount for the successful implementation of the Sustainable Development Goals. UNESCO is the only United Nations organization with a mandate to support research and capacity building in geology and geophysics. Through their flagship program IGCP, UNESCO and IUGS are committed to continue contributing to the implementation of UN Sustainable Development Goals with a special focus on empowering women (SDG 6) and enabling international collaboration (SDG 17).

USING MICRO-XRF ELEMENTAL MAPPING TO CHARACTERIZE ALTERATION AND PARAGENESIS OF THE BASS RIVER MAGNETITE IOCG PROSPECT, NOVA SCOTIA

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The regional alteration footprints of fluids responsible for the formation of metasomatic iron alkali-calcic (MIAC)-affiliated critical mineral deposits can be difficult to recognize in the field as the alteration minerals commonly pseudomorph the country rock, preserving primary textures, and there may be multiple phases of alteration in single areas. Discrimination tools using whole-rock geochemical data from multi-analytical technique methods (e.g. X-ray fluorescence on prepared borate fusions, or mass spectrometry on closed-vessel microwave multi-acid digestions) are key in identifying metasomatized rock. However, these data can be challenging to interpret when multiple hydrothermal events have altered the rocks. Additionally, important in-situ information is lost such as the mineralogical controls and paragenesis of important critical mineral commodities. In this study, false-colour elemental-distribution maps produced by micro-X-ray fluorescence (XRF) are examined for magnetite breccias of the Bass River IOCG prospect, Nova Scotia, Canada. The method uses a Bruker M4plus Tornado Super Light Element micro-XRF equipped with a Rh X-ray source at an accelerating voltage of 50 kV and a beam current of 600 nA focused to a 20 μm spot size. Maps were produced on split NQ drill core at a resolution of 60 to 100 μm between spots and a counting time of 30 ms/pixel (~6–10 hours per map). Using the M4 software, semi-quantification of trace elements in discrete phases and areas is possible to allow for detection of important critical metals. These maps show K-Fe alteration facies (biotite-magnetite) overprinting albitized (Na-altered) volcanic and metasedimentary rocks. Pyrite associated with magnetite is variably enriched and zoned in Co (up to 1.5 wt.%). Late calcite brecciates/overprints the K-Fe mineral facies and is variably enriched in Y (up to 1000 ppm), suggesting late remobilization of rare earth elements in the MIAC system of the Cobequid-Chedabucto Fault Zone of Nova Scotia. The results of this study support micro-XRF mapping as a non-destructive and relatively quick technique complementary to geochemical analysis in the discrimination of alteration footprints of MIAC systems.

REVIEW: THEORY-GUIDED MACHINE LEARNING APPLIED TO HYDROGEOLOGY—STATE OF THE ART, OPPORTUNITIES AND FUTURE CHALLENGES

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Thanks to recent technological advances, hydrogeologists now have access to large amounts of data acquired in real time. Processing these data using traditional modelling tools is difficult and poses a number of challenges especially for tasks such as extracting useful features, uncertainty quantification or identifying links between variables. Artificial intelligence, and more specifically its subset 'machine learning' (ML), may represent a way of the future in hydrogeological research and applications. Unfortunately, several aspects of machine-learning methods hamper its adoption as a complementary tool for hydrogeologists, namely the black-box nature of most models, an often limited generalization ability, a hypothetical convergence, and uncertain transferability. Recently, an entirely novel paradigm in the field of machine learning has been identified—theory-guided machine learning—in which the mod-

els integrate some specific theoretical knowledge, laws or principles of the field of study. This review article sets out to examine three theory-guided methods in their ability to overcome the limitations of machine learning for hydrogeological research and applications. These methods are, respectively, theory-guided constrained optimization (TGCO), theory-guided refinement of outputs (TGRO) and theory-guided architecture (TGA). The analyses led to the following conclusions: the opacity of ML models can be reduced by any of the three theory-guided ML methods; convergence and generalizability can be enhanced by TGCO, TGA, or a combination of at least two of the theory-guided ML methods; and no study conducted to date has made it possible to deduce the effectiveness of these methods on the transferability of ML models.

MINERALOGICAL, CHEMICAL, AND MICROBIOLOGICAL ANALYSES TO EVALUATE THE POTENTIAL IMPACTS OF SUBMERGING OXIDIZED TAILINGS AND ADDING A COVER

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Oxidation of sulphide minerals results in the generation of acid and formation of various secondary phases including Fe(III) oxyhydroxide phases, jarosite, and gypsum, which can attenuate metal(loid)s by precipitation, co-precipitation, and adsorption reactions within the tailings. The abandoned Cu-Ag mine at Mine Principale, Chibougamau, Québec, where some parts of the tailings impoundment have undergone oxidation for more than 60 years, was investigated by mineralogical, chemical, and microbiological analyses to evaluate the potential impacts of the proposed application of an elevated water table (EWT) technique on the partly oxidized tailings. The EWT technique, which usually involves raising the water table and maintaining it above reactive tailings, limits sulphide mineral oxidation by minimizing $O_2(g)$ ingress into the tailings due to the low diffusivity of $O_2(g)$ in saturated media. The EWT, however, has the potential to cause direct dissolution of soluble secondary phases, but also can potentially induce reducing conditions that promote microbially catalyzed reductive dissolution of Fe(III) oxyhydroxide phases fueled by organic C compounds. Mineralogical and selective chemical extraction techniques indicated the presence of various secondary phases including Fe(III) oxyhydroxide phases that are associated with significant amounts of hazardous metal(loid)s including As, Ni, Co, Cr, and Zn. Amplicon sequencing of ^{16}S rRNA genes showed significant abundances of sulphur- and iron-metabolizing prokaryotes in the tailing samples. Solid-phase analyses indicated a low amount of total C in the oxidized tailings; however, because the site is vegetated, the carbon content may increase with time. These findings suggest that hazardous metal(loid)s associated with various secondary phases, particularly Fe(III) oxyhydroxide phases, can potentially be remobilized via microbially catalyzed reductive dissolution reactions if the EWT technique allows infiltration of labile organic C into the tailings.

GEOCHEMICAL AND MINERALOGICAL INVESTIGATIONS OF TAILINGS AND SMELTER WASTE FROM ABANDONED GOLD, SILVER AND NIOBIUM MINES IN ONTARIO AND QUEBEC

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Geochemical and mineralogical investigations are presented from three abandoned mines in Ontario and Quebec. Niobium production near Oka, Quebec, (1961–1976) used aluminothermic reduction of pyrochlore-group minerals and generated REE-, U- and Th-rich slag that was discarded at the site. Weathering of the slag was investigated using unsaturated columns containing crushed slag (40 to 100 mm) that were leached with simulated rainwater. The primary slag mineralogy is dominated by hibonite, β-alumina, perovskite, Ca-zirconate and F-Na-bearing Ca-aluminate glass. The column effluent is characterized by high pH (maximum 13.2) and elevated concentrations (mg/L) of Al (up to 3025), F (704), Ca (586), Na (14,980) and K (538). Concentrations of Ce, U and Th were generally < 1 mg/L but U reached as high as 13 mg/L in the initial effluent. Secondary minerals are dominated by amorphous Al, Ca, Si, Fe oxyhydroxides with traces of fluorite, barite and Ba-Sr-SO_4 solid solution. Cerium is the dominant REE and it is released by weathering of perovskite, hibonite and Ca-aluminosilicate glass, but then sequestered by coprecipitation with Ca-Al oxyhydroxide. No secondary U- and Th-containing phases were identified. Silver mining at Cart Lake near Cobalt, ON, occurred intermittently from 1910 to 1983 leading to the infill of the lake with tailings which are the focus of an investigation studying the porewater geochemistry and mineralogy. The porewater pH ranges from ~7.9 to 8.5 and although Ca is the dominant cation, ranging from 22 to 192 mg/L, As is a major aqueous component, ranging from ~0.95 to 18 mg/L. The elevated As concentrations are due to oxidation of primary sulpharsenide minerals including pyrite, arsenopyrite, skutterudite, and safflorite/clinosafflorite/löllingite solid solution members. Secondary minerals formed during weathering include erythrite, ferric arsenate and mixed Ca-Fe(III)-As-O phases, all occurring as coatings on primary minerals and as infill in pore spaces. Gold mining (1908–1939) at Long Lake near Sudbury, Ontario, created arsenopyrite-rich tailings that have oxidized forming surficial crusts cemented by ferric arsenate and jarosite. Erosion and subsequent transport of the tailings and cemented crusts into Long Lake formed a delta, and burial of the oxide-phase weathering products has stimulated diagenetic reductive dissolution. Mineralogical investigations of sediment in the delta demonstrate that reductive dissolution of the ferric arsenate is incongruent, involving reductive dissolution of arsenate leaving a Fe-oxyhydroxide residual phase. Some of the Fe(III) forms unique mm-scale spheroids composed of intergrown crystalline Fe-oxyhydroxide ± Si-Al-Ca-Mg clay minerals.

GARNET U–Pb DATING BY LA-ICP-MS: A STUDY OF (EO-) VARISCAN METAMORPHIC AND HYDROTHERMAL EVENTS

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Laser-ablation ICP-MS U–Pb dating has proven to be of great value for many geoscience disciplines. For a long time, this technique has primarily been used to date accessory minerals such as rutile, monazite, and especially zircon. Recently, this technique has been applied to low U and high common Pb rock-forming minerals, such as garnet. Given its petrological importance, e.g. in metamorphic rocks, garnet has a huge potential that the geochronological community is currently (re)assessing. In this communication, we discuss a variety of garnet U–Pb dates related to (eo-) Variscan metamorphism. The investigated samples represent skarn grossular-andradite garnet and almandine-pyrope regional metamorphic garnet. The U concentrations of the selected garnet specimens range from several μg/g to below ng/g levels, facilitating an evaluation and discussion of the significant analytical challenges associated with very low U concentrations. The garnet U–Pb dating results, from diverse lithologies and localities, record many prominent Devonian–Carboniferous metamorphic and post-metamorphic events at the northern edge of Gondwana. These include (1) gneisses and eclogites from the ultra-high pressure Gneiss-Eclogite Unit (Erzgebirge, Central Europe), (2) eclogites of the high-pressure and high-temperature Upper Units of the Cabo Ortegal Complex (NW Iberia), (3) a biotite-garnet-staurolite micaschist from Le Conquet (Britany, West Europe), and (4) several skarns from the Erzgebirge (Central Europe). The garnet dates obtained are compared with published dates obtained from zircon, monazite, and whole-rock isochron analyses. With these and other examples shown during the communication, together with a previous talk covering technical and interpretative aspects of the method, an overview of the state of the art will be presented of this new and emerging geochronology tool.

MODELING THE STRATIGRAPHIC AND FACIES ARCHITECTURE OF THE CAMBRIAN ATLAS–OSSA-MORENA–NORTH-ARMORICAN RIFT ALONG WEST GONDWANA

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During Cambrian times, an active network of rift axes fringed West Gondwana, linking what we know now as the Anti-Atlas (or Souss Basin), the northern High Atlas

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and Moroccan Coastal Meseta, the Ossa-Morena Zone of the Iberian Massif, and the North Armorican Domain of the Armorican Massif, forming the so-called Atlas–Ossa-Morena–North-Armorican Rift. A latest Ediacaran to Fortunian pre-rift unconformity lies at the base of the Adoudou (Anti-Atlas), Torreárboles–Bodonal (Ossa-Morena Zone) and Couville (North Armorican Domain) formations. The overlying Terreneuvian-Miaolingian strata are punctuated by several syn-rift unconformities, recognizable as both angular discordances and paraconformities, and associated with tilting/uplifting events, and volcanic and hydrothermal pulses. For about 60 Myr, the rifting processes propagated "zip-like" along the main axes and then widened cratonward affecting inner parts of the peri-Gondwana margin. Lithological and facies indicators of subtropical climate occur in Terreneuvian-Cambrian Series 2 peritidal and shallow-water marine substrates, whereas temperate-water indicators dominate the contemporaneous deeper parts of the (half-)grabens, becoming ubiquitous in Miaolingian times. A Furongian break-up (or rift/drift) unconformity is well represented at the Tabanite/Lower Fezouata (Anti-Atlas), the Main Rifting Volcanic Group/Barriga (Ossa-Morena Zone) and the Montabot/Armorican Quartzite (North Armorican Domain) lithostratigraphic contacts. The correlative break-up unconformities are related to thermal doming, uplift and denudation of elevated areas, and are regionally known as Toledanian Phase and Lacaune Normande, which mark the beginning of passive margin conditions.

THE CRYPTIC RECORD OF THE SYN- TO POST-RIFT TRANSITION IN THE OFFSHORE CAMPOS BASIN, SE BRAZIL

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Rift basins typically comprise three main tectono-stratigraphic stages: pre-, syn-, and post-rift. The syn-rift is characterized by deposition of asymmetric wedges of growth strata that record differential subsidence caused by active normal faulting. The subsequent post-rift is defined by long-wavelength subsidence driven by lithospheric cooling and typified by the deposition of tabular stratal packages that drape rift-related relief. The stratigraphic contact between syn- and post-rift rocks is often expressed as an unconformity. However, the late syn-rift to early post-rift stratigraphic record is commonly more complex since the associated tectonic transition is not instantaneous and strain often migrates oceanward during rifting. As such, idealized tectono-stratigraphic models often fail to capture the stratigraphic position and character of the syn- to post-rift transition observed in natural rifts. The marginal basins of southeastern Brazil, including the Campos Basin, have not historically used the aforementioned tripartite scheme; the post- to pre-rift interval is instead subdivided into rift, sag, and passive margin tectono-stratigraphic stages. The sag stage has been described as late syn-rift, early post-rift, or as a transition between them, with the passive margin stage being equivalent to the classically defined post-rift stage. Two (rather than one) erosional unconformities are identified within the rift to sag succession. We use seismic reflection and borehole data to discuss the expression of and controls on the syn- to post-rift transition in the south-central Campos Basin, offshore Brazil, with focus on the tectono-stratigraphic significance and context of the sag stage within the rifting process. We show that the rift stage is characterized by wedge-shaped packages of reflections that thicken towards (half-) grabens-bounding normal faults. This stage ends with the development of an unconformity. The sag stage is subdivided into pre-salt and salt; the former is defined by packages of subparallel, continuous reflections that are lenticular and thin towards fault-bounded basement highs, that locally diverge towards rift-related normal faults. The pre-salt to salt contact is defined by an erosional unconformity that is largely restricted to basement highs, and which is inferred to have formed due to base-level fall and uplift associated with local fault reactivation. The described unconformities pre-date and thus do not originate from the breakup event; thus, we infer that the sag stage is late syn-rift at the margin-scale, but post-tectonic within the context of the study area, recording a time when rifting had migrated basinward, but not to such an extent that all inboard faults were inactive.

RESISTIVITY OF BURIED VALLEY AQUIFERS IN THE EDMONTON REGION USING NEAR SURFACE AND AIRBORNE GEOPHYSICS

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Buried valley aquifers underlying the Edmonton region are a potential source of potable groundwater in the area. The general location of the valleys has been mapped previously. However, the sedimentology of the valley fills and hydraulic properties are less known and are vital for assessing the buried valley groundwater flow systems. This study builds on previous work by more closely examining the valley network extent, depth, and geometry via water well reports, and identifying electrical resistivity tomography (ERT) sites for further valley characterization. Areas of hydrogeological interest, considerable sediment thickness and convergence of valleys were a priority. Available airborne electromagnetic (AEM) data were used to identify valleys at a larger scale. ERT resistivity values ranged from lower resistivity, indicating finer fill at 15–30 Ω$m to higher resistivity possibly indicating coarser sediment at 70–230 Ω$m. We found that varying sediment moisture content did not appear to have a strong effect on resistivity. ERT surveys done over the proposed mapped extent as well as the main thalwegs provided an understanding of geometry and further definition of the actual extent of the buried valleys with thalweg depths up to 80 m. Comparisons of geophysical results and surface outcrops in addition to well log data has confirmed that buried valleys can be composed of finer sand to coarse gravel, where coarser sediment with higher resistivities are indicated in the larger valleys originating from the west. AEM data provided confirmation of mapped valley extents for areas outside of the city of Edmonton but could not be directly compared with the ERT lines that were completed within city limits and not covered by AEM data. This improved understanding of buried valley sedimentology and extent has aided groundwater modelling to better assess the valley network flow systems within the Edmonton region. The ERT data combined with well logs, outcrop identification, and AEM has provided better characterization of buried valleys in the Edmonton area. These results can be used to make informed decisions regarding the water security of central Alberta.

WHAT THE VERTEBRATES OF BLUE BEACH, HANTSPORT, NOVA SCOTIA (HORTON BLUFF FORMATION, TOURNAISIAN) TELL US ABOUT THE NATURE OF ROMER'S GAP

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The vertebrate fossils from Blue Beach, located on the Avon River estuary near Hantsport, Nova Scotia, represent one of the earliest records (Tn2-Tn3) within the worldwide hiatus in the fossil record known as Romer's Gap. Although trackways of tetrapods were known dating from the mid-19th century, bones were not found until much more recently and, because the depositional environment was a high-energy, near-shore facies, fossils are found disarticulated. This, coupled with a lack of good comparative material from elsewhere, led to formal descriptions not appearing until 2015.The tetrapod record is diagnosable to a roughly familial level, and demonstrates a surprising overlap of taxa present much later in the Carboniferous as well as forms otherwise only known from the Late Devonian. This pattern of faunal overlap is replicated among the ray-finned fishes, which are known from both generalized forms typical of Late Devonian faunas as well as the earliest known, deep-bodied form typical of the later occurring Carboniferous genus *Platysomus*. This pattern, consistent with contemporary sites elsewhere, conflicts with what Romer had envisioned from this time, when he expected to find more species transitional between the two faunas. Furthermore, no tetrapods currently known as fossils were likely to have been terrestrial in their ecology, which presents a quandary when one considers the large number of trackways present in the various horizons outcropping at Blue Beach. Much more remains to be discovered between the tides of Minas Basin.

HINDCASTING HYDROLOGICAL SIMULATIONS IN A SMALL SNOW-DOMINATED BOREAL CATCHMENT, QUÉBEC, CANADA

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Understanding the relationship between evapotranspiration and other components of the water cycle in a humid boreal forest, and estimating evapotranspiration rates, represent a challenge because of complex climate characteristics and vegetation cover. Hindcasting climate models, that reproduce past hydrometeorological conditions, can be useful to address such challenges. The integrated surface-subsurface hydrologic model HydroGeoSphere model is applied to an experimental catchment to simulate the entire hydrological cycle over 55 years and to estimate evapotranspiration rates. The experimental catchment is located in Montmorency Forest, Québec, Canada. It has an area of about 1 km^2 and is covered mainly by balsam fir and birch. The average precipitation is about 1500 mm/year (40% as snow) while the discharge reaches about 1050 mm/year. A flux tower is located within the catchment and reports all important atmospheric variables, including net radiation, soil heat flux, and surface fluxes. The catchment is underlain by heterogeneous sediments of glacial origin, mainly tills, that were deposited on top of a low-permeability bedrock. A total of six hydrogeological units were identified and included in the HydroGeoSphere model. A three-dimensional mesh consisting of triangular prisms was constructed to represent these six units. The surface water domain was also discretized with triangular elements and refined along the main stream. The model is calibrated to reproduce the discharge data measured at a gauging station and water levels measured in two piezometers. The calibration is in two successive steps, with the first step covering the hydrological year 2017–2018, while the second step exploits the years 2015–2017 and 2018–2019. An internal module in HydroGeoSphere is used to calculate evapotranspiration and the calibrated model is then run for 55 years (1965–2020) to compare simulated evapotranspiration rates with those from the climate reanalysis of ERA5-Land and rates measured at the flux tower. Results show that the higher values of average annual evapotranspiration are for the observations (550 mm/year), followed by the numerical model (482.9 mm/year), and the ERA5-Land reanalysis (431.7 mm/year). Some divergence between the three approaches is expected since the input precipitation for the model is taken from a meteorological station located 3 km away from the study site and outside of the catchment, where total measured precipitation is lower than at the nearby flux tower. Furthermore, the ERA5-Land reanalysis further accounts for condensation, which can be significant during the snowmelt period, with a compensating effect on evapotranspiration

NEW CONSTRAINTS ON THE TIMING AND NATURE OF METAMORPHISM IN THE EASTERN MEGUMA TERRANE, NOVA SCOTIA, CANADA

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The Meguma terrane of mainland Nova Scotia consists mainly of Cambrian to Ordovician metasedimentary rocks intruded by peraluminous leucogranite, and minor diorite and tonalite between 380 Ma to 360 Ma. The metasedimentary rocks were variably metamorphosed to greenschist to amphibolite facies during the Devonian, but the timing of the metamorphic events is poorly constrained. Northeast of Sherbrooke, rocks of the Halifax and Goldenville Groups are exposed south of the West River St. Mary's Fault where they are intruded by the granitic Kelly Brook and Cranberry Lake plutons which are variably mylonitized. The pelitic rocks in this area contain muscovite + biotite ± garnet ± staurolite. Garnet and staurolite are present as idioblastic porphyroblasts. Foliation trails in garnets are at a high angle to the external foliations and external foliation wraps around garnet grains whereas trails in staurolite are mostly continuous internally and externally. Garnet is interpreted as the earliest porphyroblastic phase while syn- to post-deformational staurolite post-dates garnet. Garnets have distinct Mn-rich cores transitioning to Mg-rich rims typical of prograde metamorphic growth zoning. The growth of staurolite after garnet suggests that amphibolite facies conditions persisted for some time. P-T estimates indicate peak metamorphic conditions of at least 550–620°C and 4–6 kbar. A new garnet Lu–Hf age of 372.7 ± 1.4 Ma constrains the timing of amphibolite facies metamorphism. This age is indistinguishable from the published U–Pb zircon crystallization age of 375 ± 4.6 Ma for the deformed Kelly Brook pluton which intrudes these metapelitic rocks. Together with a 369 ± 1.2 Ma $^{40}Ar/^{39}Ar$ muscovite cooling age also from the Kelly Brook pluton, it is clear that this area reached amphibolite facies metamorphic conditions characterized by rapid porphyroblast growth during or shortly after granite emplacement. The whole northeastern Meguma terrane was an extremely active tectonic environment between 375 Ma and 365 Ma where regional-scale deformation and contact metamorphism overlapped in time and space, and was rapidly followed by exhumation. Major intrusive episodes with associated high-grade metamorphism and regional-scale exhumation in the southern Meguma terrane are separated by at least 40 Ma in contrast to the northern part, which was the leading edge of Meguma during its collision with Avalonia.

AGE, PETROLOGY, AND CRITICAL ELEMENT POTENTIAL OF DEVONIAN PLUTONIC ROCKS IN THE EASTERN MEGUMA TERRANE, NOVA SCOTIA

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The eastern Meguma terrane is characterized by a 7750 m-thick succession of Cambrian-Ordovician metasedimentary rocks representing the upper part of the Goldenville Group and lower part of the Halifax Group that were intruded by abundant mid- to late Devonian granitoid plutons. Less voluminous intrusions of diorite-tonalite and minor gabbro are associated with plutons along the northern margin of the terrane (Trafalgar plutonic suite, Cranberry Lake pluton, Bull Ridge pluton, Lost Lake pluton). The mafic-intermediate intrusions contain abundant metasedimentary xenoliths and show magma mingling textures with their adjacent granitic plutons. Mafic-intermediate rocks do not appear to be associated with larger plutons (e.g. Halfway Cove, Larrys River, Queensport, Sherbrooke, Canso) in the easternmost part of the terrane at the present level or erosion. A swarm of lamprophyric dykes along the southern coast of the eastern Meguma terrane does not appear to be associated with granitoid bodies. All the mafic-intermediate rocks are calc-alkalic and have chemical characteristics consistent with origin in a continental margin magmatic arc, this providing constraints on the tectonic setting of the spatially and temporally associated granitic magmatism. The granitoid plutons consist of peraluminous granite to granodiorite, contain abundant metasedimentary xenoliths and have "S-type" geochemical characteristics including high SiO_2 concentrations (> 65 wt.% SiO_2), primary muscovite, and garnet. Whole-rock chemical data from more than 200 representative samples from granitoid plutons and related pegmatite dykes show that all the plutons have similar major, trace element and rare-earth element compositions. Whole-rock epsilon Nd(t) values are between +1.9 (quartz diorite) and -8.1 (biotite granite) but most samples, including both granitoid and mafic-intermediate samples, have values between -2.0 and -4.0. Several of the granitoid plutons are associated spatially and temporally with pegmatite and greisen containing rare element mineralization. Some pegmatite dykes contain cm-sized beryl and others contain Nb-Ta oxides. On-going work using zircon U–Pb, trace element, and Hf-O isotopic data will better constrain the ages of both mafic-intermediate and granitic rocks and will enable better evaluation of the crustal and mantle components of these rocks and their genetic relationship.

TESTING PETROGENETIC MODELS FOR CONTEMPORANEOUS MAFIC AND FELSIC-INTERMEDIATE MAGMATISM

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Tectonomagmatic processes can transport large volumes of magma generated in the deep crust as discrete pulses to shallower crustal depths, resulting in the incremental

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construction of large composite batholiths that are assembled over thousands to tens of millions of years. Rocks with felsic to intermediate compositions dominate these batholiths but they are commonly associated with mafic plutons and enclaves. Even in different tectonic settings, mafic and felsic-intermediate rocks can share similar trace and rare-earth element concentrations. Models of fractionation of a mafic magma to generate the felsic-intermediate magmas are commonly invoked. However, the genetic relationships between the apparently coeval but compositionally dissimilar magmas are unclear. To test the relationship between apparently coeval mafic and felsic-intermediate magmas, we selected two areas where the regional geological context is well-known including Ediacaran plutons in the Antigonish Highlands, Nova Scotia and Silurian-Devonian plutons in northwestern Ireland. Gabbroic and dioritic to granitic plutons in the Antigonish Highlands have geochemical characteristics indicative of a calc-alkaline arc tectonic setting. These plutons were emplaced at shallow crustal depths, and some were comagmatic with volcanic components of their host rocks. U–Pb zircon dating shows the gabbroic and dioritic to granitic plutons were coeval and emplaced between ca. 615 to 604 Ma. The Silurian to early Devonian Donegal composite batholith in Ireland is a classic example for which regional geological syntheses and lithogeochemical data show emplacement was syn- and post-kinematic with respect to the terminal phases of the Caledonian orogeny (ca. 437–415 Ma). Geochemical characteristics favor a model in which emplacement occurred in a slab-failure tectonic setting. Regional syntheses indicate that the onset of slab failure magmatism was likely diachronous along the length of the collision zone. If so, slab failure may have propagated laterally, possibly initiating where promontories collided. Detailed imaging of zircon and titanite reveals complex, zoned grains with distinct autocrystic (growth during pluton emplacement) and antecrystic (growth during lower crustal incubation) domains, as well as xenocrysts (incorporated from wall rocks) in both mafic and felsic-intermediate rocks. Zircon and titanite U–Pb isotopic data indicate that granitoid magmatism occurred over at least 30 million years, between ca. 430 Ma and 400 Ma. Although apparently volumetrically minor in the Donegal composite batholith, U–Pb data from spatially associated mafic rocks (appinites, lamprophyre dykes, and mafic enclaves in granitoid plutons) yield ages ranging from ca. 431 to 416 Ma, which indicates ongoing mafic magmatism during emplacement of the batholith.

THREE ENDANGERED SITES ON SHORELINE ROADS, BAY BULLS, NEWFOUNDLAND

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Bay Bulls is a small fishing town situated on the east coast of the Avalon Peninsula, in Newfoundland and Labrador, Canada. Bay Bulls is a deep bay that opens to the southeast. As a result of the physical context of the bay, the shoreline roads are endangered by coastal erosion. There are three main areas of concern areas on roads near steep coastal cliffs on both sides of the bay. Bread and Cheese is on the north side of the bay over a beach being undercut by waves. The second study area, the Cliffs, is on the northwest of the bay, facing a marine terminal and shielded from wave action. Here there is a 99 m-long wooden retaining wall constructed on the cliff face, and the volume between the wall and the original slope is filled in with rocks and soil. The third area of interest, the Quays, is on the south side of the bay where a narrow inlet, with steep cliffs, comes very close to road. The bedrock under the sites is composed of moderately to steeply dipping Late Precambrian sandstones and siltstones, where the trend of the bedding is at a steep angle to the shoreline. The bedrock is generally covered by a veneer of glacial till and vegetation. To image the subsurface structure in these three areas, three geophysical methods were employed: ground penetrating radar (GPR), direct current resistivity/induced polarization (DCR/IP), and real-time kinetics global positioning system (RTK). The DCR/IP surveys showed how the resistivity and chargeability, and therefore the type of soils and rocks or the degree of water saturation, varies with location along the surface and with depth into the ground. The DCR method for this research involved Schlumberger, Wenner and dipole-dipole arrays. 250 MHZ shielded GPR antennas were used to study the subsurface of all three sites down to the depth of 5 m. The GPR showed the depth to bedrock, the location of culverts, and the extent of the fractured (weak, vulnerable) region under the road. The RTK method obtained surface locations for the DCR and GPR surveys in 3-D with a precision of a few centimetres and revealed places where the road surface was subject to slumping toward the bay.

SPATIOTEMPORAL MODELLING OF SPECIES TRANSPORT IN CANADA'S DEEP GEOLOGICAL REPOSITORY

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Deep geological repositories (DGRs) are considered best practice by various countries, including Canada, for the safe long-term storage of used nuclear fuels. Canadian DGR's design includes an engineered barrier system (EBS) within placement rooms constructed in a low permeability host rock, which acts as a natural barrier. The EBS consists of used fuel containers (UFCs) made of carbon steel and coated with 3 mm of copper, which serves as a corrosion resistant barrier. Although the copper coating is thermodynamically stable in oxygen-free environments, it is susceptible to microbiologically influenced corrosion (MIC) during anoxic conditions. Depending on site-specific conditions (e.g. host rock type, groundwater chemistry, microbial growth conditions), bisulphide (HS^-) produced by sulphate reducing bacteria near the rock-bentonite interface could diffuse slowly through HCB to the UFC surface and corrode the copper coating. This transport is affected by the transient conditions in a DGR, such as saturation, temperature, microbial and geochemical conditions which are all interconnected and, therefore, requires a robust numerical model to understand possible transport mechanisms. Towards this goal, a multi-dimensional numerical model was developed using COMSOL that couples species transport, geochemical reactions, barrier saturation, and energy transport to understand the governing processes relevant to HS^- corrosion and hydrogen (H_2) evolution in two potential Canadian host rocks (crystalline and sedimentary). This model revealed both HS^- corrosion and H_2 evolution dynamics anticipated in the DGR over space and time. In addition, various sorption/geochemical mechanisms are being explored to bolster confidence in the assumptions embedded in modelling HS^- transport. This study presents a comprehensive modelling approach (e.g. appropriate set of differential equations, parameter selection, and validation processes), that is underway to reliably forecast HS^- corrosion and H_2 evolution. These results will be used in assessing the performance of EBS, thereby supporting the safe management of used nuclear fuel in Canada and worldwide.

ZIRCON U–Pb AGES AND GEOCHEMISTRY OF THE OUED TAMOUSSIFT TONALITE FROM THE BAS DRAA INLIER (WESTERN ANTI-ATLAS, MOROCCO)

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The Paleoproterozoic basement of the Bas Draa inlier consists of: (i) low-grade supracrustal metamorphic rocks, mainly greenschist facies and, (ii) widespread batholiths including diorite, leucogranite, granodiorite, tonalite, and granite. The late Neoproterozoic granite of Taourgha that intrudes the Paleoproterozoic series is related to the post-collisional event of the Ouarzazate Group. Geochronological analyses (LA-ICP-MS, U–Pb on zircon) yielded Paleoproterozoic age for the crystallization of the Oued Tamousift tonalite, (around 2.05 Ga). The mineral assemblage of the tonalites includes plagioclase, biotite, quartz, muscovite, microcline and garnet. They have SiO_2 content ranging from 59 to 66 wt.%, Al_2O_3 content ranging from 17.22 to 14.4 wt.% and their Na_2O+K_2O is higher than 6 wt.%. They display medium-K calc-alkaline affinities and a peraluminous character (A/CNK> 1). Trace elements argue for an arc environment for the genesis of the magma. However, compared to ocean ridge granite, the tonalities show Low field strength (LFS) element depletion, negative Ba and Nb anomalies and high Ce and Sm contents. These characteristics are discussed with respect to the Paleoproterozoic magmatic setting of the northwestern edge of the West African Craton.

STRUCTURAL CONTROLS ON LATERAL VARIATIONS IN MEGATHRUST FAULT COUPLING IN SOUTHERN HIKURANGI, NEW ZEALAND

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Megathrusts form the low angle interface between the tectonic plates at a subduction zone, and are the world's greatest seismic hazard. Not all megathrust slip gives rise to earthquakes; aseismic creep and slow-slip events (SSE) can also occur. The Hikurangi subduction zone offshore northern New Zealand displays all three types of fault slip along its length. It is widely thought that temperature and the presence of water play important roles in determining these behaviours: where water is overpressured, slow slip is promoted, and at elevated temperatures (> 350°C) there is ductile creep. In Hikurangi, the transition between seismogenic, SSE, and aseismic creep occurs along the same megathrust depth contours, where temperature and pressure conditions are essentially identical, calling into question these effects on the mode of slip. Also, calculations of the forces required in mountain building above the Hikurangi megathrust show that it must be weak everywhere, implying very high pore-fluid pressures everywhere that cannot explain along-strike variations in the mode of megathrust slip. The unusual rock serpentinite has also been identified at the megathrust in some subduction zones, in regions of SSE, and it has been proposed that its weak and slippery nature is the key factor that causes creep or slow-slip behaviour. Here we search for evidence of serpentinites along the Hikurangi megathrust to examine its relation to fault slip. We hypothesize that, where there is no serpentinite the fault is locked, eventually rupturing during an earthquake; and where there is, it can slip easily either as a SSE or aseismic creep. Deep SSEs in SW Hikurangi occur on the megathrust down dip of the seismogenic portion, where it is in contact with mantle rocks. Seismic imaging and gravity studies indicate that some of that mantle has been altered to serpentinite. In this work we calculate teleseismic receiver functions for all seismograph stations in the Hikurangi forearc to detect serpentinites. These rocks have unusually low seismic wave-speeds and are highly foliated, imparting significant seismic anisotropy in receiver function signals. We first model seismic anisotropy in receiver functions that arise from various subduction zone structure containing serpentinites. We also attempt to characterize observed receiver function signals in terms of abundance of serpentinites by performing a Monte Carlo search of structural model parameters, including anisotropy. Ultimately, these results will be combined with gravity anomalies to fully characterize the presence of serpentinites in relation with fault slip.

MINERAL-CHEMICAL RELATIONS OF CHLORITE REPLACEMENT OF MAGMATIC BIOTITE FROM SILURIAN–DEVONIAN FELSIC INTRUSIONS, NEW BRUNSWICK, CANADA

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Chlorite is the dominant pseudomorphic alteration product that mainly occurs along the cleavage planes of magmatic biotites in Silurian-Devonian felsic intrusions of New Brunswick. The chemical composition of chlorite from eight barren and mineralized intrusions was studied using an electron microprobe. The composition of the examined grains seems to be controlled by their host biotite and varies considerably between these intrusions. Chlorite grains from the barren intrusions have the lowest Al_2O_3 (12–15 wt.%), MnO (0.4–0.6 wt.%), and the highest K_2O (3–6 wt.%), whereas the grains from Sn-W-related intrusions have the lowest SiO_2 (24–26 wt.%) and highest Al_2O_3 (17–20 wt.%), MnO (0.7–1.5 wt.%), and FeO^t (28–42 wt.%). Chlorite grains from the Cu-Mo-related intrusions have the lowest Fe/(Fe+Mg) ratio of 0.44, which increases to 0.55 in Sn-W-related intrusions, 0.67 in Mo-related intrusions, and reaches to its highest value of 0.88 in barren intrusions. The high ratio of calculated Fe^{3+}/Fe^{2+} within most of the examined grains may indicate that chloritization reactions occurred under relatively oxidizing conditions. Secondary rutile and to less extent magnetite occurrence in association with chlorite in many of the examined grains is consistent with this observation. Most alkali elements, including K, Na, Ba, and Rb, have been leached from the magmatic biotite. Additionally, chlorite grains seem to have higher Mg and Si content compared to their parent biotite. As a result, it is believed that chloritization of biotite is responsible for the enrichment of ferromagnesian elements like Fe, Mg, and Mn. The analyzed grains are trioctahedral chlorite as their Si cation totals are less than 6.25 atoms per formula unit (apfu), and the sum of octahedral cations is very close to 12. Further calculation of mole fraction of chlorite in the interlayered phase (X_c) showed a variation between 0.70 and 0.95 confirming the lack of smectite layers in these grains. The result of calculated Al in chlorite thermometry showed a large variation in temperature from 300° to 390°C with an average of 350°C. Such low T reactions are typical in hypabyssal granitic rocks with propylitic alteration formed in response to late to post magmatic fluids, and probable meteoric water infiltration.

INTRUSIVE GABBROIC BODIES AS A SOURCE OF Cu, Zn, Co, AND Ni IN THE CENTRAL AFRICAN COPPERBELT

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The Central African Copperbelt (CACB) is considered the world's largest and highest grade sedimentary copper province. Recent estimations calculated that the basin contains about 200 Mt of copper associated with the largest cobalt reserve in the world, in addition to large zinc, nickel, and lead deposits. The metal deposits are hosted in the rocks of the Neoproterozoic Katangan Supergroup (880 to 600 Ma), which was formed in depocentres and intracratronic extensions after Rodinia's breakup. The basin was affected by magmatic events recorded between 765 and 735 Ma and later the basin inversion during the Pan-African (590 to 500 Ma) Lufilian orogeny. A total of 20 gabbro samples were selected as representatives of different progressive stages of alteration for six mining districts: Kipushi SE (3 samples), Luswishi (3 samples), Kipushi SW (3 samples), Kansanshi (2 samples), Luswishi NW (7 samples), and Kipushi (2 samples). The characterization of the intrusive rocks from the research areas led to a classification scheme of progressive alteration, which in some research areas represent the full length of the alteration stages and others only some of them. Our analysis identified four different stages, determined by a different set of assemblages: primary igneous, regional metamorphic, scapolite, and finally carbonate, that ultimately led to heavily leached rocks. The progressive alteration stages that the intrusive rocks of the CACB underwent imply that initially Cu and Zn were carried out by Cl^- ligands after sulphides were broken down in the scapolite stage. Later, Co and Ni were released to be transported by C-rich fluids that were responsible for wholesale alteration of Fe-Ti oxides and Mg-rich silicates to rutile and carbonate, respectively. Considering the approximate volume of the gabbroic bodies of these districts and a conservative estimative that 30% of them are leached, we estimate that around 277,331 t of Cu, 189,089 t of Zn, 252,119 t of Co, and 267,246 t of Ni were released to the basinal fluids during early scapolite and later carbonate alteration stages. The metagabbro of the CACB, traditionally dismissed and rejected as a possible source of metals for the many Cu, Zn, Co, and Ni deposits hosted in sedimentary rocks, must now be revisited. We propose the hypothesis that it was likely to have been a dominant source of metals for the CACB deposits and therefore could return valuable information when considered in exploratory programs together with other methods aiming to find new prospects.

AN UNEXPECTED GROUNDWATER SUPPLY IN STEWIACKE NOVA SCOTIA: GLACIAL OUTWASH, CRETACEOUS SEDIMENTS, CARBONIFEROUS ROCK?

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The Town of Stewiacke, Nova Scotia is located in an area where underlying geology is typically characterized as being a poor target for groundwater supply. The geology underlying the town is mapped as a Carboniferous basin with marine infill sequence of evaporites, limestone and sediments. The water supply for the Town of Stewiacke has been the St. Andrews River for decades, but increasing regulatory control and effects of climate change are limiting the quantity of water that can be extracted from the river. Water supply is a limiting factor for development in the town which is well positioned for growth. The need for an alternative water supply to support growth has motivated the town to investigate a potential groundwater supply. A field program was developed and implemented to investigate the subsurface conditions beneath the town. Core drilling, well installations and aquifer testing programs indi-

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cate a high yield aquifer is present that could support the growth of the town. The investigation program has identified sediments and fractured rock that includes sand, gravel and limestone. The strata may include glacial deposits such as eskers, Cretaceous sediments and fractured limestone of the Watering Brook Formation. The exploration for groundwater may present new opportunities to expand the understanding of the geology in central Nova Scotia.

A PROTOCOL TO IMPROVE REPRODUCIBILITY AND QUALITY OF IMAGE ACQUISITION FOR DEEP LEARNING APPLICATIONS IN MINERALOGY

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Mineral identification is essential for mineral exploration and, in particular, indicator mineral samples. The latest research on mineral identification by machine-learning algorithms using photographs or photomicrographs confirms this approach as fast, low cost, and reliable. Although the number of published papers demonstrating machine-learning mineral recognition is increasing rapidly, little research has dealt explicitly with the image acquisition stages. Moreover, the effectiveness of machine learning is highly dependent on the quality and quantity of the training data. A novel application, such as mineral identification, requires a robust and reproducible image acquisition protocol. Our study proposes a practical image acquisition protocol for optical microscopes. This protocol focuses on the two main objectives of ensuring reproducibility and enhancing mineral image quality. In terms of reproducibility, we detail means of limiting camera errors and standardizing utilization and experimental parameters, such as external light and temperature. Our objective of enhancing images is fulfilled by determining the optimal lighting choice and its impact on algorithm accuracy, lens selection, and white-balance calibration. Our protocol is then applied to a practical case of mineral identification using machine learning algorithms. The sample is a heavy mineral concentrate of till comprising about 15 mineral species. This protocol will ensure the reliability of data acquisition and increase image quality for a range of photomicrographic deep-learning applications such as mineral recognition.

DISTRIBUTION OF REE+Y IN DIFFERENT TYPES OF FLUORITE FROM THE GRANITE-RELATED SADDLE ZONE OF MOUNT PLEASANT (Sn-Zn-In) (W-Mo-Bi) DEPOSITS, SW NEW BRUNSWICK

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Three episodes of Late Devonian, highly evolved, A-type granites intruded into the Mount Pleasant area, along the SW margin of the Mount Pleasant Caldera complex, forming three separate mineralized zones in their cupolas, namely, Fire Tower, North, and Saddle zones. Micro-X-ray fluorescence spectrometry (μXRF) is employed to elucidate REE+Y distribution within different types of coarse-grained fluorites in two representative quartz-fluorite (QF) veins of the Saddle Zone. This zone is characterized by a rhyolitic crystal tuff in the shallower parts, with granites IIA and IIB intersected at depth. These veins, enveloped by thin argillic alteration, are closely associated with granite IIA. Silicic, chloritic, sericitic, and argillic alteration types are widespread in the host granite. QF I is distinguished by the presence of abundant REE+Y minerals, including monazite, xenotime, and fluorite. Disseminations of sphalerite, galena, native Bi, and arsenopyrite can be found throughout this vein. Three main types of fluorite are identified in the QF I vein: (I) euhedral, coarse-grained, planar zoned, brown fluorite, (II) euhedral, coarse-grained, planar zoned, green fluorite, typically rims fluorite (I) and forms crystals up to 4 cm across; (III) late anhedral dark purple fluorite, which fills the voids inside the vein. QF II vein is characterized by the intense formation of euhedral, medium-grained, homogeneous purple fluorite (IV). This fluorite is accompanied by disseminated sphalerite, cassiterite, and the locally abundant hubnerite. Based on μXRF data, Bi mineralization occurs as the fine-grained native Bi disseminations infill the pores of host granite II and the veins. This mineral locally rims fluorite (II) in QF I vein. In this vein, monazite and xenotime are La-Ce-Th-enriched and Y-rich, respectively. Besides, Ce, Nd, and Y show a distinct zonation along the growth lines of the fluorite (II), implying a primary growth feature. A comparatively pale Ce and Y zonation can also be visible in fluorite (IV). Chaotic zonation of Y in some fluorite (IV) presumably indicates dissolution-reprecipitation processes in preference to the initial growth. Consequently, different fluorites with different REE+Y contents show interplay of fluorite-bearing hydrothermal fluids of different origins. Solubility of fluorite decreases with decreasing in the temperature and salinity of the fluorine-bearing hydrothermal fluids. Decreasing pressure also takes a leading role in saturation of fluorite in the hydrothermal systems. Owing to the shallow emplacement of the granitic intrusions in the Mount Pleasant area, it is predicted that such low pressures paved the way to the ubiquitous formation of fluorite in this deposit.

AMBIENT NOISE SEISMOLOGY ACROSS EASTERN CANADA AND THE NORTHEASTERN USA

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The crust across eastern Canada preserves ~3/4 of Earth's history and exhibits a highly complex seismic structure. Using an ambient noise tomography technique and more than two years of broadband seismic datasets, we take a detailed look at the crustal structure beneath the southeasternmost Archean Superior Province, the Proterozoic eastern Grenville Province, and the Phanerozoic northern Appalachian orogen. We observe that systematic differences in seismic signatures exist between the three major tectonic provinces covered in this study. Our tomographic models suggest that the velocities in different crustal layers generally decrease with age from the SE Superior Province to the northern Appalachians. It is also suggested that the relative thicknesses of the upper and lower crustal layers are significantly different between the eastern Grenville and the northern Appalachian domains. Our period-dependent azimuthal anisotropy results suggest that, while orogenic-related deformation is well preserved across the region, some localized anomalies may result from preservation of post- or pre-orogenic crustal fabrics. In our study area, the Moho depth is interpreted to vary in the ~30–50 km range, with the most variation observed beneath the younger northern Appalachian domain. A step-like Moho feature is also observed beneath the Appalachians and along the main NE-SW orogen trend, which could be interpreted as the boundary separating the domains with different tectonic heritage at depth (i.e. Peri-Laurentian and Peri-Gondwanan). In addition to producing high-resolution tomographic models, we developed a new back-projection technique to analyze the directional and seasonal variations of the ambient seismic noise at different passbands of the noise spectrum. The results of this analysis suggest that the strongest noise sources at different passbands are located in different oceanic regions, with distinct patterns of temporal variations. Although this confirms that the ambient noise field is not homogeneous, our tests suggest that high-quality datasets and reliable tomographic models were obtained in this study.

THE GEOLOGY, GEOCHEMISTRY, AND PARENTAL MAGMA OF THE LEGRIS LAKE MAFIC-ULTRAMAFIC COMPLEX

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The Archean Legris Lake intrusive complex in northwestern Ontario has an unambiguous spatial (~11 km SE) and temporal (~2.69 Ga) association with the world class Lac Des Iles (LDI) palladium deposit. Here we present an overview of the geology of the Legris complex and new whole rock geochemistry, mineral chemistry, and Sm–Nd isotope data from the major cumulate lithologies in the complex. The intrusive rocks in the Legris system range from dunnite to gabbrodiorite, with most of the complex being primarily composed of several varieties of leucogabbro. The bulk of the PGE mineralization in the system is hosted in a white leucogabbro (LGAB-M) which occurs along the outer margins of the complex either as homogenous masses of plagioclase and clinopyroxene or as a component of heterolithic breccias. Primitive mantle-normalized whole rock trace element plots from LGAB-M show moderate to strongly fractionated light rare earth element patterns, strongly negative Ta, Nb, Zr, and Hf anomalies, positive Eu anomalies, and strong enrichment in the large ion lithophile elements and Pb. These features are consistent with low degrees of partial melting of metasomatized mantle in a subduction-related continental arc setting. Moreover, the trace element patterns of the major intrusive units in the Legris complex resemble that of the local metasedimentary country rock

(MTSD), suggesting that assimilation of MTSD was a major control on the chemical evolution of this system. This is supported by mixing models between MTSD and primitive mantle melt which closely reproduce the observed trace element patterns of the cumulate rock in the Legris system. Furthermore, calculated parental magma compositions for the LGAB-M reflect/overlap the trace element pattern of the MTSD. This suggests that assimilated metasedimentary country rock was a major component of the silicate melt in this system. This interpretation is supported by the observation of partly melted or assimilated MTSD xenoliths throughout the Legris complex and suggests that silicate melts at depth interacted extensively with metasedimentary country rock during the emplacement of each intrusive unit. This likely drove the evolution of silicate melts in the system toward a more fractionated leucogabbro composition. However, S saturation in the LGAB-M occurred at depth, prior to emplacement, and high degrees of contamination are negatively correlated with sulphide content and PGE grades. This suggests that the formation of sulphide melt in this system was likely the result of melt evolution at depth rather than the introduction of an external sulphur source via the assimilation of MTSD.

NEW INSIGHTS INTO THE PROPERTIES OF AQUEOUS FLUIDS AND SILICATE MELTS AT THE MAGMATIC-TO-HYDROTHERMAL TRANSITION

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We present new data from coeval fluid and melt inclusion assemblages hosted in unidirectional solidification textures (USTs) at Saginaw Hill – a small, shallow porphyry-Cu system in southwestern Arizona. Successive generations of monomineralic quartz and aplite-hosted quartz phenocrysts in UST bands from Saginaw Hill formed along the periphery of the silicate melt in this system, and trapped inclusions that record a unique, time-integrated record of melt evolution and fluid exsolution. The cores of quartz crystals throughout the UST bands host coeval silicate melt and brine inclusions but lack vapor-rich inclusions, suggesting either the preferential expulsion of vapour and trapping of high-density brine during episodes of fracturing, or the direct exsolution of single phase high-salinity brine from the silicate melt. In contrast, the rims of UST quartz host abundant coeval brine and vapour inclusions, consistent with liquid-vapour immiscibility at lower pressures compared to the corresponding quartz cores. This transition from dominantly coeval silicate melt inclusions and brine in phenocryst cores, to coeval brine and vapour in the rims, suggests that the exsolution of metal-rich fluids in the Saginaw Hill system was part of a dynamic processes involving repeated episodes of fluid exsolution, accumulation, overpressure, and release during UST formation. Melt inclusion data indicate that this process coincided with high degrees of fractionation in the silicate melt. Metal concentrations in the brine were comparable to or higher than those in fluids reported in world-class porphyry Cu systems and were likely the result of both igneous fractionation and the high chloride content of the exsolved fluids. While limited in scale, Saginaw Hill provides direct evidence for processes that are predicted by numerical simulations to occur at the magmatic-to-hydrothermal transition during the formation of large, well-mineralized porphyry systems.

THE EVOLUTION OF S AND Cl IN A MAGMATIC SYSTEM AS SEEN BY CLINOPYROXENE PHENOCRYSTS

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Sulphur and chlorine play crucial roles in the transport of critical metals that may lead to enrichments significant enough to form ore deposits. Understanding the evolution of these volatiles during the lifetimes of magmatic systems will not only aid our understanding of how critical metals are transported and stored in trans-crustal magma chambers, but also may provide guides to the exploration for critical metals. However, analysis of original magmatic sulphur and chlorine concentrations in degassed lavas and cumulate rocks is often challenging, if not impossible. We developed protocols for analyzing sulphur and chlorine by synchrotron X-ray fluorescence (SXRF) at ppm levels and micron-scale spatial resolution, as well as using previously established analytical protocols for the ion microprobe to measure chlorine and fluorine at similar concentrations and spatial scales. We determined the partition coefficients of these elements between crystals, primarily clinopyroxene, and melts. These tools allowed us to investigate the degassing of the magmatic systems from several large igneous provinces (LIPs: Deccan Traps, Central Atlantic Magmatic Province, Siberian Traps) on Earth and 3 Martian meteorites. Most LIP demonstrate that the melts from which they grew contained sulphur concentrations below, or near, that needed for sulphide saturation, but bulk rock and mesostasis analyses demonstrate volatile loss after the termination of clinopyroxene growth. LIP clinopyroxenes most often show little-to-no zoning, but some meteoritic clinopyroxene zoning profiles show a complex volatile history with evidence of the incorporation of sulphur by assimilation, a process often inferred as necessary for the formation of some critical metal ore deposits. SXRF mapping of the spatial distribution of volatiles in two cumulate Martian clinopyroxene crystals (from meteorite MIL03346, 13) demonstrates that S and Cl concentrations of the evolving melts changed significantly from the core to the rim. Increasing S and Cl concentrations and a changing Cl/S ratio in crystal are interpreted to reflect incorporation of volatiles through assimilation. Near the crystal rim, however, Cl and S concentrations decrease significantly, most probably due to volatile degassing during the final stages of clinopyroxene growth. Although we know of no ore deposits associated with this sample, these clinopyroxenes demonstrate the potential of SXRF mapping for the investigation of complex volatile histories in terrestrial magma chambers and the search for critical metal ore deposits. We hope to obtain samples of terrestrial igneous minerals associated with critical metal ore deposits to investigate their S, F, and Cl histories.

USE OF GEOELECTRICAL TECHNIQUES FOR MONITORING THE STRUCTURAL INTEGRITY OF EARTHEN FLOOD EMBANKMENTS

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River embankments are constructed to protect areas of high economic and societal value from water inundation. It is therefore vital to ensure that their integrity is maintained to prevent embankment failure, damage to protected infrastructure, disruption to society and risk to human life. River embankments encompass large areas across many countries. In the United Kingdom they span 34,000 km in length, making comprehensive coverage through monitoring challenging. Traditionally, embankments have been monitored with visual inspection and geotechnical investigations. However, these are limited by lack of sensitivity to internal structure during walkover surveys and limited spatial coverage of boreholes. Geophysical techniques can provide a non-invasive means to identify potential concerns within river embankments. It is impossible to cover the entirety of embankments upon surveying, but targeted deployment of such techniques can give coverage of large areas. Electromagnetic induction (EMI) and electrical resistivity tomography (ERT) are particularly useful because of their sensitivity to changes in moisture content, which may indicate potential seepage issues within an embankment. ERT and EMI have therefore been utilized to monitor embankments at three sites in the United Kingdom: 1) Haweswater Way, Hull; 2) Paull Holme Strays; 3) Hadleigh Marsh, Essex, where monitoring was required to gain insight to potential issues and visualize subsurface conditions. ERT and EMI surveys across these sites were able to successfully visualize embankment structure, geology, dynamic changes through time and identify regions where water content was high. Analysis of the geophysical data, with use of geological knowledge of the area, enabled identification of potential seepage areas for further investigation. This has shown the potential for geoelectrical techniques to be used in conjunction, in order to visualize the internal structure of embankments in river and estuarine settings. In combination with geotechnical data such surveys can provide useful interpretations and identifications of structural flaws within embankments and how variance with time affects data.

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GEOSTATISTICAL QUANTIFICATION OF SPATIAL HETEROGENEITY IN MINE WASTE-ROCK PILES

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Open-pit mining operations generate large quantities of sulphide-bearing waste rock, demanding sustainable management. Spatial heterogeneity raises challenges for waste-rock characterization, with solid-phase C and S contents as important geological parameters. We conducted transdisciplinary studies of three waste-rock projects at small-scale test piles, medium-scale stockpiles, and an operational-scale pile at three mine sites (Diavik diamond mine, Detour Lake gold mine, and Faro Mine Complex) in northern Canada over the past 20 years. Geostatistical analyses of over 1000 samples suggest that although log-normal distribution of the C and S contents persists, there is no spatial dependence of the C and S contents, indicating random heterogeneity in the spatial distribution of geological parameters in waste-rock piles. The findings will facilitate prediction of waste-rock weathering and mine-drainage evolution using reactive transport modelling and a stochastic framework. The results can better advance long-term waste-rock management and storage strategies, and improved remediation and reclamation of waste-rock piles in many jurisdictions of the world.

THE APPLICATION OF MULTIPLE SULPHUR ISOTOPES TO DETERMINE THE ARCHITECTURE OF ARCHEAN VMS DEPOSITS

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The source of sulphur in volcanogenic massive sulphide (VMS) deposits is known to be mainly derived from magmatic sulphur mixed with other sulphur reservoirs including seawater sulphate and sulphur from the surrounding country rocks. Seawater sulphate can be incorporated into the circulating hydrothermal fluid by thermochemical sulphate reduction (TSR) and variations in its proportion can be tracked with multiple sulphur isotopes. Although seawater sulphate incorporation in Archean VMS deposits has been suggested, no direct evidence or quantification of its proportion as a function of VMS type is available. Here, we propose to determine the proportion of seawater sulphate incorporation in relation to metal endowment with the aim to determine a new vectoring tool for VMS targeting. We use multiple sulphur isotope analysis (MSI; $\delta^{33}S$ and $\delta^{34}S$) on well-preserved, weakly to moderate metamorphosed Neoarchean VMS deposits and associated exhalites from the Noranda camp and the McLeod Deep mine in the Matagami camp. The latter corresponds to a sub-seafloor replacement VMS, whereas the Noranda camp exhalites and VMS are interlayered with pillow-lavas, indicating of a direct link to seawater. Our analyses show that each type of deposit has a specific isotopic signature. The McLeod Deep sub-seafloor replacement deposit shows a typical magmatic signature with $\delta^{34}S$ and $\Delta^{33}S$ near 0‰ (-0.51‰ ±0.57 and -0.04‰ ± 0.02, respectively), recording no evidence for seawater sulphate incorporation. Contrastingly, exhalites from the Noranda camp yield $\delta^{34}S$ = +3.03‰ ±0.54 and $\Delta^{33}S$ = -0.78‰ ±0.11, which is interpreted to record significant influx of seawater sulphate. The seafloor VMS deposits from the Noranda camp show intermediate signatures between the two other types with $\delta^{34}S$ = +1.34‰ ± 0.49 and $\Delta^{33}S$ = -0.14‰ ± 0.05, interpreted to record smaller contributions of seawater sulphate. These differences are also associated with metal endowment of deposits, those in which seawater sulphate is less abundant are richer in Zn and Cu whereas those with a higher proportion of seawater sulphate are more abundant in Fe-rich sulphide exhalites. The characteristics of the latter are interpreted as being due to their distal location where the temperature is lower and the proportion of seawater is greater. If the isotopic signatures show an influence of seawater sulphates, this implies a seafloor VMS deposit, as opposed to sub-seafloor VMS with no seawater interaction. These specific signatures can thus act as a vectoring tool to better predict the metal endowment of the VMS deposits studied.

IN-SITU SULPHIDE SULPHUR ISOTOPES BY LA-ICP-QQQ-MS

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Sulphur isotopes ratios ($^{33}S/^{32}S$, $^{34}S/^{32}S$, $^{36}S/^{32}S$) are essential for understanding the formation of mineral deposits, as sulphur is the main complexing ligand for gold transport and/or causes metal precipitation (e.g. Cu, Ni, Co, Zn, Pb). Studying sulphur isotopes allow to constrain the source and to monitor the variation on the redox and temperature conditions leading to the ore sulphides. Different bulk methods by sample transformation into SO_2 or SF_6 exist to determine S isotopic signature of sulphides, but it involves the loss of textural constraints on sulphide occurrence and within-grain isotopic heterogeneities. This information can be obtained using secondary ion mass spectrometry (SIMS), but sample preparation is time consuming. Here, we developed a protocol for in-situ sulphide sulphur isotope analysis using an Applied Spectra 193 nm ArF excimer laser ablation system coupled to an Agilent 8900 Triple Quadrupole ICP-MS (LA-ICP-QQQ-MS). This technique has the advantage of requiring minimal sample preparation as only a flat surface is required, which allows for analyses directly in petrographically characterized thin sections. The main obstacle to ICP-MS analysis of sulphur isotopes is isobaric mass interferences such as oxides (O_2, NO) and with argon (plasma gas) overlapping with the analyzed mass. The ICP-QQQ-MS system is used with a middle reaction cell with oxygen to remove these interferences. After passing through the first quadrupole to filter to the desired S isotopes masses (i.e. S^{32+}), the oxygen reacts with the ionized sulphur to add a mass of 16 to its initial mass (i.e. SO^{48+}), thereby allowing the second quadrupole to separate it from unreacting mass interferences in the reaction cell (i.e. O_2^{32+}). To perform high precision analyses, we developed new matrix-matched natural reference materials for the main sulphides (pyrite, chalcopyrite and pyrrhotite) to correct for instrumental fractionation. For each mineral, their chemical homogeneity by EPMA, their isotopic homogeneity by SIMS and their precise signature by bulk fluorination-IRMS have been verified. Influences of the different LA-ICP-QQQ-MS parameters (i.e. spot size, repetition rate, laser fluence, He carrier gas flow…) have been tested to establish the best analytical protocol. Our preliminary results on pyrite yield an uncertainty on the reproducibility of the $\delta^{34}S$ value of about 0.5‰ (1 standard deviation). These results demonstrate that LA-ICP-QQQ-MS can perform in-situ $\delta^{34}S$ measurements at low cost with minimal sample preparation to track inter- and intra-grain isotopic variation in sulphides with an accuracy capable of tackling most ore deposit research problems.

HYDROGEOLOGIC CONTROLS ON GROUNDWATER DISCHARGE TO FALL AND WINTER STREAMFLOW IN THE CANADIAN ROCKY MOUNTAINS

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Headwaters in the Canadian Rocky Mountains supply essential water resources to downstream communities and ecosystems. Sustainable management of these water resources requires an understanding of hydrologic processes in alpine watersheds. Alpine groundwater processes are of particular interest, as fall and winter streamflows in the Rockies are largely sustained by groundwater discharge. Previous studies have examined alpine groundwater processes at hillslope and regional scales, but relationships between observations at the two scales must be better understood to improve water resource management tools. The objective of this study was to advance the hillslope-scale conceptual model of alpine groundwater flow and storage so that it could be used to explain regional-scale trends in fall and winter streamflow. The investigation consisted of two phases: analysis of streamflow records, and simulation of groundwater flow in alpine hillslopes. In the first phase, fall and winter streamflow records from 19 watersheds in the Rocky Mountains were analyzed. Fall and winter streamflow rates in most watersheds were observed to have periods of fast exponential decay followed by periods of slower exponential decay. The rates of

decay were found to be related to bedrock age. The timing of the transition between the two periods was related to watershed elevation, suggesting a climatic control. In the second phase of the study, generic, two-dimensional, variably saturated models of alpine hillslopes were constructed to represent competing conceptual models. It was found that a layer of fine sediment at the base of the hillslope was needed to produce the 'fast-slow' pattern of streamflow decay observed in the first phase of the study. The pattern could not be explained by other conceptual models such as 'filling and spilling' across bedrock depressions in the hillslope. Varying the thickness and conductivity of the fine sediment layer changed the rate of streamflow decay, and may offer an explanation for the geologic control observed in the first phase of the study. Changes in the timing of precipitation applied to the models caused changes in the timing of the transition day, consistent with the regional-scale observations. This study found that fine sediment plays an important role in groundwater flow and storage in alpine hillslopes, and that this conceptual model offers explanations for observed geologic and climatic controls on fall and winter streamflow. By developing a conceptual model that can be applied regionally, we hope to support the development of improved tools for sustainable mountain water resource management.

CHARACTERISTICS OF ALTERATION AND GOLD MINERALIZATION IN THE PALEOPROTEROZOIC PINE LAKE GREENSTONE BELT, TRANS-HUDSON OROGEN: CONSTRAINTS FROM THE SANTOY MINE COMPLEX AND FISHER PROPERTY, SEABEE GOLD OPERATION, SASKATCHEWAN

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The Seabee Gold Operation (SGO), located approximately 125 km northeast of La Ronge, Saskatchewan, hosts the Seabee and Santoy mine complexes adjacent to SSR Mining's Fisher property. These properties are situated in the Paleoproterozoic Pine Lake greenstone belt within the Glennie domain of the larger Trans-Hudson orogen, which formed during consecutive stages of accretion and convergence. At Santoy, gold mineralization is hosted by the Santoy shear system, which roughly defines basalt-granodiorite contacts, and is thought to splay off a ductile component of the Tabbernor system. These lithological units and structures extend onto the Fisher property, south of the Santoy Mine Complex; however, the timing and nature of gold mineralization, and relationship with adjacent intrusions across the SGO are still unknown. To investigate these questions, mineralized samples were collected from drillholes over a 16 km trend along the Santoy shear zone, extending from the Santoy 7 and Santoy Gap deposits (Santoy Mine Complex), to the Fisher property, and analyzed to determine and compare petrographic and compositional characteristics. The mineralized host rocks primarily comprise fine-grained, sheared basalt to chlorite-hornblende-biotite±garnet schists, with intrusive rocks dominated by granodiorite, quartz diorite, and tonalite. The mineral assemblages in these host rocks indicate that lower amphibolite facies metamorphic conditions were achieved across the investigated length of the Santoy shear zone. Similar to the alteration style observed at the Santoy Mine Complex, Fisher samples show variably extensive distal sericite-biotite-epidote (± albite, titanite) alteration and more proximal sericite-biotite-chlorite-actinolite-titanite-albite-calcite (± apatite, epidote) associated with auriferous quartz veins. Additionally, thin (~1–15 cm), vein-adjacent, coarse-grained diopside-K-feldspar-albite-actinolite (± apatite, titanite) calc-silicate alteration in a fine-grained sericite-epidote matrix is associated with vein- and wall rock-hosted pyrite-chalcopyrite-pyrrhotite (± sphalerite, ilmenite, magnetite, arsenopyrite, galena, tellurides, gold) mineralization. The alteration minerals at each location are analyzed by electron microprobe to compare mineral compositions related to gold mineralization across the SGO and Fisher property. Preliminary work also suggests that the paragenesis of sulphide-gold mineralization stages at Fisher and Santoy are similar. A Re–Os model age of 1765 ± 6 Ma was obtained for Fisher low-level highly radiogenic pyrite in this study, which overlaps with the 1755 ± 8 Ma U–Pb age of titanite in alteration associated with gold mineralization at Santoy. Further U–Pb dating of a shear-proximal granodiorite sill and felsic ash tuff from Fisher will provide an opportunity to compare their ages to that of the Lizard Lake pluton (ca. 1875 Ma), which hosts multiple gold deposits at Santoy.

IDENTIFYING CONDITIONS THAT SUPPRESS MICROBIAL GROWTH IN BENTONITE CLAY INTENDED FOR USE IN A DEEP GEOLOGICAL REPOSITORY FOR USED NUCLEAR FUEL

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Nuclear power is an important source of non-greenhouse gas producing energy. However, after a fuel bundle has served its purpose in a nuclear reactor, it remains radioactive and must be stored safely for approximately one million years until it returns to the radioactivity level of naturally occurring uranium ore. Canada is among many countries in the process of designing a deep geological repository (DGR) for the long-term storage of used nuclear fuel. To ensure the long-term integrity of a DGR, it is important to study microorganisms that may be associated with DGR design components, specifically the bentonite clay that will surround the metal containers encasing nuclear waste, and the subsurface rock that will host the DGR. Of particular importance are microorganisms that can contribute to corrosion of used fuel containers, such as sulphate-reducing bacteria (SRB), or those that produce gases that could lead to the formation of permeability fissures, such as denitrifying bacteria. In this study, metal containers ("pressure vessels") designed to hold saturated bentonite clay at a set dry density were used to investigate conditions that suppress microbial growth and to identify the taxa associated with these clays after incubation at pressure. Saturated bentonites were analyzed at multiple time points over a year of incubation in pressure vessels, at dry bentonite densities between 1.1 g/cm^3 and 1.6 g/cm^3, using both powdered and granulated bentonite clay. The number of culturable SRB and heterotrophs were measured, and 16S rRNA genes from DNA extracts were amplified and sequenced. Our results reveal an initial increase in microbial abundance by the one-month time point, but no significant increases in culturable SRB or heterotrophs subsequently, suggesting that microbial growth was suppressed in all pressure vessels. Beyond six months, the 1.6 g/cm^3 pressure vessel samples had culturable heterotroph and SRB abundances that were not significantly different than dry clay starting material. Most saturated pressure vessel 16S rRNA gene profiles were dominated by sequences associated with Bacillus and Pseudomonas, which could represent either spore-forming or desiccation-resistant taxa that proliferate as pressure vessels saturate initially. Additional experiments set up under anoxic conditions will help test whether SRB growth is also suppressed in the absence of oxygen and identify a dry density threshold that will prevent microbial growth beyond the initial phase of pressure vessel saturation in a DGR.

USER-FRIENDLY TOOLKITS FOR GEOSCIENTISTS: HOW TO BRING GEOLOGY EXPERTS TO THE PUBLIC

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A growing number of countries are committed to reduce their carbon emissions and are transitioning towards renewable and clean energy sources, leading to an increase in demand for metals and minerals. This is especially the case for a short list of what are called "critical minerals" which are considered essential to economic development, including the transition to a low-carbon economy and national security. The reliability of their supply chain raises concerns considering geological scarcity, difficulty to extract and/or political factors influencing their availability. At the same time, public awareness and perception of geoscience are eroding and there is more and more reluctance towards mining projects, even from traditionally favourable communities. To face this challenge, promote public interest and outline the contribution of geological sciences to society, geoscientists of the Geological Survey of Canada (GSC-Québec) have designed and put together a portable display that includes a suite of mineral and metal samples considered critical for the sustainable success of Canada's transition towards a clean and digital economy. The display is a user-friendly toolkit that can be used by any GSC geoscientists during outreach activities, in classrooms as well as during public open houses. It comes with straightforward pedagogical material and content, along with presentation scenarios. To broaden and adapt the workshops to specific expectations, additional toolkits were developed and all are contained within easy to carry travel cases. These cover a vari-

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ety of topics and can be presented as stand-alone displays or be used complementary to one another. For example, the "Mines and minerals" collection may serve as a supplement to the "Critical minerals" display to present everyday objects in which minerals are as used as well as ore samples from active mines to illustrate the intertwining between mining activities and our everyday lives. Another display covers the ever-popular fossils thematic with the "Sedimentary rocks and fossils" collection and gives an opportunity to address key geoscience themes such as life evolution and biological crisis along with groundwater reservoirs and resources. The "Magmatic rocks" display touches on the formation of rocks from magmas, the different types and active processes of volcanoes, and discusses the risks and benefits related to volcanic activity. Hopefully, these four ready-to-use portable displays will encourage more GSC geoscientists to engage in public oriented activities to make geosciences more accessible, change perceptions and offer an overall tangible scientific experience for people.

GEOLOGICAL FIELD TRIP GUIDE FOR THE EASTERN AND CENTRAL ANTI-ATLAS OF MOROCCO

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The Anti-Atlas belt of Southern Morocco is a segment of the Neoproterozoic Pan-African belt system located on the northern edge of the Paleoproterozoic West African craton. The orogen is exposed in a series of NNE-SSW aligned inliers beneath a thick folded package of Paleozoic sedimentary rocks. The area covered by this excursion guide is part of the central and eastern Anti-Atlas. It is focused on the NE-trending Saghro inlier, and the NW-trending Bou-Azzer inlier. This area is characterized by its great diversity of geological outcrops that record a history of more than 760 Ma, from Neoproterozoic to Recent. The oldest rocks are represented by the Neoproterozoic intra-oceanic arc systems (Ait Hmane ophiolites) and its varied mineralization exposed in the Bou-Azzer inlier. In the westernmost part of Saghro massif, exceptional outcrops of stromatolites within shallow-marine carbonate platforms formed in a lacustrine environment represent early morphological evidence for late Ediacaran (ca. 571 Ma) life on Earth. In the Agdez region, Cambrian to Ordovician biostratigraphic units with attractively preserved faunas and notable lithofacies variation provide key chemo- and chronostratigraphic information for global correlation. In the Aghbar region (Bou Azzer inlier), trachytic sills with an alkaline-shoshonitic affinity are interbedded with the Lower Cambrian platform sedimentary series (Taroudant Group). Together with the related Jbel Boho volcanic ash beds and flows of the southern Bou-Azzer inlier, they represent one of the preserved magmatic events emplaced in Lower Cambrian host rocks of Morocco, which triggered a post-orogenic extensional environment that led to the opening of the Rheic Ocean. The geology of Ait Hmane region in the Bou Azzer inlier is marked by the presence of Snowball Earth-related glaciogenic diamictites that were deposited during a late Ediacaran glacial period dated between ca. 592 Ma and ca. 579 Ma. Northeast of Bou-Azzer village, a huge volume of late Ediacaran mainly highly silicic volcanic and volcano-sedimentary rocks of the Ouarzazate Group record the onset of a post-collisional magmatic episode. The overlying lower Cambrian, passive margin platform limestones (Adoudou Formation, Taroudant Group) record the beginning of a strong marine incursion. The famous and huge NW-trending Triassic/Jurassic (ca. 201 Ma) Foum Zguid gabbroic dyke of the Central Atlantic Magmatic Province (CAMP) crosses the entire Bou-Azzer inlier and show clear lineation on satellite images. It was part of a magmatic event as a result of the Pangean rifting that led to the opening of the Central Atlantic Ocean.

IRON SULPHIDE VARIANT OF IOCG-STYLE MINERALIZATION IN THE CLONCURRY DISTRICT, AUSTRALIA

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Classification schemes for metasomatic iron oxide-related deposits have continued to expand and evolve ever since the discovery of Olympic Dam in 1975. The broad diversity of Fe-Cu-Au (± Co, Ag, U, REE) deposits, generally described as "IOCG", are anchored by the overwhelming dominance of iron (typically 10 to 40% Fe) both in the regional alteration pattern and as the proximal gangue co-host. The mineralogical form of Fe can vary greatly both within and between mineral districts depending on past metasomatic fluid sources, pathways, host rock settings, crustal levels, basinal interactions, temperatures and redox conditions at time of formation. Iron oxides (magnetite, haematite) are the better-known Fe species of this Fe-Cu-Au association and have formed the basis for most IOCG exploration strategies utilizing magnetic and/or gravity data. Increasingly being recognized though is Fe present in other mineralogical forms such as iron sulphides, carbonates and silicates. These may be present in equally large volumes and provide similar vectors to Fe-Cu-Au mineralization centres, but from an exploration viewpoint require a complete re-evaluation of exploration strategies and exploration tools utilized to ensure success. A simple separation into "magnetite style" and "haematite style" targets is no longer adequate for high-cost exploration, particularly under cover. An exploration strategy targeting the iron sulphide variant to the classic IOCG style of mineralization, has successfully demonstrated widespread occurrences of this Fe-Cu-Au style. Iron sulphide copper-gold mineralization (ISCG), dominated by iron in the form of pyrrhotite instead of magnetite or haematite, is a viable exploration target that requires a significantly different exploration strategy. The highly conductive nature of the dominant pyrrhotite component means electrical geophysical methods, airborne regional and ground surveys, are an effective subsurface detection method. Conversely, the limited magnetic susceptibility of pyrrhotite, and the tendency for ISCG mineralization to develop as thinner, long strike-length tabular bodies along structures and rheological contacts, means gravity and magnetics are largely ineffective as exploration tools. The Eloise Mine, having produced over 340,000 t Cu and 170,000 oz. Au since 1996 and with a remaining resource of 4.4 Mt @ 2.3% Cu, 0.7 g/t Au, is the pre-eminent example of the ISCG mineralization style. Minotaur Exploration's ISCG strategy within the Cloncurry District has been very successful, resulting in four pyrrhotite-dominated Fe-Cu-Au deposit discoveries to date (Cormorant, Artemis, Iris-Electra and Jericho) within a district containing numerous IOCG deposits.

IRON ISOTOPE FRACTIONATION BETWEEN OLIVINE AND METAL: IMPLICATIONS FOR THE FORMATION OF PALLASITE METEORITES

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The origin of pallasite meteorites has long been debated. Classically, pallasites were thought to represent samples from the core-mantle boundary of a differentiated planetesimal. More recent studies, however, have advocated for an origin in the shallow mantle based on palaeomagnetic data. It has also been noted that the wide variety of metallographic cooling rates recorded by pallasites are at odds with a core-mantle boundary origin. To test models of pallasite formation, we determined if the olivine and metal that comprise these meteorites were equilibrated at high temperatures. First, we measured the Fe-isotope composition of olivine and metal in eleven main group pallasites (MGPs). We found consistent olivine-metal fractionations, with olivine being isotopically lighter than metal ($\Delta^{56}Fe_{olivine\text{-}metal}$ = -0.049 ± 0.016‰). To interpret the fractionation observed in MGPs, we determined the equilibrium fractionation of Fe-isotopes between olivine and metal using high temperature experiments and first principles calculations. These independent approaches show that olivine is isotopically heavier than metal at equilibrium. Our high temperature experiments, in which liquid Fe ± Ni metal is equilibrated with olivine (Fo# ≈ 78), provide the most direct comparison with pallasite meteorites. These experiments show that $\Delta^{56}Fe_{olivine\text{-}metal}$ = 0.059 ± 0.027‰ at 1673°K. The opposite sense of olivine-metal Fe-isotope fractionation recorded by MGPs versus our experiments and calculations indicates that olivine and metal in MGPs were not isotopically equilibrated. Isotopic equilibration is achieved quickly at high temperatures, and pallasites must therefore have cooled rapidly to the closure temperature for Fe-isotopes in olivine. We coupled calculations of isotope diffusion in olivine with cooling histories extracted from 1D conductive cooling models, to determine which regions of a planetesimal mantle possess conditions that preclude olivine-metal equilibrium. For plausible differentiated planetesimal radii (> 100 km), models indicate that cooling in the mid to shallow mantle is required to prevent equilibration. Our results cannot be reconciled with a core-mantle boundary origin for pallasites, in agreement with

assertions made on the basis of palaeomagnetic data. This consensus between independent geochemical and geophysical approaches is an encouraging step towards a concordant model for the formation of pallasite meteorites.

FUTURE PROSPECTS OF SHALLOW GEOTHERMAL HEAT RECYCLING

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More than 60% of the residential energy consumption in Canada is used for space heating; in Atlantic Canada the number is closer to 70%. In order to meet the country's 2030 and 2050 targets for greenhouse gas emissions, we must particularly focus on decarbonizing the heating sector. At the same time, ground temperatures are increasing due to climate change and anthropogenic waste heat such as urban heat islands. Here we present a global analysis of the feasibility of extracting this accumulated ground heat through shallow geothermal systems to meet local annual heating demands. Based on more than 8000 mostly rural groundwater temperature observation locations our analysis reveals that over 50% of sites are thermally polluted and that recycling this heat over a 20 m thick zone of permeable ground could fulfill local heating demands for more than 1 year. For 25% of locations, heat recycling could meet a notable percentage of local heating demands by recycling the annual heat input into the underground from surface and buildings. For locations with additional small-scale heat sources such as underground parking, underground retail space, and underground railways, the annual heat input might even be as high as annual heating demands without including the geothermal heat flow. Based on the future climate scenarios RCP 4.5 and 8.5 of the CMIP5 framework, we also quantify future scenarios in which subsurface temperatures are kept to current unpolluted levels by continuously recycling the annual heat input. For RCP 4.5, 81% of sites (99% for RCP 8.5) can fulfill one quarter of their local (future) heating demands in 2099 by simply recycling the annual heat input from the surface to the groundwater table elevation given the additional downward heat flux due to climate change. For 73% of sites (97% for RCP 8.5), the annual heating demand can be entirely met if the technologies are available to extract it in an economically viable manner. Results point to the need for more in-depth studies of the viability of large-scale shallow ground energy recycling.

THE IMPACT OF OUR WARMING CLIMATE ON GLOBAL GROUNDWATER TEMPERATURE

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Despite the concerted efforts projecting air, sea surface, and land surface temperatures for the coming century, very little thought is spent on what is happening beneath our feet in shallow aquifers thermal regimes. Meanwhile, changing groundwater temperatures have far-reaching implications. They impact groundwater quality through changing pH values and oxygen saturation, provide sustainable heating through shallow geothermal energy systems, and threaten groundwater dependent ecosystems in the aquifer and in receiving surface water bodies. Herein, we developed the first global model of groundwater temperature patterns in space and time. Existing analytical solutions to conductive heat transport are combined with global high-resolution maps of diffusivity (estimated from sediment types) and geothermal gradient and forced with soil temperatures at 0–7 cm depth from the ERA5-Land climate reanalysis product. Groundwater temperatures are presented as a Google Earth Engine web application allowing any user to estimate and visualizes temperature depth profiles down to 50 m at any location for the past two decades. Based on our database of more than 8000 individual groundwater temperature measurement locations, the global groundwater temperature model has an RMSE of 1.5°C and the coefficient of determination r^2 of 0.72. We then apply the model to generate groundwater temperature projections using monthly soil temperatures of the CMIP5 scenarios RCP 4.5 and RCP 8.5 out to 2100 as surface boundary conditions. Over the last 20 years, global groundwater temperatures have only increased by 0.1 (0.0, 0.5)°C (median, 10th and 90th percentile). Changes were most drastic in South America and Northeastern Europe, whereas parts of Canada (particularly Northern Ontario) experienced decreasing temperatures. Aquifer temperatures in Atlantic Canada on the other hand increased by 0.1°C. Warming will intensify and by the end of the century global average temperatures at the groundwater table are projected to increase by an additional 1.0 (0.0, 2.2)°C following RCP 4.5 or 1.4 (0.0, 4.2)°C following RCP 8.5. In Canada (and all North America), this change will particularly impact regions East of the Rocky Mountains with temperatures in Atlantic Canada increasing on average by 1.0°C (RCP 4.5) or 1.8°C (RCP 8.5). These groundwater warming rates warrant further analysis particularly in groundwater warming 'hot spots' to assess where warming aquifers may influence drinking water quality or aquatic habitat.

EPISODES AND AGID – TWO VENTURES WITH CANADIAN ROOTS

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Episodes is the quarterly journal of the International Union of Geological Sciences, and an important channel of communication to earth scientists around the world. From its beginnings in Ottawa, and after travelling to the US, the UK, China and India, the journal is now produced in South Korea as an on-line open-access publication with a respectable impact factor. This talk traces the history of Episodes, its importance to IUGS and to geological standards, as well as the arrangement for co-publication of IUGS books with the Geological Society of London. Another venture that began in Canada in the 1970s was the Association of Geoscientists for International Development, perhaps the first international society specifically dedicated to building science in the Third World. As scientific institutions and communities in Africa, Asia and Latin America grew and the internet developed, other organizations became more active in supporting international earth science, and AGID faded out. It left behind a legacy of contributions among others to the global management and dissemination of scientific information, and to working with small-scale and artisanal miners.

A NEW PROGRAM AIMED AT UNDERSTANDING IMPACTS OF ARTISANAL AND SMALL-SCALE GOLD MINING IN THE AMAZON (IGCP PROJECT 696)

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Largely because of use during the exploitation of gold, mercury (Hg) is a health concern in many regions of the developing world including the Amazon. Mercury use and release is associated with artisanal and small-scale gold mining (ASGM), which is done by individuals or groups of miners mostly operating informally with little to no regulation. This type of mining uses rudimentary methods including Hg amalgamation and impacts local, regional and global environments through contamination and land use change. Globally, ASGM is also considered the largest primary source of Hg pollution to the atmosphere and to water. After Hg enters terrestrial and aquatic ecosystems, it can be converted to methylmercury that bioaccumulates in aquatic food webs. Unfortunately, there are still many gaps in our understanding of the cycling of Hg in Amazonian ecosystems, particularly in areas with ASGM. These uncertainties are driven by many factors related to ASGM being largely informal and encompassing a wide variety and scale of gold extraction practices that use and release different amounts of Hg. Furthermore, as ASGM is often unregulated and sometimes practised illegally, significant constraints are placed on accessibility and the instruments that can be used for data and sample collection. The need for more and better estimates of ASGM Hg inputs to both air and water was highlighted in the most recent Global Mercury Assessment by the UN Environment Program since these estimates are the basis of global modelling efforts. Our IGCP project (696, Impacts from Artisanal and Small-Scale Gold Mining in the Amazon) aims to integrate and generate scientific knowledge to better understand how Hg pollution from ASGM is transported, transformed, bioaccumulated and sequestered in Amazonian ecosystems. Thus, we are focused on understanding the biogeochemical cycling of Hg, and how changes in mining practices and land use can help reduce

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Hg exposure for people working in ASGM and for people and wildlife dependent on the aquatic food webs that bioaccumulate Hg. Although workshops and field work were postponed due to the pandemic, our group met pre-pandemic for initial planning and continued to meet via Zoom over the last two years, and several PhD and Master's projects were successfully completed as well. Results of students associated with the program and our collaborations are presented in addition to our future goals.

IMPLICATIONS OF THE 20 MYR GENERATION AND ASSEMBLY OF THE LATE DEVONIAN SOUTH MOUNTAIN BATHOLITH (NOVA SCOTIA, CANADA) FROM ZIRCON U–Pb DATING, GEOCHEMISTRY AND Hf-O ISOTOPES

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The composite South Mountain Batholith (SMB) of Nova Scotia (Canada) is the largest (~7300 km^2) exposed granitoid intrusion in the Appalachians. It lies entirely within and is the most dominant geological feature of the Meguma terrane, which is the most outboard terrane of this part of the Appalachians. Despite its geotectonic relevance, its precise time of magma generation and termination of emplacement are poorly constrained. To resolve this problem, in situ and CA-TIMS U–Pb dating combined with in situ isotopes (Lu–Hf, O) and geochemistry for different zircon domains (i.e. xenocrystic, antecrystic, autocrystic) from all phases of the SMB have been obtained. The CA-ID-TIMS data crystallization and emplacement for the early-stage granodiorite (378.7 ± 1.2 to 375.4 ± 0.8 Ma) to late-stage leucogranite (375.4 to 371.8 ± 0.8 Ma) spanned over 10 Myr. Furthermore, in situ SHRIMP, LA-MC-ICP-MS, and SIMS dating targeting analyses of distinct cathodoluminescence domains in zircon domains reveal: 1) abundant ancient xenocrysts with ages of (~420 Ma to 2.2 Ga); 2) antecryst ages ca. 3 to 15 Myr older than the time of SMB emplacement (i.e. to 390 Ma); 3) autocryst $\delta^{18}O$ values between +7.3 and +9.1‰ (V-SMOW); and 4) generally similar Hf isotopes, REE signatures, and derived fO_2 values among antecrysts and autocrysts; but 5) εHf values for the 371.8 ± 0.8 Ma autocrysts of the Davis Lake Pluton (DLP) are higher (+1.74 to +4.38) than the rest of the SMB (-2.99 to +1.68). Collectively the data indicate a protracted magmatic evolution for the SMB with melt generation and assembly from ~390 to 370 Ma. Thus, inception of SMB magmatism was coeval with the regional deformation (i.e. ~415 to 390 Ma) tied to dextral transpression between the Avalon and Meguma terranes, commensurate with destruction of the Rheic Ocean. The range of zircon domain ages and the coupled isotopic signatures (Hf-O) and geochemistry of SMB zircons suggest magma generation via a modified melting, assimilation, storage and homogenization (MASH) model that was initiated by involving partial melting of a metasomatized mantle or SCLM region followed by contamination at different crustal levels which involved igneous suites of the underthrust Avalonia terrane (deep) and Meguma metasedimentary rocks (shallow). The most southwestern part of the SMB (i.e. DLP) represents a petrogenetically distinct magmatic phase that underwent less overall contamination than the rest of the SMB, which may have metallogenic implications given that it hosts a significant Sn deposit.

MAJOR- AND TRACE-ELEMENT GEOCHEMISTRY OF PEGMATITES OF THE HALL PENINSULA, BAFFIN ISLAND, NUNAVUT: IMPLICATIONS FOR PETROGENESIS, TECTONIC SETTING, AND MINERAL POTENTIAL

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Numerous simple granitic pegmatites intrude the Paleoproterozoic country rock of the Hall Peninsula, on southern Baffin Island, Nunavut. The pegmatites are interpreted as having intruded in the late stages of the Trans-Hudson Orogen's tectonic evolution. They are generally undeformed, are usually concordant with the foliation of the country rock, and display primary characteristics including centimetre-scale crystals, graphic quartz-feldspar intergrowth and comb-textured tourmaline. This work was done to determine the source of the pegmatites' parent melts and timing of their formation with respect to orogenic evolution, and to ascertain their absolute ages of emplacement, using whole-rock geochemistry, LA-ICP-MS on selected minerals, and U–Pb geochronology. Detailed geochemical analysis of over 60 representative samples from the Hall Peninsula study area has allowed the identification of two separate generations of pegmatites. The older pegmatite population crystallized at ~1860 Ma, corresponding closely to the intrusion of the Cumberland Batholith. The younger pegmatite population crystallized at ~1795 Ma, which corresponds with the terminal accretion phase of the Trans-Hudson Orogen. The two populations can be distinguished based on ratios of trace-element concentrations, including Nb/Ta and Rb/Sr vs Sr/Ba. The Rb/Sr vs Sr/Ba values for the samples suggest that the older pegmatites crystallized from magmas that assimilated or hybridized with much of the available biotite, muscovite, and K-feldspar in the parent rock, and the melt which formed the younger pegmatites was much drier, with little to no vapour or fluid phase present. The identification of these two populations may have implications for characterizing the mineral potential of pegmatites on southern Baffin Island: the pegmatites with Nb/Ta greater than 8, those with the highest REE values, and those with Rb/Sr greater than Sr/Ba, as well as the pegmatite which hosted the single beryl crystal identified during the field work, are all part of the older population.

EXPERIMENTAL AND THEORETICAL SILLIMANITE AND CORUNDUM NUCLEATION IN A PERALUMINOUS PEGMATITE: THE SURPRISING CASE OF THE MT. MICA PEGMATITE

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Peraluminous pegmatites are common in nature and are mainly composed of sodic plagioclase, K-feldspar, and quartz, but little-to-no aluminosilicate minerals. It was therefore surprising when crystallization experiments performed on a peraluminous granite composition produced stable aluminosilicate and corundum. Experiments designed to investigate the nucleation delay of crystals in a hydrous peraluminous granitic melt of the Mt. Mica pegmatite composition (ME, USA, ASI = 1.45) at increasing degrees of undercooling were performed at 630 MPa between 850° and 1000°C for 5 to 211 hours. Experimental run products were investigated by SEM microscopy, with EDS analyses of crystalline and quenched liquid phases and compared to a theoretical nucleation delay model based on the classical nucleation theory. These experiments produced stable corundum and an aluminosilicate mineral, which is thought to be sillimanite due to the range of pressures and temperatures at which the experiments were performed, though the natural rock lacks these aluminum-rich minerals. Experiments demonstrated the stability of sillimanite and corundum at temperatures approximately 200°C higher than feldspar and quartz stability, and the classical nucleation theory accurately predicted their nucleation within a factor of 3 in time. The absence of sillimanite and corundum in the natural rocks of Mt. Mica is hypothesized to be caused by corundum being removed at lower temperature to produce feldspar and sillimanite, in analogy to the reaction between corundum and mullite in the Na_2O-SiO_2-Al_2O_3 phase diagram. Subsequently, as the system reaches even lower temperature, sillimanite could undergo the following reaction: sillimanite + melt = muscovite + H_2O + quartz + plagioclase to remove sillimanite and produce muscovite, plagioclase, and quartz, which are abundant in the rocks of Mt. Mica. The discovery of stable sillimanite and corundum near the liquidus of this peraluminous composition raises the possibility that fractionation of these aluminous phases can lead to a sequence of granitic magmas with decreasing aluminum concentrations, which is contrary to the common suggestion that peraluminous melts are generated by fractional crystallization in metaluminous magmas.

GEOCHEMICAL VARIATION IN JURASSIC–CRETACEOUS STRATA OF THE BACCALIEU I-78 WELL, FLEMISH PASS BASIN, CANADA: CHEMOSTRATIGRAPHIC AND PALEOENVIRONMENTAL IMPLICATIONS

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The Jurassic–Cretaceous boundary is notoriously difficult to detect in the absence of fossils as it is not associated with any major glacio-eustatic fluctuations or remarkable global change in lithology. It remains the only Phanerozoic period-level boundary that is missing a golden spike on the geological time scale. Previous palynological analyses have suggested that the Jurassic–Cretaceous boundary resides within the Esso Parex et al Baccalieu I-78 well, with one study reporting that the boundary occurs in core 3. Profiles of paleoenvironmental proxies for core 3, generated from stable isotope and trace element analyses, exhibit a geochemical anomaly between 3288.5 m and 3289 m. Variations in these profiles, corresponding to the anomaly, provide insights into changes in the paleoenvironment during this interval. Anoxic conditions are interpreted to have occurred during deposition of the strata associated with the anomaly based on the $\delta^{34}S$, Fe, Mn, Th/U, and Ce/Ce* trends. This is further supported by a peak in total organic carbon (TOC) within the interval, which implies that paleoredox conditions were conducive to the preservation of organic matter. A reversion to background levels above the anomaly for these paleoredox proxies, suggests a change to more oxygenated settings. Low primary productivity across the anomaly is indicated by consistent shifts in the $\delta^{13}C$, $\delta^{15}N$, P, Ni, Zn, and Cu profiles, which was followed by an increase in primary productivity above the anomaly associated with the onset of upwelling. Paleo-salinity peaks within the anomaly, as indicated by Sr/Ba, B/Ga, and %S/TOC, suggesting a highly restricted environment, but declines above the anomaly implying an uptick in circulation. The various geochemical analyses indicate that the anomaly is associated with a fall in relative sea level, which led to restricted circulation, a stratified ocean, and widespread anoxia. The fall in sea level coupled with an arid climate further resulted in diminished terrestrial input and limited nutrient supply that led to a reduction in primary productivity during deposition of the strata associated with the anomaly. Our results suggest that the Jurassic–Cretaceous boundary in Baccalieu I-78 may fall within the geochemical anomaly (3288.5–3289 m). This is consistent with global trends related to the boundary that indicate a late Tithonian fall in relative sea level, typically linked to tectonism (as opposed to eustasy) in a semi-arid to arid climate. The current investigation demonstrates the usefulness of geochemical analyses in the identification of stratigraphic boundaries (chemostratigraphy) and in paleoenvironmental interpretation.

CRITICAL METALS IN SUBSURFACE BRINES OF SASKATCHEWAN

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The transition to low carbon and renewable energy sources will be mineral intensive, requiring new sources of critical metals including Li and rare earth elements (REE) in order to meet growing demand for clean energy technologies. Subsurface brines from sedimentary basins have been identified as a potential source of these metals, with brines from the Western Canada Sedimentary Basin receiving considerable attention for Li abundances in recent years. While previous work has focused on measuring Li concentrations in brines from across Alberta and southeastern Saskatchewan, the abundances of REE as well as the sources, distribution, and controls on enrichment for these critical minerals remain poorly understood. In this work, brine samples collected from petroleum wells in western and southeastern Saskatchewan were analyzed for their inorganic geochemistry, including Li and REE. These data were integrated with geochemical analyses of drill core and subjected to statistical analyses and machine learning algorithms to constrain the potential sources of these elements. The results indicate that Li abundances are greater in brines from Paleozoic sedimentary strata of southeastern Saskatchewan and could be sourced from either the hydrothermal circulation of fluids originating from the Precambrian basement or water rock interactions with clay minerals formed through the weathering of Li rich igneous rocks. Conversely, REE are more concentrated in Mesozoic strata from western Saskatchewan with core geochemical analyses indicating a detrital source. Our study aids in understanding the origins of critical metals in basinal brines and provides insights essential to determining where economic abundances of these elements occur. Identifying new sources of critical metals in Canada is crucial in order to meet our future energy demands in a low carbon future.

LANDSLIDES THAT HAVE RESULTED IN FATALITIES IN CANADA (1771–2022)

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A revised compilation of historical fatal landslide events revealed that at least 808 people perished in Canada from 1771–2021. British Columbia (BC) experienced the highest number of fatalities at 375 (46%) and Québec, the 2nd highest, at 239 (30%). These fatalities mainly reflect development within the landslide prone mountainous terrain in BC, and sensitive glaciomarine clay areas in Québec. The mountains of Alberta have witnessed one event (73 fatalities; 9%) which is the worst Canadian landslide disaster. In Newfoundland and Labrador, rockfalls from rugged terrain are the main reason for 103 fatalities (13%). Fatalities only occurred in two other provinces and territories each: Ontario, 15 fatalities (2%), New Brunswick, Northwest Territories and Yukon, 1 fatality each (0.1% each). The lack of fatalities elsewhere is likely related to fewer landslide events and low population density and development. The highest number of landslides and fatalities occurred from the 1880s to 1920s when major infrastructure corridors were being developed, but landslide hazards were poorly understood. Québec City suffered great losses during the 1800s mainly due to rock slides within the same vicinity. The most common months for fatal landslide events were September to January. In BC, this reflects the occurrence of debris flows triggered along steep channels by high intensity rainfall events during the fall and winter months as observed in November 2021. In the St. Lawrence Lowlands, spring and fall months are the most common for fatal landslides in sensitive clays. In Québec, 35 historical landslides caused 239 fatalities; 24 of these fatal events occurred from landslides in sensitive clays. Since 2003, the Québec Ministry of Transportation developed regional landslide susceptibility maps to help mitigate landslides. Moreover, through time, understanding of landslides events and their potential triggers has led to several mitigation measures and thus, fewer fatalities per decade and per event.

TRIANGLE ZONE THRUST GEOMETRY AS A NATURAL FOCUSING MECHANISM IN OROGENIC GOLD SYSTEMS

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Orogenic gold mineral systems are typically associated with deep-reaching fault systems active at the peak of, or late during, a major orogenic shortening episode. Although often steepened or even overturned by later deformation, and overprinted by late strike-slip movements, the critical faults acted as thick-skinned thrusts during the onset of mineralization, thus promoting large-scale fluid advection. This can be shown by detailed structural and kinematic studies, but, where severely overprinted and confused by later strike-slip movements, it is also indicated by preferential preservation of upper crustal syn-orogenic clastic deposits in footwall panels or synclines on one side of the major faults. Gold endowment is also typically asymmetric across these faults, with higher gold endowment on the more completely preserved footwall side of these fault systems, with complementary parts having been removed by uplift and erosion on the hanging-wall side. Type examples of this setting are the highly endowed Timmins and Kirkland Lake gold camps of the Abitibi greenstone belt. Other camps with essentially identical setup, across geological time, are the Barberton greenstone belt (3.2 Ga), the Yellowknife belt (2.7–2.6 Ga), systems in the Trans-Hudson orogen (1.8 Ga), the central Grenville orogen (1.1 Ga), the gold belt of central Newfoundland (0.4 Ga), and even younger systems such as the Motherlode system (0.1 Ga) of California. We are engaged in an in-depth comparative study among some of these settings, specifically between the Archean Abitibi systems and the emerging gold belt of central Newfoundland. These two well-endowed settings, on either end of the temporal spectrum, show amazing similarities in overall struc-

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tural and lithological architecture, and in terms of key processes and rates. Gold is spatially associated with narrow panels or belts of syn-orogenic clastic deposits, preserved in the structural footwalls of first-order thrust systems. Bimodal syn-orogenic magmatism occurred prior to thick-skinned thrusting, suggesting that the first-order thrust faults inverted earlier extensional fault systems. A potentially critical insight of our comparative study is the realization that the key thrust faults also wedged into the orogenic foreland, in a "triangle zone"-like geometry, forcing reactivation of older thrust systems of opposite dip. Importantly, this geometry sets up an upward-converging geometry of active faults where advecting fluids are naturally contained and focused, to create a narrow domain affected by cyclic fluid over-pressuring. We hypothesize that this triangle zone geometry is critical to forming some of the world's richest orogenic gold districts.

NOT SO OLD: THE NUVVUAGITTUQ GREENSTONE REMNANT OF THE NORTHERN SUPERIOR CRATON

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Despite an intense search in recent decades, the terrestrial record of pre-3.8 Ga, Hadean crust remains extremely sparse. Among the ~35 Archean craton fragments, the Superior craton similarly has only a very sparse pre-3.8 Ga record, mainly based on a few detrital zircons. There is however the claim of pre-4.0 Ga mafic rocks in the Nuvvuagittuq greenstone belt remnant. This claim, based on complex Sm–Nd systematics, remains disputed. This intensely deformed greenstone remnant, enclosed among voluminous ~3.66 Ga metatonalites, has not produced any zircons older than 3.8 Ga, rendering claims for ~4.2 Ga protolith ages unlikely. This would appeal to a ~400 Myr interval of preservation without any melting and zircon production, a scenario that we consider unlikely. Structurally interleaved with the metavolcanic rocks are indisputable metasedimentary rocks varying from conglomerates with quartz and metatonalite pebbles to fuchsitic quartzites, and upward-fining metapelitic rocks, all preserving primary features such as bedding and heavy mineral laminations. Well-preserved fuchsitic quartzite with deformed but distinct compositional layering, and heavy mineral enrichment of zircon, rutile, and chromite in certain layers, is unmistakable as an Archean, mature, quartz-rich sedimentary rock, enriched in detrital chromite from the erosion of older mafic sources. The association of this quartzite with conglomerate likely points to at least one important unconformity in the Nuvvuagittuq tectono-stratigraphy. We collected several large samples from these metasedimentary rocks and made polished slabs to further document key characteristics. One large sample consisting of quartz-pebble conglomerate to fuchsitic quartzite was separated for detrital zircons, which was then imaged and analyzed by SHRIMP at the GSC, in Ottawa. Old zircon grains are very sparse and top out at ~3.78 Ga. The main detrital mode is 3.66 Ga, which is the age of voluminous surrounding metatonalites. There are several younger minor modes between 3.6 and 3.4 Ga, all including grains with preserved oscillatory zoning, normal Th/U values for igneous zircons, and slight rounding, with the latter overgrown by ~2.7 Ga metamorphic rims. We are confident that most, if not all, of these zircon grains are detrital in origin. A single youngest grain with similar characteristics is ~3035 Ma. We conclude that abundant siliciclastic metasedimentary units of the Nuvvuagittuq greenstone belt are younger than 3.40 Ga, and likely younger than 3.04 Ga. The fuchsitic quartzite is a genuine mature quartzitic metasedimentary rock, not metasomatized metatonalite. Collectively the observations suggest a transposed unconformity, along which quartz-rich sedimentary rocks younger than 3.4 Ga, and likely younger than 3.04 Ga, were deposited across older metavolcanic rocks with an age of ~3.85–3.75 Ga.

A POSSIBLE RESOLUTION TO APPARENT CONTRADICTIONS IN THE NEOPROTEROZOIC HISTORY OF GANDERIA

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This contribution examines published data on the Neoproterozoic history of Ganderia and attempts to resolve apparently contradictory evidence regarding its origins and interactions with other terranes and cratons. Little is known directly of Ganderia's basement save for ~975 Ma anorthosite of Grenvillian affinity found in core from New Brunswick. Most Neoproterozoic and Cambrian rocks have detrital zircon (DZ) and Hf data that point to Baltica as the craton of origin. In New Hampshire, the ~625 Ma Massabesic Gneiss has orthogneiss with continental rift chemistry. The preceding is consistent with a Neoproterozoic location of Ganderia along the Grenvillian Amazonia-Baltica suture, which rifted prior to ~600 Ma opening of the Tornquist Ocean. This is a common site for Ganderia in the literature and this is a suitable starting location for its traverse across the Iapetus. However, DZ age data from Proterozoic sandstones in the Islesboro block (Maine) and Grand Manan Island (New Brunswick) have a large Eburnean peak (~2 Ga) and strongly resemble DZ spectra of Proterozoic passive margin rocks of the West Africa Craton (WAC). The Islesboro block contains a ~647 Ma pegmatite, also found in a Grand Manan conglomerate. In Newfoundland, the Cinq Cerf gneiss includes ~675 Ma granitic orthogneiss implying a magmatic arc setting. Plots of Ganderian εHf vs DZ age suggest a 770–650 Ma arc built on Mesoproterozoic to Paleoproterozoic crust prior to continental collision at ~650 Ma. Other geologic evidence also points to tectonism ~650 Ma in Ganderia and Avalonia. Studies of the Anti-Atlas suggest the Avalonia arc collided with WAC at ~650 Ma (Pan-Africa I orogeny). A scenario that fits these observations (and builds on existing WAC models) considers Ganderia as a composite terrane. Part "A" originates on the Amazonia-Baltica suture. Part "B" rifts from Baltica, along with Avalonia on the outboard side. Subduction ensues (prior to 650 Ma), Avalonia hosts an arc and Ganderia is a back-arc trailing margin. At 650 Ma Avalonia collides with WAC, the back-arc closes, Ganderia collides with Avalonia (Pan-Africa I, injection of Islesboro Pegmatite), and Baltica sediments recycle onto the WAC margin and Ganderia. Subduction jumps outboard until the MOR is subducted, initiating sinistral strike-slip motion. Ganderia "B" slides along the WAC toward Amazonia and "A", incorporating slivers of Proterozoic WAC margin and perhaps slivers of Avalonia along the way. Avalonia trails behind Ganderia. At ~550 Ma, "A" and "B" amalgamate (culmination of Pan Africa II orogeny) to form composite Ganderia prior to traversing the Iapetus.

COMMUNITY ENGAGEMENT THROUGH CITIZEN SCIENCE PROJECTS FOR CANADIAN CORDILLERA ARRAY AND EON-ROSE

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EON–ROSE (Earth-System Observing Network – Reseau d'Observation du Systeme terrestrE) is a new international research collaboration that aims to bring an EarthScope-like program to Canada. The Canadian Cordillera Array (CCArray), extending across the Cordillera from the Beaufort Sea to the U.S. border is being considered as a pilot phase. To progress beyond the methods used in the EarthScope experiment, our intention is to expand the research network to enable holistic examination of Earth Systems from the ionosphere through the critical zone into the core. The envisioned foundation for EON-ROSE will be >1400 telemetered and powered observatories with broadband seismometers, GNSS receivers, infrasound and pressure sensors, weather packages, riometers, permafrost monitors, etc., that will produce real-time data that will be openly available. The first station was installed in July 2018 at Kluane Lake Research Station in Yukon Territory (funded by seed grants from the University of Calgary). Two pilot projects monitoring induced seismicity around Fort St John, BC, and examining the potential for geothermal energy production around Mount Meager, BC, started in 2019. A four-day series of workshops in Nanaimo, BC, will report on the findings from these two pilot projects. Two other days will be used to develop further pilot projects with a mineral exploration collaboration in the Golden Triangle in NW BC and a Global Navigation Satellite System (GNSS) equipment deployment to monitor space weather, tectonics, and environmental factors such as glacial isostatic adjustment and soil moisture. The "Community Science Liaison" (CSL) program will support Canadian communities to design kindergarten to grade 12 (K–12) curriculum- and place-based citizen science research projects using the data produced by their local observatories. The EON-ROSE research community will support these CSLs by developing their training program, providing guidance for project design, assisting with data interpretation, and providing remote presentations. Representatives from the CSL program will be at the EON-ROSE conference, where they will start translating the scientific presentations into citizen science research projects for their classrooms. Community input will also be included when designing the future Earth System Observatories. The purpose of this design is to create community engagement for the EON-ROSE program across Canada.

THE MACKENZIE DELTA; A POTENTIAL UNESCO GLOBAL GEOPARK FOR THE FUTURE

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One exciting potential future Canadian UNESCO Global Geopark is the Mackenzie Delta region in the Northwest Territories. None of the current 178 Geoparks across 45 countries cover permafrost landscapes. Northern Canada is undergoing a transformation, driven by climate change, that will be a defining issue for Canada through the 21st Century. Climate has warmed across the western Arctic with temperatures at their warmest in more than 14,000 years. How Canada responds to this challenge will define our success in mitigating the impacts of these changes on physical infrastructure, ecosystems, food security and communities. Similar challenges are being experienced by all countries with permafrost landscapes across the Arctic implying the required international significance for Geoparks. Our team was just starting to establish the necessary community relations with the local education and research facilities in Tuktoyaktuk, Inuvik, Aklavik, Tsiigehtchic and Fort McPherson before the pandemic. We were also just starting to work with the local Gwichin and Inuvialuit Development Corporations to explore opportunities for developing environmentally sustainable tourism to benefit these communities. In 2018, the Inuvik to Tuktoyaktuk highway (ITH) extension to the Dempster highway opened providing year-round access to the Arctic Ocean for the first time in Canada. Opening this highway was challenging due to a very wet spring that triggered ~80 mudslides along the ITH route forcing a delay to the opening ceremonies. The Geological Survey of Canada has had a long-standing program monitoring the impacts of climate change to the Beaufort Coastline and Mackenzie Delta region because thawing permafrost is literally removing the glue that holds these unconsolidated sediments together. Retreating sea ice is also exposing this region to the impacts of earlier spring and later fall storms. While the ITH was originally planned to provide access to the Mackenzie Delta for petroleum companies, there has been a moratorium on petroleum development across the region (2016 to end of 2021) that is currently under revision. Now that the ITH is completed, the potential for ecotourism development is high, especially for tourists interested in exploring these very remote regions for either 24-hour sunlight in the summer or viewing the aurora borealis in the winter. Just outside of Tuktoyaktuk is the Pingo Canadian Landmark that contains eight pingos which underscores some of the exciting opportunities represented for a Geopark in this region. This presentation will explore the potential for this exciting new Geopark.

SEQUENTIAL DUCTILE TO BRITTLE TRANSITIONS CONTROL THE ARCHITECTURE OF THE THIN SKINNED NAUKLUFT NAPPE COMPLEX

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The architecture of thin-skinned fold and thrust belts depends on the strength of faults and shear zones. In shallow fold-thrust belts or on small scales, this can be simply modeled with friction laws, but in some settings, such as in the Neoproterozoic-Cambrian Naukluft Nappe Complex in central Namibia, faults sole into ductile shear zones or migrate between ductile (deeper) and brittle (shallower) regimes during activity. Ductile shearing is facilitated by crystal plastic deformation, leading to grain size reduction, and grain boundary sliding. Brittle deformation is recorded by localized brecciation and the development of discrete faults. Through linked field investigations and microstructural analysis, we aim to investigate how changes in fault strength contributed to larger scale architectural evolution of the fold and thrust belt. scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) reveal the mineralogy and electron backscatter diffraction (EBSD) reveal the deformation mechanisms as shear initiated. We show that the progression of nappe bounding structures through ductile to brittle regimes during in-sequence thrusting, culminating in overthrusting of the Cambrian Nama Basin along the primarily brittle and seismic Naukluft Thrust. Field relations reveal syn-kinematic sequential transitions between distributed folding and shearing, to the development of localized mylonites, to embrittlement recorded by the brecciation of mylonites and development of discrete faults. Younger faults which are structurally lower show a reduced thickness of mylonite and ductile deformation zones, and increased development of brittle fault rocks. We show that first the ductile, then the brittle phase accommodates the displacement as the nappe stack propagates. Both the localized mylonites and the discrete faults that overprint them trend similarly. The brittle discrete faults follow the same orientation as the overall transport direction of the nappe complex. This work shows how brittle and ductile behaviours interplay and accommodate mountain building. This suggests that it may be important to consider the effects of deeper ductile behaviour in "Coulomb wedge" descriptions of thin-skinned thrust belts.

ESTIMATION OF THE GROUNDWATER RESIDENCE TIMES IN THE LAURENTIDES REGION BY $^{3}H/^{3}He$, $U+Th/^{4}He$, ^{14}C AND $^{234}U/^{238}U$ ISOTOPIC APPROACH

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The Laurentides Region (11,500 km^2) has been subject to the peri-urban development of the Montreal region, with surrounding regional county municipalities (MRC) having experienced a population growth of 3–43% between 2001 and 2017. Groundwater is a vital resource for nearly 44% of the Laurentides population and increased development exerts additional pressure on groundwater resources, already threatened by the effects of climate change. The objectives of this MSc project are three-fold: quantify the residence time of groundwater utilized by municipal drinking water supply systems, identify the groundwater's sources and assess the vulnerability of granular and fractured aquifers exploited in the Grenville geological province. To this end, 31 groundwater samples were collected during the summers of 2019 and 2020 to measure various geochronometers including stable water isotopes (^{2}H, ^{18}O), tritium (^{3}H), helium isotopes (^{3}He and ^{4}He), uranium isotopes ($^{234}U/^{238}U$) and ^{14}C activity. The ^{3}H and ^{14}C samples were analyzed at the University of Ottawa, while the stable isotopes of noble gases and uranium were analyzed in the Geotop laboratories at UQAM. Stable water isotopes were analyzed and situated along the local meteoric line, illustrating that Laurentian groundwater originates primarily from spring recharge with (^{2}H, ^{18}O) values ranging from (-86, -12.6) to (-69, -10.0) ‰ vs. V-SMOW. Regionally, analysis of activity of the sampled geochronometers is indicative of piston flow across the watersheds. Geochronometers further illustrate that exploited groundwater consists of a mixture of modern (5–50 years old) and millennial (0–7000 years old) water, resulting in a Ca-HCO_3-type geochemical facies. The absence of groundwater with ^{14}C-calculated residence times older than 7 ka suggests that the aquifers of the region were completely depleted of older groundwater at the end of the main phase of the glacial isostatic rebound (12.7–6.7 ka) that ushered in the region's present-day hydrogeological network.

GEOCHEMISTRY AND Sm-Nd-Lu-Hf ISOTOPIC CHARACTERISTICS OF THE AVANAVERO MAFIC INTRUSIONS OCCURRING IN NW GUYANA, GUIANA SHIELD, SOUTH AMERICA

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Avanavero mafic dykes and sills are widespread in the Amazonian Craton, South America. Although the complete extent of the Avanavero magmatism is currently unclear, it has been found in places where it hadn't been previously mapped (e.g. NW Guyana, the focus of this study). The Avanavero event is recognized to extend over 300,000 km^2 and to have a minimum volume of 30,000 km^3. It has been proposed to be linked with similar age units in the formerly adjacent West African craton. For the purpose of this study, in addition to fresh unmetamorphosed samples, we also recognize some more highly weathered samples which we term Avanavero-like samples. Most of the Avanavero-like samples have Avanavero chemistry apart from two samples 19-BC-33 and 19-BC-45, which may belong to a different event. The Avanavero and Avanavero-like samples range from andesitic basalts to basalts and have a tholeiitic signature, and in the literature, the Avanavero LIP samples can be divided into high-Ti and low-Ti groups; however, all the samples from NW Guyana have low TiO_2. The chondrite-normalized diagram for the rare earth elements (REE) displays a slight enrichment in the light-REE relative to the heavy-

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REE, and negative anomalies of Nb and Ti in the primitive mantle-normalized multielement diagram. The slightly flat HREE patterns suggest that residual garnet did not take part during melting, and that melting should be within the stability of the spinel lherzolite field, also seen by the TiO_2/Yb vs. Nb/Yb projection where the samples plot within the MORB+OPB+IAB array. The good positive correlation between Zr and Y, Nb, Th, Ce, Gd and Yb shows that there should not be a significant mobilization by any post-magmatic alteration, meaning that the data presented here reflect the primary mantle composition. The depletion of high-field-strength elements (HFSE), such as Nb and Zr, relative to the light-REE including La can be attributed to interaction with subduction modified lithospheric mantle. The Sm–Nd isotopic data shows that there is not a significant variation in the initial $^{143}Nd/^{144}Nd$ ratios for the main Avanavero samples and for the Avanavero-like samples of NW Guyana. The initial $^{176}Hf/^{177}Hf$ ratios suggest (so far) that these samples are not rigorously cogenetic, and each group has a different mantle source, with the Avanavero-like group showing a higher interaction and/or contamination with crustal components.

DISTRIBUTION, AGE AND DURATION OF VOLCANISM OF THE CHEAKAMUS BASALTS, GARIBALDI VOLCANIC BELT, BC: PALEOENVIRONMENTAL IMPLICATIONS

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The Cheakamus basalts comprise a group of Quaternary olivine tholeiite lavas in the Garibaldi Volcanic Belt of British Columbia, distributed within the Cheakamus River and Callaghan valleys, 12 km SW of Whistler. The basalts are > 26 km in length, with lateral extents of 1–2 km, and thickness of ≤ 80 m where exposed in sections through paleo-valleys. Previous studies assert basic distributions, lithology, and geochemistry and posit a partial glaciovolcanic origin. However, the basalt's eruptive source, definitive age, distribution, and eruptive duration remain unestablished. Work in the 2021 field season updated stratigraphy and located the eruptive vent, increasing the aerial extent of the basalt lavas by ~2.5 km² to a total of ~35 km². New $^{40}Ar/^{39}Ar$ dates places the oldest, bedrock-contact lavas at 23.9 ± 15.7 ka, and stratigraphically highest lavas at 23.9 ± 14.4 ka. These results improve on previous age estimates (i.e. ^{14}C and K–Ar ages) and indicate rapid emplacement of the first and last eruptive phases with little separation in time. Paleomagnetic results further establish that all Cheakamus basalt lavas were emplaced within the same paleomagnetic moment, the duration of which is estimated at < 2000 years. The basalts record evidence for both subaerial and ice/meltwater-contact cooling surfaces, as well as inter- and post-emplacement erosional features such as glaciated surfaces and incised meltwater channels. Improving age constraints, distributions, and emplacement textures of the basalts allow us to begin a paleoenvironmental reconstruction with implications for the timing and extent of ice cover during the penultimate and Fraser glaciations. Our radiometric dating and paleomagnetic results suggest that both the eruption and the multitude of paleoenvironments and glacial erosional events recorded by the Cheakamus basalts were not protracted events but rather occurred during a rapid and dynamic moment in time.

LESSONS LEARNED FROM 10 YEARS OF RESEARCH ON IMPACTS OF UNCONVENTIONAL HYDROCARBON EXPLOITATION ON GROUNDWATER QUALITY

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In the 2010s, unconventional hydrocarbon production increased tremendously in North America, leading to strong public protests and concerns notably over potential contamination of drinking groundwater resources. As a result, several jurisdictions imposed moratoria on hydraulic fracturing, until sufficient scientific knowledge was produced to assess the environmental and health risks. In the following years, many research groups and organizations have tackled the issue. Among them, the Geological Survey of Canada launched three successive projects in Canada, namely in Quebec, New Brunswick, and Alberta. The progression between projects has allowed the development of a geochemical methodology involving several isotopes and other analytical parameters, which was first tested in a "simple" region where very few wells had been drilled and fracked. It was then applied and further developed in other regions with very different socio-economic, geological, and oil and gas development contexts. The first project took place in Saint-Edouard, Quebec, where no commercial production has taken place. Hence, methane found in groundwater is more likely to be naturally occurring. The second project was in the region of Sussex, New Brunswick, where moderate hydrocarbon production was taking place (32 hydrocarbon wells, with around 20 years of operating history). The third (and current) project is in the Fox Creek area of Alberta, a region of significant production over the past 50 years (> 775 hydrocarbon wells in our 700 km² study area). For these two projects, the methane found in groundwater could possibly be either natural or anthropogenic. In all three regions, methane in the shallow aquifers was found to be of natural origin, and no cases of anthropogenic contamination were identified. Most interestingly, however, the complexity that arose in identifying the origin of methane was not related to the number of hydrocarbon wells, but rather to the geological and hydrogeological characteristics of the region. This finding highlights the need to conduct baseline groundwater quality characterization prior to any hydrocarbon activities in a given region, in order to thoroughly understand the groundwater geochemical dynamics. While petroleum production will likely decline in many jurisdictions over the next years, other activities involving deep geological strata will increase, including CO_2 sequestration and/or hydrogen storage. In the event of a leak, these compounds would cause geochemical reactions in aquifers that are different from a hydrocarbon leak, but many of the lessons learned from such environmental studies will also be appropriate for establishing guidelines for these other activities.

GIS-BASED WATER BUDGET FRAMEWORK FOR ASSESSING REGIONAL SCALE SPATIO-TEMPORAL VARIATION AND THE IMPACT OF CLIMATE CHANGE ON GROUNDWATER RECHARGE OVER THE PAST 100 YEARS

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Knowledge of groundwater recharge (GWR) and its distribution are necessary for sustainable groundwater resources management. However, quantifying GWR remains particularly challenging as this parameter cannot be measured directly. At the regional scale, GWR varies spatially, and under current climate change, it is expected to vary with time. The proposed communication aims (i) to demonstrate a pragmatic GIS-based water budget framework for assessing GWR at a regional scale, and (ii) to evaluate the effect of climate change over a period of 100 years (1910–2009). The Saguenay-Lac-Saint-Jean region (13,200 km²) of Quebec (Canada) was selected for this study. The GIS-based water budget framework was based on a model incorporating vertical inflows (VI), actual evapotranspiration (AET), and surface runoff (RuS). Vertical inflows include water amounts from rainfall and snowmelt that were provided by the Centre expertise hydrique du Québec (CEHQ). The CEHQ used the physically based distributed hydrological model HYDROTEL for computing the water amounts derived from snowmelt. VI data were generated on daily time intervals over a period of 100 years (1910–2009). With 165 interpolated VI observation points over the SLSJ region, more than 60,000 values for each year over 100 years were considered in this study. The potential evapotranspiration (PET) was estimated using an empirical equation developed for the particular northern humid climatic conditions of Quebec. VI and PET were then combined to calculate the actual evapotranspiration (AET). Based on the SLSJ surface deposits, soil types were grouped according to their water infiltration capacity, which was combined with land use characteristics and terrain slope to estimate surface runoff (RuS) using the curve number method. The trend analysis of temperature time series reveals an average of 1.1 ± 0.6°C increase over 100 years. Also, an increase in the water budget components is observed. Despite the increasing trends of RuS and AET, GWR still showed an increasing trend with an average increase of 0.7 ± 0.4

mm/yr over the past 100 years. The last 10 years of the observations period (2000–2009) indicate that 6% of the study area has GWR rates of 35–50% of the VI. GWR rates of 20–35% of the VI occur in 58% of the study area, while 36% has GWR rates of 5–20% of the VI. This finding provides useful information for future studies focusing on predicting long-term GWR evolution and for the development of efficient long-term groundwater management strategies.

WHICH AQUIFER FACTORS ARE MOST IMPORTANT FOR ASSESSING AQUIFER VULNERABILITY TO CONTAMINATION?

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The vulnerability of aquifers to contamination can be assessed using DRASTIC index. The ratings and relative weights of the DRASTIC factors are subjective and have been modified for different case studies; such modifications included adding and/or ignoring some factors, often combined by modifying the factor weights. However, there is no clear agreement about which factors, or their respective weights, are most important for assessing the vulnerability of aquifers to contamination. This communication focuses on an operational methodology allowing to (1) identify the relevant factors for assessing aquifer vulnerability to contamination; and (2) determine the relative importance of the selected factors. The Saguenay–Lac-Saint-Jean region of Quebec (Canada) was selected to guide this operational methodology, which integrates groundwater quality data and land-use effects with a data set of the DRASTIC factors. The developed methodology can be useful not only for identifying the relevant aquifer factors and their weights when assessing aquifer vulnerability, but also to adapt index-based methods of aquifer vulnerability assessment to different study regions.

MIGRATION BEHAVIOUR OF FUGITIVE METHANE, FROM OIL AND GAS WELL CASINGS, IN POROUS MEDIA: MULTIPHASE NUMERICAL MODELLING OF FIELD-SCALE CONCEPTUAL MODELS

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Methane leakage represents a major challenge to oil and gas (O&G) companies, which in today's alarming climate context must prove their efforts to reduce migration through the geological formations in the subsurface before being emitted to groundwater. A better understanding is needed to identify the risks of fugitive methane emissions on shallow aquifers and develop monitoring and mitigation strategies. In this study, we apply the multiphase numerical model DuMux to better understand the migration behaviour of methane from deep shale formations into shallow aquifers, and to provide insight into potential impacts on shallow groundwater resources. The simulations include groundwater flow and the migration of gas-phase and dissolved phase methane, applied to field-scale conceptual models. The primary transport mechanisms simulated with DuMux are groundwater flow, transport of free phase methane subject to capillary and buoyancy forces, methane dissolution into the flowing groundwater, and advective-diffusive transport of dissolved phase methane. DuMux multi-phase simulations are based on capillary pressure curves which are calibrated using the Brooks and Corey model. The model is first tested on a series of 2-D laboratory cell experiments of methane gas injection performed at Queen's University under a background flow gradient and including homogeneous and heterogeneous structures. Field-scale 3-D simulations are then carried out on hydrogeological systems based on the Saint-Edouard site in the Saint Lawrence Lowlands, southern Quebec. The site consists of spatially and lithologically heterogeneous, unconsolidated fluvioglacial deposits overlying fractured rock, and contains a single exploration well completed at a depth of 2000 m. Most residential wells target the upper 30 m of the fractured rock aquifer, as the Quaternary deposits rarely yield sufficient water. Methane leakage is assumed to originate where the exploration well intersects the base of the fractured rock. Equilibrium gas dissolution is assumed, leading to conservative (maximum) dissolved-phase migration distances. Conceptual models for selected additional sites include emissions from methane sources in confined and semi-confined aquifers. Intrinsic parameters of the porous medium, in particular its permeability and porosity, as well as the capillary parameters, including entry pressure and residual gas saturation, are shown to control gas migration. The impact of spatial distributions of properties on methane migration and methane longevity (gaseous and dissolved methane) in the aquifer is also discussed. The results will help in the design of effective monitoring strategies for methane leaks and migration.

THE ASSABET BARCODE: EARLY NEOPROTEROZOIC ARRIVAL OF MESOPROTEROZOIC DETRITAL ZIRCONS ON THE WEST AFRICAN CRATON IN MAURITANIA

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Detrital zircon data from 14 samples of Mesoproterozoic to Ordovician strata in the West African Craton's Taoudeni Basin in Mauritania show four distinct, sequential age distributions, or "barcodes". From oldest to youngest they are the Char, Assabet, Téniagouri, and Oujeft barcodes, named after group-level rock units but emphasizing geochronology rather than lithostratigraphy. The Char barcode, from Mesoproterozoic (ca. 1100 Ma) strata, yielded age maxima in Geons 24, 21, and 20, all traceable to West African sources. The Assabet barcode, from Neoproterozoic strata deposited between ca. 883 and ca. 570 Ma, shows a remarkable influx of detritus, largely from new sources, with maxima in Geons 21, 20, 17, 15, 12, 10, and 9, and a pronounced minimum in Geon 16. Only a small fraction of the Assabet's zircons could have come from the West African craton. The Téniagouri barcode, from strata deposited at ca. 569 Ma, yielded maxima in Geons 19, 18, 15, 12, 11, 9, and 6. The Oujeft barcode, from strata deposited between ca. 543 and 444 Ma (Cambrian–Ordovician), has age maxima in Geons 21, 20, 11, 6, and 5. The latter two barcodes suggest input from Pan-African orogens. Detrital zircons from 15 additional, unfossiliferous metasedimentary rock samples in the Mauritanide orogen yielded detrital zircon age spectra that match the Taoudeni Basin's Assabet, Teniagouri, and Oujeft barcodes. These results imply new depositional age constraints based on barcode correlations, and suggest a broad affinity between Mauritanide strata and the West African Craton. Detrital zircon age distributions that resemble the Assabet barcode have been reported from the Neoproterozoic of Morocco, Ghana, Greece, Brazil, Russia, and Ganderian and Avalonian crustal blocks in New England, USA, and Canadian Maritime Provinces. The recent Rodinia reconstruction of Evans restores these far-flung localities to a more compact area, with Avalonia, Ganderia, and other peri-Gondwanan terranes occupying an oblong area between Amazonia, Laurentia, Baltica, and West Africa. We suggest that these places all received detritus from the same giant continent-scale fluvial system as West Africa. Among West Africa's nearest Rodinia neighbours in the Evans reconstruction, Amazonia and Baltica have known igneous rocks corresponding to all of the major Assabet age populations. Amazonia, unlike Baltica, also has a magmatic gap during Geon 16 (DateView geochronology database, University of Saskatchewan). An Amazonian provenance is also consistent with overall north-directed paleocurrents across the West African Craton in correlatives of strata that carry the Assabet barcode.

POLYMETAMORPHISM OF ULTRAMAFIC ROCKS—INSIGHTS FROM THE EAST DOVER META-DUNITE, VERMONT

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The mineralogy and geochemistry of variably serpentinized ultramafic rocks marking orogenic suture zones preserve a record of polymetamorphism related to partial melting in the mantle, serpentinization, and regional metamorphism during accretion. The largest ultramafic body in the northern USA Appalachian orogen occurs as a partially serpentinized meta-dunite located in East Dover, Vermont. We report the first discovery of nickel arsenide minerals and podiform chromitite with inclu-

sions containing platinum-group elements (PGE) from this meta-dunite. We also report metamorphic olivine, which occurs in structures that crosscut serpentinized olivine. Quantitative electron microprobe wavelength dispersive spectroscopy (WDS) was used to document mineral compositions to constrain their petrogenesis. The PGE alloys and minerals are rare and occur as micro-inclusions (10–30 μm in diameter) in podiform chromitite. The PGE assemblage includes alloys (primarily of osmium, iridium, and ruthenium), ruthenarsenite (RuAs), and geversite ($PtSb_2$). WDS compositional maps and spot analyses indicate that the PGE alloys are zoned (e.g. cores enriched in Pd). The high Cr# (Cr/[Cr+Al]) of the host chromite (0.8–0.9) and forsteritic olivine (Fo_{92}) inclusions in chromite suggests formation by fluid/melt-rock interaction during partial melting events that produced the dunite, likely in a supra-subduction setting. In the serpentinized matrix, arsenide minerals were discovered ranging in size from 10–60 μm in diameter. Maucherite ($Ni_{11}As_8$) and orcelite $Ni_{5-x}As_2$ (x ~0.25) are the most common arsenides and often occur proximal to nickel sulphides in the most serpentinized samples. Nickeline (NiAs) was also identified, but it was only rarely observed as inclusions in spinel. The ubiquitous occurrence of arsenide minerals in fully serpentinized samples suggest that most of the arsenic was introduced into the ultramafic rocks during serpentinization. Whole-rock geochemical analyses also indicate that highly serpentinized samples contain the highest concentrations of arsenic (compared to weakly serpentinized samples). Lastly, metamorphic olivine occurs in vein-like structures that cross-cut serpentinized olivine, and its composition is nearly pure forsterite (up to Fo_{97}). Its textural occurrence and geochemistry indicate that it formed after serpentinization, and we propose that metamorphic olivine formed during the Acadian orogeny when regional metamorphism reached temperatures above the stability of serpentine in this area. Together with the discovery of nickel arsenide minerals and podiform chromitite inclusion suites, these results indicate that the East Dover meta-dunite preserves a record of at least three metamorphic events.

HEAD-SMASHED-IN BUFFALO JUMP: A UNESCO WORLD HERITAGE SITE IN THE PORCUPINE HILLS OF SOUTHWESTERN ALBERTA, CANADA

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More than 6000 years ago, Indigenous groups in southern Alberta were rounding up and driving large herds of bison towards the edge of step cliffs that flank the Porcupine Hills Formation (PHF). The most spectacular of these buffalo jump sites is Head-Smashed-In. It is a Provincial, National and UNESCO designated site. The large-scale killing of bison was facilitated by the bedrock geology of southwestern Alberta; specifically, outcroppings of PHF sandstone that have fractured and eroded to produce massive cliffs suitable for use as buffalo jumps. The PHF is a mid to late Paleocene age unit that occupies a portion of the Western Canada Sedimentary Basin. It was first described and named by the pioneering Canadian geologist George Dawson. The PHF consists of calcareous cross-bedded sandstones and siltstones interbedded with olive-brown shales. The eastern sides of the Porcupine Hills tilt down gently towards the eastern Plains, creating many north-south faces of exposed and fractured bedrock that range from a few metres to tens of metres in height. With west winds coming over the hills, these east-facing cliffs are ideal for driving herds of bison towards the precipice. Head-Smashed-In is just one of many bison kill sites located along the eastern flanks of the Porcupine Hills. These sites were used countless times over the millennia resulting in the death of tens of thousands of bison – one of the most productive food-getting activities ever devised by human hunters.

DOWNSTREAM TRENDS OF MUD CLASTS AND MUD CONTENT IN HYBRID EVENT BEDS OF THE LOWER CLORIDORME FORMATION, QUEBEC: IMPLICATIONS FOR FLOW TRANSFORMATION IN DEEP-WATER SYSTEMS

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Submarine gravity flows build some of the largest accumulations of sediment on Earth and they host a significant portion of the world's oil and gas. Hybrid event beds (HEBs) are the products of a type of deep-water sediment gravity flow that consist of an argillaceous mud-clast-rich division (debrite), which overlies a banded or structureless sandstone (turbidite). HEBs are becoming more commonly recognized as a key element of deep-water systems across a wide range of tectonic settings. However, the role of mud in the transformation of these flows from high density turbulent flows to laminar debritic flows is not well understood. This study investigates downflow facies transitions within HEBs of the Lower Cloridorme Formation of the Gaspe Peninsula, Quebec, with a focus on the systematic changes in mud content and mud clasts in various divisions of HEBs. Mud clasts have been suggested to play a key role in the generation of hybrid flows, and this study investigates the correlation between mud clast dimensions and the mud content within the matrix, and how their incorporation relates to the flow transformation process. Here, we present results from grain size analysis and Fourier power spectra (FPS)-based elliptic Fourier analysis of mud clasts to highlight the relationship between changing clay content within the matrix of HEBs and associated changes to mud clast shape and size. Samples are disaggregated using a selfrag machine, after which their grain size distributions are analyzed using a Malvern Mastersizer 3000. The well-exposed beds along the coast of the Gaspé Peninsula allow for extremely detailed facies classifications and long-distance tracing of individual beds across downflow distances of ~38 km. Our results highlight the diversity, complexity, and abrupt downstream changes of HEB facies, which contributes to our understanding of HEBs and the distributions of mud in deep water depositional systems.

GLACIAL DYNAMICS IN THE WEST-CENTRAL KEEWATIN SECTOR OF THE LAURENTIDE ICE SHEET (NORTHWEST TERRITORIES AND NUNAVUT) – PRELIMINARY SURFICIAL FIELD DATABASE

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West-central Keewatin, in northern Canada (eastern Northwest Territories and central mainland Nunavut) is one of the least studied deglaciated regions in North America in terms of paleo-ice dynamics and ice-sheet retreat chronology. Yet, during the last glacial episode (29–8 ka), this region was host to one of the major domes of the Laurentide Ice Sheet (LIS) – the Keewatin Dome. Limited work suggests complex glacial landsystems resulting from multiple glacial events, migration of ice centres, ice streaming and old landscape preservation. Overall, the sequence of ice flows shifting and overprinting, and the duration of glacial and deglacial events have not been systematically identified and/or correlated. This is mainly due to the paucity of surficial mapping coupled with limited field and chronological data, which restricts the interpretation of ice sheet dynamics and glacial history. Much of this region is also heavily covered with glacial sediments that impede both bedrock mapping and mineral exploration. This lack of a surficial geological framework therefore hinders our comprehension of the physical environment of the region, which is vital to land-based ventures and decision-making (e.g. infrastructure, mineral exploration, permafrost, ice-sheet modelling for past changes in sea level and climate). Therefore, a surficial geological framework consisting of a new compilation of glacigenic features and landsystems supported by targeted field investigations is needed. The initial step to address this lack of regional geoscience context in relation to LIS glacial history, was to compile existing and accessible field data that relates to glacial history into a digital database for a region covering ~348,000 km^2. The compilation builds on recent mapping efforts (Canada's Geomapping for Energy and Minerals Programs; 2008–2020) as well as legacy fieldwork data, which go back to the end of the 19th century. This database, comprising data from 2475 field stations, forms the foundation for forthcoming mapping, targeted field investigations and interpretative Quaternary research in the west-central Keewatin region under the GEM GeoNorth program (2020–2024). Furthermore, the recently compiled datasets provide a template for preliminary interpretations of the ice-flow chronology and paleo-ice dynamics, which will help, decipher glacial transport, and dispersal patterns - a crucial component for the application of drift prospecting techniques in mineral exploration.

RISK, RESILIENCY, RESPONSIBILITY: MOVING TOWARDS A HOLISTIC FRAMEWORK FOR SOURCE WATER RISK ASSESSMENT

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Protecting source water is a critical practice to help ensure a safe drinking water supply, ecosystem integrity and health, and the continuation of water-based cultural practices. The source water protection (SWP) paradigm has been embraced by Canadian municipalities for years, yet First Nations face barriers to engagement in SWP initiatives, including numerous jurisdictional, political, logistical, and economic challenges. Risk assessment is a key part of source water protection frameworks. To properly engage in risk assessment related to water protection, it is essential that approaches are informed by multiple knowledge systems – but the source water risk assessment frameworks that are typically used focus mostly on what can be viewed through the lens of Westernized science, to the exclusion and erasure of Indigenous worldviews and knowledge systems. Researchers at the University of Guelph have been working with members of the Chippewas of Nawash Unceded First Nation (CNUFN) since 2014 to develop a source water protection plan for their currently held territory (Neyaashiinigmiing, on the east coast of the Saugeen Peninsula in central Ontario). In the most recent research, a scoping review and interviews with key community members were undertaken in order to work towards a community-and-literature-informed risk assessment framework that could be used in future SWP programs, in Indigenous-held jurisdictions or otherwise. The proposed framework emphasizes the importance of Indigenous knowledge systems in tandem with Westernized scientific approaches, expands the types of risks and impacts that are considered in risk assessment, and includes factors relating to resiliency of communities and land. It is anticipated that this framework can be used to support Indigenous communities and their allies who are seeking to ensure water protection in all jurisdictions.

THE STYLE AND TEMPO OF PLATE TECTONICS IN THE PROTEROZOIC

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In 2006, based on differences in the crustal record of metamorphism, I argued that the style of plate tectonics during most of the Proterozoic differed from that since the Cryogenian, which is characterized by cold subduction and transport of continental crust to and from mantle depths as evidenced by widespread ultrahigh-pressure metamorphism. We have continued to investigate the crustal record of both metamorphism and magmatism, and we have used thermo-mechanical modelling to test the null hypothesis of no change in the style of plate tectonics since the early Paleoproterozoic. In summary, metamorphism has been characterized using a dataset of pressure (P), temperature (T) and age determinations from > 560 localities, and classified into three types based on the thermobaric ratio (T/P), which varies spatially in young orogens from lower T/P in the suture to higher T/P in the hinterland. A strong temporal clustering of metamorphism during periods of supercontinentality is well established, and we have recently confirmed the long-conjectured spatial relationship between type of metamorphism and inferred plate margins since the Archean. Statistical analysis of T/P shows that bimodality—a characteristic feature of metamorphism associated with convergent plate boundaries since the Triassic—developed during the Paleoproterozoic and became increasingly distinct through the Proterozoic; late Archean metamorphism is unimodal. Based on the crustal record of metamorphism, a strong case can be made for a plate tectonics mode back to the early Paleoproterozoic, consistent with many other lines of evidence. Using statistical analysis of time series of T/P and cooling rate, we have identified change points in the Paleoproterozoic and early Paleozoic. These change points record two state shifts: first following stabilization of subduction after the Siderian glaciations, amid a period of increased plate tectonic activity following an enhanced supply of sediments to continental margins; and second following the Cryogenian glaciations and an increased sediment load in trenches that enabled the modern style of plate tectonics. By contrast, in the Mesoproterozoic, a peak in T/P and predominantly anorthosite and rapakivi suite magmatism suggest a plate slowdown. Prior to the Proterozoic, evidence of plate tectonics in the geological record is equivocal. During the Neoarchean, the global tectonic mode may have been in transition from a sluggish or squishy lid to plate tectonics. Prior to the Neoarchean, subduction may have started multiple times, creating conflicting signals in the geological record, but may not have been stable, precluding an earlier transition to plate tectonics.

EVALUATING PORT AND SEAL PLACEMENT IN BACKFILLED MULTILEVEL SYSTEM INSTALLATIONS USING FIBRE OPTIC ACTIVE DISTRIBUTED TEMPERATURE SENSING (A-DTS)

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The use of multilevel systems in fractured bedrock aquifers has proven useful for monitoring hydraulic head and groundwater quality at multiple, depth-discrete intervals within a single borehole. Backfilled multilevel systems consist of alternating sand and bentonite layers to establish monitoring and seal intervals, respectively. Although a tremie pipe is used to facilitate placement followed by tamping and tagging, it can be difficult to position these intervals exactly, thus some uncertainty exists in the resultant multilevel install. Fibre optic Active Distributed Temperature Sensing (A-DTS) is an emerging method that can be used to quantify natural gradient flow rates in sealed bedrock boreholes. A new application of A-DTS is demonstrated here to verify the positioning of the sand and bentonite layers post installation, and identify inconsistencies in bentonite seal integrity. A-DTS operates by actively heating a composite fibre optic cable containing both optical fibres and heating wires for an extended period (10+ hours). The temperature response across distributed intervals along the full fibre can be measured with a distributed sensor unit. The rate of temperature increase during heating can be used to determine the apparent thermal conductivity at different depths, from which groundwater flow rates can be estimated. If the fibre optic cable is co-deployed with a backfilled multilevel system, the different backfill materials (e.g. sand and bentonite) impart a strong thermal signature based on their contrasting thermal conductivities. This effect is most prominent in the early portion of the thermal test (0–15 mins), where the response is dominated by the materials immediately surrounding the cable. In contrast, the later heating data is more reflective of the geological materials and enhanced heat dissipation from groundwater flow. Analysis of this early heating data was conducted for A-DTS tests in three boreholes where a composite fibre optic cable was co-deployed with a backfilled G360 multilevel system. The interfaces between the sand and bentonite layers could be clearly identified, allowing the as-built reports and data interpretations to reflect the true conditions more accurately. Moreover, instances of bridging in the bentonite intervals were observed that could impact the integrity of the seals. This method could likely be adapted to other seal integrity assessments such as identifying the continuity of cement grout behind surface casing and being a distributed fibre optic method, easily scales to deep borehole applications.

NEW APPROACHES TO DISCERN THE POTENTIALLY POLYMETAMORPHIC HISTORY OF THE GASSETTS SCHIST, VERMONT

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The aluminous Gassetts Schist from Vermont, as well as the likely correlative Hoosac Schist in Massachusetts, are renowned for their spectacular cm-sized and microstructurally complex mineral porphyroblasts. However, no consensus has been reached as to the extent to which garnet—which contain pronounced core-rim textural unconformities—from these shists record deformational events from both the Ordovician Taconic and Devonian Acadian orogenies. In 1968, it was argued that garnet cores grew during Taconic metamorphism while rims grew during the Acadian. Thirty years later, it was stated that the rocks reached peak metamorphism during the Acadian but show indication of pre-Acadian growth. Others suggested that the garnets could have formed during a single orogenic event, with resorption and the formation of a new cleavage driving the development of unconformities, respectively. In this study, the Gassetts Schist is being investigated to assess these hypotheses. Petrographic observations are integrated with spatially resolved major

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and trace element zoning—determined via EPMA and LA-ICP-MS raster mapping, respectively—to demonstrate their potential for elucidating reaction sequences during garnet growth. Prograde major and trace element zoning in rutile-, staurolite- and chloritoid-rich cores is typical, and chemical discontinuities at core-rim boundaries are consistent with their formation via a rock-wide episode of garnet resorption. Rim zoning alludes to a second and distinct phase of prograde growth in a bulk composition re-enriched in trace elements, in which a second chemically distinct generation of staurolite grew. Targeted phase equilibria modeling sheds new light on this polyphase P-T history over which garnet crystallized after incipient core growth at ca. 540°C and 6–7 kbar. Zircons with detrital cores and metamorphic overgrowths in both garnet and the matrix rarely exceed 30 μm in diameter. While this precludes discernment of multiple in situ U–Pb ages from single grains using LA-ICP-MS, mixed ages are determined from zircon included in both the cores and rims of garnet and in the matrix. Combined, these approaches provide new constraints on the complex framework of reaction and metamorphism in the New England Appalachians.

CRITICAL METAL ENDOWMENT OF THE EUROPEAN VARISCIDES – FROM FORMATION TO PRESERVATION

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The European Variscides host significant resources of energy and technology critical raw materials (ETRs) associated with various types of hydrothermal systems. Hydrothermal mineralization in central and western Europe is related to i) the amalgamation and ii) the breakup of the supercontinent Pangea during the late Paleozoic and Mesozoic, respectively. These tectonic events also facilitated the formation of hydrothermal critical mineral deposits in northern Africa and eastern North America, including Nova Scotia. Late Paleozoic magmatic-hydrothermal activity was associated with the formation of greisen, skarn and epithermal vein systems that host valuable Li, Sn, W, Ag, Zn, Sb, Cu, and In. Conversely, Mesozoic rift-related hydrothermal activity resulted in the formation of unconformity-related vein and some MVT type mineralization, which host significant resources of Co, Ni, Bi, Ag, Zn, and fluorite. This talk provides a brief overview on the different deposit types and associated ETRs in central Europe and discusses ore-forming mechanisms in two distinctly different geological environments (orogenic vs rift-related) to assess how ETRs may be enriched through a combination of various magmatic and hydrothermal processes. After discussing ore-forming mechanisms on the deposit and province scale, the findings are complemented by a large amount of recent geochronological data (mainly in-situ LA-ICP-MS U–Pb) that constrain the age of individual ore deposits and mineral occurrences in the context of the larger tectonic framework of central Europe. These results are integrated into preliminary continental-scale geological models for late Paleozoic and Mesozoic hydrothermal phases that caused crustal endowment of critical metals in central and western Europe. Apart from the actual hypogene enrichment processes, a critical factor for the accessibility of mineral resources is the potential for regional preservation. Crucial for exploration targeting, the original formation depth of mineralized systems relative to the present-day erosional level will be discussed in the context of a complex geological history, which spans from Late Variscan uplift and subsidence to Mesozoic subsidence to eventually Cenozoic uplift. The sum of critical factors discussed – from enrichment to preservation – provides the basis towards a holistic metallogenetic model for ETR deposits in Europe that could guide future generations in the search of undiscovered mineral resources.

EVIDENCE FOR AN IOAA-U SYSTEM IN THE KIGGAVIK REGION, NUNAVUT, CANADA

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The Thelon Basin, Nunavut, shares many similarities with the U-producing Athabasca Basin in Saskatchewan. A series of uranium deposits and showings including the Kiggavik, Bong, End, and Andrew Lake deposits are predominantly hosted in metasedimentary basement rocks along a ~30 km structural trend just outside the present margin of the Northeast Thelon basin. Uranium mineralization in these deposits was preceded by albitization, brecciation, silicification, hematization, and sericitization of host rocks. Uranium mineralization comprises three stages, with the first subdivided into three substages. Vein-hosted (U1a; 1553 ± 16 Ma), euhedral disseminated (U1b; 1553 ± 16 Ma), and front-style (U1c; 1594 ± 95 Ma) uraninite, coffinite, and brannerite are associated with illitization and bleaching, which overprinted earlier styles of alteration. This bleached assemblage is dominated by illite, with lesser sudoite, carbonate, quartz, and apatite. Vein-hosted, U1a occurs as both monometallic and uncommon polymetallic mineralization, with U minerals locally associated with Fe-Pb-Cu-Mo sulphides, native Au and Bi, Bi ± Cu sulphides/selenides/tellurides, Be-silicates, and barite. The 1553 ± 16 Ma age is consistent with the 1540 ± 30 Ma Kuungmi potassic basalts which cap the Thelon Basin, and a regional shift from sandstone to shale and carbonate deposition. Fractured and texturally-altered uraninite, coffinite, and brannerite associated with U1a, b, and c (U2) records multiple isotopic resetting/U remobilization events at 1417 ± 17 Ma, ~1267 Ma, 937 ± 24 Ma, and 274 ± 69 Ma. Galena yields a Pb–Pb isochron age of 896 ± 68 Ma. Late uranium minerals associated with orange goethite-bearing alteration (U3) have very low PbO contents, indicating recent (< 1 Ma) formation or isotopic resetting. The Kiggavik deposit is partially hosted in ~1800 Ma granite. While uraninite comprises most of this U, some is hosted by zircon and uranothorite. The latter minerals, together with Ti-oxides and other refractory accessory minerals, are heavily concentrated into miarolitic cavities and display evidence of dissolution and reprecipitation, synchronous with albitization. Subsequent hematization, clay alteration, and U mineralization are similar to what is observed in the metasedimentary rocks. Although the geochronology, structural controls, and some aspects of mineralogy, are generally consistent with that of basement-hosted unconformity-related U deposits in the Athabasca Basin, they are also consistent with Iron Oxide Alkali-Altered (IOAA)-style mineralization. The early albitization, polymetallic nature of U mineralization, presence of hydrothermal zircon, brannerite, and specular hematite, absence of dravite, minor graphite, and strong spatial and temporal links to magmatic-hydrothermal processes favours the IOAA model.

INVESTIGATIONS INTO SHEAR ZONE-HOSTED GOLD MINERALIZATION AT THE ELMTREE DEPOSIT, NORTHEASTERN NEW BRUNSWICK

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The Elmtree Deposit is the largest of several shear zone-hosted gold occurrences in northeastern New Brunswick associated with regional-scale faults active during the Salinic and Acadian orogenies. The deposit contains an NI-43-101 resource of approximately 300,000 ounces of gold and subordinate polymetallic (Ag, Zn, Pb, and Sb) sulphide mineralization hosted in three zones: the West Gabbro, South Gold, and Discovery zones. Gold at the Elmtree Deposit straddles a locally faulted Silurian angular unconformity that separates an accretionary wedge complex from overlying syn-orogenic sedimentary clastic, carbonate, and minor volcaniclastic rocks. The largest of the three zones, the West Gabbro Zone, contains gold mineralization hosted in a metagabbro to anorthosite dyke/sill that intruded argillite of the Ordovician Elmtree Formation and subsequently incorporated into the Belledune River Mélange. Mineralization at the South Gold zone is hosted within unconformably overlying Silurian conglomerate, calcareous siltstone/sandstone, and minor volcaniclastic rocks (Quinn Point Group) within approximately 40 m of the locally faulted unconformity. The Discovery Zone is situated along the sheared unconformity and hosts both early gold and the bulk of the later, cross-cutting, polymetallic mineralization. In all three zones, gold is primarily refractory in sulphides (i.e. arsenopyrite ± pyrite) with pyrrhotite and was precipitated during the sulphidation of Fe-oxides and silicates via reaction with infiltrating hydrothermal fluids focused along the fault zone. Gold mineralization occurs as wall rock replacements and is associated with deformed quartz (± carbonate) veins, sericitization, and locally carbonatization of wall rocks. Subsequent desulphidation of pyrite resulted in the formation of pyrrhotite and locally associated free gold/electrum at the West Gabbro Zone, and remobilization of gold/electrum with Sb-Ni alloys and sulphides at the South Gold Zone. Morphology and trace-element composition (laser ablation ICP-MS) of pyrite indicate multiple episodes of sulphidation with distinct compo-

sitions, though mineralization is compatible with either a magmatic or metamorphic fluid source. Host rock alteration is characterized by enrichments of Au, As, W, S, Sb, Rb, and K_2O and depletion of Na_2O in most host units. The association of gold mineralization with syn-orogenic conglomerate and regional-scale faults is characteristic of some other gold districts in Atlantic Canada, e.g. the Dunnage Zone in Newfoundland. Ongoing work will place further geochronological constraints on the system and allow for a detailed interpretation of the tectonic setting and mechanisms responsible for gold mineralization. This continuing research into gold mineralization in northern New Brunswick will allow for contextualization relative to other gold systems in Canada.

ECOSYSTEMS AND ENVIRONMENTS ACROSS THE DEVONIAN-CARBONIFEROUS BOUNDARY IN EAST GREENLAND

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East Greenland, with vast areas of exposed sedimentary rocks extending up to and straddling the Devonian–Carboniferous boundary, provides a window on the beginning of Romer's Gap from a mid-continental location with Laurussia. We are currently investigating this time window on the basis of fossil material collected from the Stensiö Bjerg Formation and overlying Obrutschew Bjerg Formation of Celsius Bjerg, Ymer Island. In this section, the Hangenberg Event is represented by a black lacustrine shale in the Obrutschew Bjerg Formation that marks a drastic environmental change from the terrestrial, somewhat arid depositional environments of the Late Devonian. UV-damaged spores within the shale point to ozone layer depletion as a possible kill mechanism for the Hangenberg extinction. We are describing a previously unknown latest Devonian tetrapod assemblage from the Stensiö Bjerg Formation and a coprolite assemblage from the black shale, both by means of synchrotron microtomography. The Stensiö Bjerg tetrapods include at least one form that is more crownward than the late Famennian (Aina Dal and Britta Dal Formations) genera *Ichthyostega* and *Acanthostega*, with derived features including open lateral line grooves on the cheek, a reduced preopercular, and a small temporal fenestra. An associated shoulder girdle, probably belonging to the same taxon (and individual), is robust, with a small cleithrum and large coracoid plate, but still lacks a distinct scapular blade. The black shale coprolite assemblage is associated with a body fossil assemblage comprising the actinopterygian *Cuneognathus*, the acanthodian *Acanthodes* and a ctenacanth shark. It is thus of typical Early Carboniferous aspect and may represent the earliest post-Hangenberg vertebrate assemblage in the world. Synchrotron microtomography allows us to reliably categorize the different coprolite types according to both internal and external morphology. Remarkably, the coprolite diversity is more than twice as high as the body fossil diversity, indicating the presence of a 'shadow fauna' not captured by the body-fossil record, and it includes large non-spiral coprolites that were almost certainly made by a tetrapod. The tetrapod fed preferentially on *Cuneognathus* and to a lesser extent *Acanthodes*, showing that it must have been an accomplished swimmer. This was thus not a low-diversity fauna or 'disaster taxa', but something considerably more elaborate.

UNESCO GLOBAL GEOPARKS IN CANADA: THEIR GROWTH, POTENTIAL, AND CHALLENGES

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Just 6 years after the inception of Global Geoparks in 2004, Canada and North America welcomed its first Global Geopark. By 2020 that number had grown to 5: Tumbler Ridge (BC), Percé (QC), Stonehammer (NB), Cliffs of Fundy (NS) and Discovery (NL), with numerous aspiring geoparks working to join this UNESCO family. It is anticipated that the number of UGGps in Canada will double to 10 by the end of this decade. The rich geodiversity and cultural mosaic of Canada lends itself to a near endless possibility of geologically and culturally distinct geopark designations. The high representation of geoparks in Atlantic Canada may reflect the great geodiversity there inherited from a complex plate tectonic history coupled with dramatic coastal exposures of their geology, and also the promise of rural economic development via geotourism in less economically thriving regions. Globally, there are 178 UNESCO Global Geoparks in 45 countries at present. These are concentrated in Europe and China, founding members of Global Geoparks, but countries in Latin America, Africa, Arab states and small island nations are all working to develop applications for aspiring geoparks and UNESCO is supporting their development in underrepresented regions. Geoparks are not geological preserves for professional geoscientists and aspiring students, they are places where the links between geology and culture are celebrated by communities. This is one key aspect that differentiates the two UNESCO programs of World Heritage and Global Geoparks. Global Geoparks became a full UNESCO program in 2016, and with that change, demonstration of international geoscientific significance became more important., Assessing this criterion now falls to IUGS evaluators. Unlike extractive industries, UNESCO Global Geoparks have the potential to be truly sustainable – if long-term funding of such essentially grassroots, local undertakings can be met. This in fact, may be Global Geoparks greatest challenge in Canada, to manage a UNESCO designation at the community level. Geoscientists, in particular those who can convey the complexity of geology to the public, play a vital role in the success of a Global Geopark.

TRACKING BACKGROUND DISSOLVED GASES TO MONITOR STRAY GAS FROM LEAKING NATURAL GAS WELLS

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Natural gas production is a key contributor to global energy demands; however, producing, decommissioned, and abandoned natural gas wells can leak due to damaged or inadequately sealed well casings. This can allow gas to enter shallow aquifers or migrate to the surface creating potential explosion risks, degradation to water quality, and greenhouse gas emissions. Field and laboratory studies have shown that stray gas leaks are difficult to detect at ground surface (surface expression) and dissolved in groundwater (aqueous expression), in part due to methane oxidation or extensive lateral gas migration along subsurface heterogeneities. The goal of this study is to investigate if abundant background dissolved gases, specifically those less susceptible to degradation (e.g. nitrogen), can be used as an indicator of stray gas migration in shallow aquifers. A series of laboratory experiments were conducted in a quasi-2-D flow cell (40 cm x 40 cm x 1.2 cm). Different heterogeneous sand packs were generated using a 3-D printer-based packing technique to produce finger-dominated and pool-dominated gas architectures, and subjected to aqueous flow during and after gas (argon) injection. Dissolved oxygen (DO) concentration in the effluent water was measured continuously during gas injection and dissolution. Oxygen was used as a surrogate for nitrogen due to the ease of measurement in a laboratory setting and argon was used as a surrogate for methane. To simulate an active gas leak, argon gas was injected into the flow cell at 10 ml/min until DO concentrations reached a steady state. The gas flow was then stopped, representing a successful well repair, and DO concentrations returned to initial conditions. The results of this study show that there is a detectable change in background dissolved gases during gas injection and post-repair dissolution, and that these changes depend on source architecture and groundwater velocity. Pool-dominated source architectures resulted in lower steady-state DO concentrations during prolonged gas injections compared to finger-dominated source architectures. The time to return to initial conditions post-repair were also longer for pool-dominated source zones. Additionally, higher groundwater velocities resulted in lower steady-state DO concentrations during gas injections but had little impact on post-repair dissolution times. Experimental results will be discussed along with simulations of other dissolved gases and background gas conditions. The response observed in the background dissolved gases suggests that monitoring of these gases could support screening-level monitoring efforts, particularly for identifying successful well repairs and subsequent improvements to groundwater quality.

TERROIR DISCRIMINATION BASED ON PHENOLIC COMPOSITION OF SYRAH GRAPES FROM WALLA WALLA AVA, WASHINGTON

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Terroir influences the phenolic composition of grapes and thus greatly controls the quality of wine. This investigation examines the relationship between soil character-

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istics and the phenolic compound concentrations of Syrah grapes in the Walla Walla American Viticultural Area (AVA) in Washington state, USA. We collected collocated samples of vineyard soils and Syrah grapes during the 2014 harvest from 11 vineyards planted in four distinct Walla Walla terroirs. The four terroirs defined include loess over Missoula Flood sediments, thick loess over Columbia River basalts, thin loess over weathered basalt, and basalt cobblestone river gravels. Vineyard soils were analyzed for bulk major and trace element chemistry by X-ray fluorescence, plant available nutrients, soil mineralogy by X-ray diffraction, and soil grain size by Malvern Mastersizer. Grape phenolic profile analyses were performed by ETS Laboratory by high performance liquid chromatography. In addition, soil data from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), Web Soil Survey (WSS) were compiled and plotted using the geographic information system (GIS) software program Esri ArcGIS Desktop to geospatially characterize the vineyards. The soil drainage classes indicate overall good conditions for the vines in the Walla Walla AVA with well drained soils across terroirs 1, 2, and 3, and somewhat excessively drained soils in terroir 4. The grain size analysis reveals silt loam vineyard soils in terroirs 1, 3, and 4, and silt soils in terroir 2. XRD analysis indicates a rather uniform soil mineralogy dominated by quartz, plagioclase (albite/anorthite/labradorite) and/or orthoclase (microcline/sanidine), with minor muscovite, biotite, amphibole, apatite and clay minerals (vermiculite, montmorillonite). Thus, the mineralogy confirms the overall glacially derived origin of the soils, though the mafic minerals are predominantly present in the basalt-influenced terroirs 3 and 4. The wide variation in the bulk chemical composition of the vineyard soils reflects the diversity of parent materials in which the soils have developed. For example, SiO_2 varies between 55.4–64.7 wt.% and plots between the basalt and Missoula flood end members on variation diagrams. At first glance, no significant statistical differences were noted for phenolic grape composition between the four soil terroirs. Consequently, principal component analysis (PCA) was applied to soil and grape data to evaluate geochemical differences derived from the four designated terroirs. Basalt-influenced terroir 4 was effectively discriminated based on soil chemistry and grape phenolic composition. Catechin, catechin/tannin index, and polymeric anthocyanins/tannin index best discriminated the distinct phenolic fingerprint of terroir 4.

GLACIOTECTONIC FEATURES SOUTH AND NORTH OF GANDER LAKE, NEWFOUNDLAND: IMPLICATIONS FOR LATE GLACIAL ICE FLOW IN NORTHEAST NEWFOUNDLAND

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Glaciotectonic features, including folds, faults and thrusts were observed in the uppermost layers of stratigraphic sections along a 70 km-long by 15 km-wide corridor, extending from the Beaver Brook antimony mine, in the south, to Ten Mile Lake and Gander Bay South, in northeast Newfoundland. This corridor includes large-scale, north-northwest (in the west) and north-northeast (in the east) trending landforms forming the subglacial footprint of the last ice-flow event in this region, visible as streamlined landforms on the 5 m Digital Elevation Model (DEM). The folds, faults and thrusts are formed in brecciated, locally derived Davidsville Group siltstone, sandstones, and diamicton layers that are interpreted as glaciotectonites, and are spatially associated with the north-northwest- to north-northeast-trending landforms. The fold limbs, fold axial traces and thrust planes dip to the south-southwest and to the south-southeast, which is consistent with their emplacement by later north-northeast and north-northwest flow. Glaciotectonites preserved in two stratigraphic sections south and north of Gander Lake are transitional layers between deformed diamicton, deformed bedrock, and subglacial traction till, which are inferred to have formed in-situ from the same ice flow as other glaciotectonites in the region. The glaciotectonites vary texturally from south to north, with immature bedrock-dominated glaciotectonites in sections south of Gander Lake grading into a mixed fissile, silty-sand diamicton north of Gander Lake, and immature bedrock-dominated glaciotectonites in sections south of Gander Bay and directly east of Ten Mile Lake. The shallowness of the subglacial traction till and glaciotectonite units, their stratigraphic position, the limited depth of deformation, and locally derived clasts suggests that the glaciotectonized material was formed by a thin, ice lobe (or ice lobes?) upon deglaciation. The down-ice textural differences among sites suggests that 1) the velocity of the ice lobes may have varied, with the glacial bed freezing onto and thawing from the bedrock substrate at different stages of deglaciation, or 2) there was differential erosion due to contrasts in bedrock competencies through the corridor. Future studies characterizing vertical and lateral (down-ice) textural and geochemical variations of the glaciotectonically deformed unit should assist in understanding the transport of material and the subglacial conditions of the ice lobe(s?) upon deglaciation.

ASSESSING THE CARBON SEQUESTRATION POTENTIAL OF SEDIMENTARY BASINS IN ATLANTIC CANADA

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Capture and storage of carbon dioxide in porous sedimentary rocks is a strategy for reducing greenhouse gas emissions that has gained momentum in recent years. There are several active carbon sequestration projects in the Western Canada Sedimentary Basin, but the potential for carbon storage in Atlantic Canada remains little explored. Developing geologic carbon storage in Atlantic Canada may be critical, not only to store its own emissions, but due to its proximity to the emission-dense areas of southern Ontario and Quebec. Natural Resources Canada is therefore exploring potential opportunities for geologic carbon storage in Atlantic Canada, beginning with a scoping assessment of all sedimentary basins in the region for rocks suitable for carbon sequestration. The methodology of this assessment is derived from the Geological Survey of Canada's recent approach to qualitative petroleum resource assessment for Canadian offshore areas. Sedimentary basins are subdivided into areas where structural and depositional constraints are similar, and the chance of finding suitable reservoir rocks, impermeable seals, and traps is assessed for each potential play. These three chances of success are multiplied together, and a scaling factor expressing the size of the likely closures applied to obtain a measure of carbon sequestration potential in the area. The Atlantic Provinces contain possible targets in three groups of sedimentary basins: 1) Cambrian to Middle Ordovician successions from the Laurentian continental margin; 2) Late Ordovician to Carboniferous rocks in basins related to Appalachian orogenies; and 3) Mesozoic to Cenozoic basins associated with the opening of the Atlantic. The best early Paleozoic targets are hydrothermal dolomites in the carbonate platform rocks from western Newfoundland and northern Gulf of St. Lawrence. Later Paleozoic targets are found in onshore basins in all four Atlantic Provinces and several large offshore basins, such as Magdalen Basin in the Gulf of St. Lawrence. Reservoir rocks could include Carboniferous sandstones in traps formed by structural deformation, including salt tectonics. The Mesozoic–Cenozoic basins are almost entirely offshore, found from Nova Scotia to Labrador, and include some of the best potential reservoirs. The amount of information on subsurface structures and lithology varies widely and is greatest where there has been significant petroleum industry interest in the past. This study identifies areas where the geology is suitable for carbon sequestration. Subsequent work will focus on targets for further evaluation chosen based on proximity to carbon emitters and infrastructure.

THE WILLNER MADGE GALLERY DAWN OF LIFE: EXPOSING THE LAST FOUR BILLION YEARS OF LIFE ON EARTH AT THE ROYAL ONTARIO MUSEUM

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The Royal Ontario Museum recently opened the Willner Madge Gallery Dawn of Life, which narrates the story of life from its earliest forms to the end of the Triassic Period. Decades in the making, this 929 m^2 (10,000 ft^2) permanent gallery complements chronologically the existing ROM palaeontology galleries dedicated to dinosaurs and mammals, finally offering visitors a nearly complete story of life. The majority of 1000 fossil specimens on display come from across Canada, representing all provinces and territories, and many sites of historical and scientific significance. These include four Canadian UNESCO World Heritage Sites: Mistaken Point (Ediacaran) in Newfoundland, the Burgess Shale (Cambrian) in British Columbia, Joggins Fossil Cliffs (Carboniferous) in Nova Scotia, and Miguasha (Devonian), in Que-

bec. Fossils from a fifth site – Anticosti Island (Ordovician–Silurian) in Quebec, currently on the World Heritage tentative list – are also prominently featured. No other country in the world can claim to have such an extraordinary record of early life, and no other museum has ever presented these Canadian treasures together in a single display. Dawn of Life provides an opportunity for visitors to learn not only about deep time, the story of life, and how our great geo-heritage contributes to major scientific advances on a global stage, but also to explore and discover the land of Canada.

GEODYNAMIC SIGNIFICANCE OF THE ORDOVICIAN EVENTS IN THE PYRENEES AND SURROUNDING AREAS, SW EUROPE

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The aim of this work is to discuss the geodynamic significance of the collectively known as "Sardic Phase" (ca. 475–450 Ma) recorded by the basement rocks of the Pyrenees. The phase includes several events, such as: (a) a Mid-Ordovician forced regression, related to generalized uplift conditions, with subaerial exposure and partial erosion of older rocks, (b) the onset of pre-unconformity foliation-free open folds, sealed by (c) a distinct unconformity, ranging from 0º paraconformity to 90° angular discordance, involving a gap of ca. 30 Myr with Upper Ordovician strata sealing an inherited palaeorelief, related to (d) Mid to Late Ordovician voluminous calc-alkaline siliceous magmatism, and, finally, (e) a succession of Late Ordovician synsedimentary extensional faults controlling sharp modifications in thickness of contemporaneous strata. Such events also occur in neighbouring areas of the northern Gondwana margin, such as Sardinia and the Occitan Domain (southern French Massif Central). Similar geological processes developed earlier (ca. 495–475 Ma) in the Iberian Massif, where the events are named "Toledanian Phase" and are linked to the "Ollo de Sapo" magmatism. We elucidate if, taken together, the Sardic Phase represents a Mid-Late Ordovician mafic underplating causing thermal doming of the uppermost crust (with emersion and extension) and partial melting of the lowermost crust (voluminous silicic magmatism) that define a large igneous province (LIP). This mafic underplating, in turn, may be indicative of mantle superplume activity, which could be compatible with a Cambrian to Early Ordovician rift/continental break-up that post-dated Pannotia's amalgamation. That is, we discuss if the regional geological evidence may serve as a test for the different geodynamic scenarios proposed for this segment of the northern Gondwana margin and for the genesis of the Rheic Ocean during early Paleozoic times.

GEOCHEMISTRY AND PALEOTECTONIC SETTING OF ARCHEAN MAFIC VOLCANIC ROCKS AND MASSIVE SULPHIDE MINERALIZATION, ARROWHEAD OUTLIER, SLAVE CRATON, NORTHWEST TERRITORIES, CANADA

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Geochemical studies of Archean volcanic rocks are essential to providing important constraints on tectonic models and the evolution of Archean cratons. Volcanogenic massive sulphide (VMS) deposits form during distinct periods of rifting within overall collisional environments (ocean-ocean and ocean-continent). Thus, the recognition of Archean VMS deposit can also elucidate Archean tectonic processes. The Arrowhead Outlier is a dominantly mafic volcanic feature in the west-central region of the Slave craton, located 300 kilometers northeast of Yellowknife in the Northwest Territories. While its origin and evolution are enigmatic, fieldwork within the 61 km^2 arrowhead-shaped outlier identified the main volcanic lithologies as massive to pillow basalt with lesser mafic tuff, mafic breccia, heterolithic tuff, heterolithic breccia, and felsic tuff. Turbidite-like successions of psammite and lesser semipelite are locally intercalated with the volcanic rocks. Pyrite, chalcopyrite, arsenopyrite, pyrrhotite, bornite, and sphalerite replacement-style sulphide mineralization is hosted primarily within quartz-epidote altered mafic volcanic rocks and silicified intermediate-felsic volcanic rocks, indicating VMS-type mineralization within the Arrowhead Outlier. Hyaloclastite is seldom observed between less deformed pillow basalts and VMS-type mineralization within the basalts provide evidence for a subaqueous eruption of the mafic volcanic rocks. Results from geochemical analysis indicate that volcanic rocks of the Arrowhead Outlier are dominantly subalkaline basalt showing both tholeiitic and transitional affinities. Basalts range from normal mid-ocean ridge basalt to slightly enriched mid-ocean ridge basalt with lesser basaltic-andesite. On a primitive mantle-normalized multi-element plot they have relatively flat light rare earth element slopes, relatively high La/Nb ratios, and depletions in P and Ti, characteristics similar to modern arc or back-arc volcanic settings. Geochemical signatures similar to those of modern back-arc basins have implications for Archean back-arc style tectonics in the Slave craton. Comparison with other regional volcanic rocks will offer further insight into the role and significance of the Arrowhead Outlier in the geological history of the Slave craton. The recognition of VMS-type mineralization within the Arrowhead Outlier has increased its mineral resource potential, specifically for Zn and Cu, both of which are mined from VMS deposits and considered critical minerals by the Canadian government.

THE STONE CABIN FORMATION, NEVADA, USA: GEOCHEMICAL AND ISOTOPIC INDICATORS OF MAGMA SOURCES AND CRUSTAL INFLUENCE IN AN EOCENE CALDERA SYSTEM

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Stone Cabin Formation (SCF) ignimbrites and related Eocene volcanic activity of this study are located in eastern Nevada within the Central Nevada Volcanic Field. The SCF is a part of the 40–25 Ma, subduction-related, primarily intermediate to silicic volcanism termed the Ignimbrite Flareup. This project aims to determine the magma source or sources of the SCF and determine the existence/extent of crustal contamination during petrogenesis using whole-rock major element, trace element, and Pb-Sr-Nd-Hf isotopic analysis. On a broader scale, these Eocene igneous rocks are important in a larger study of the isotopic transition zone that runs through Nevada between Precambrian basement terranes to the east and Phanerozoic accreted mafic terranes to the west. The source of Stone Cabin Formation ignimbrites has recently been determined to be the White River caldera southwest of Ely, NV. The caldera includes SCF tuffs, low-Si to high-Si rhyolite lavas, and andesite lava flows. Outflow tuffs of SCT composition are widely exposed southwest, west, and northeast of the caldera. Over sixty samples of Eocene volcanic and intrusive rocks were collected from intracaldera and extracaldera locations. $^{40}Ar/^{39}Ar$ dates from SCT tuffs and post-collapse rhyolite to dacite lavas are indistinguishable about 35.8 Ma. The Stone Cabin area igneous rocks range from subalkaline basaltic andesite to high-Si rhyolite in composition – with most of the samples in the andesitic to rhyolitic range. The samples show normalized incompatible element patterns similar to rhyolite ignimbrites from other caldera complexes of the Ignimbrite Flareup. Of the SCF and related nearby igneous rocks analyzed to date, the initial isotope ratios are: $^{87}Sr/^{86}Sr$ = 0.710872 to 0.712564, $^{143}Nd/^{144}Nd$ = 0.511981 to 0.512046 (εNd = -10.65 to -11.92), $^{176}Hf/^{177}Hf$ = 0.282380 to 0.282330 (εHf = -3.52 to -15.30), and $^{208}Pb/^{204}Pb$ = 39.18 to 39.47. The andesite lavas have the highest Nd and Hf and the lowest Sr and Pb isotope ratios. The primary magma source appears to be Precambrian mantle as the andesite $^{87}Sr/^{86}Sr$ values are well over 0.708 with a minimum value of 0.710872. The evolved magmas show strong correlations between both Th/La and isotopic ratios with increasing SiO_2 content, indicating that crustal contamination is a major process in magma evolution. The crustal component in the felsic lavas has highly negative εNd and εHf that are consistent with a Precambrian crustal source. Other major ignimbrites in the region underlain by Precambrian basement have similar isotopic characteristics and appear to have major interaction with the crust.

THERMO-STRATIGRAPHY OF THE DUKE RIVER AREA IN SOUTHWESTERN YUKON

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Deep, low-temperature geothermal energy could be used to reduce or replace diesel for heating in remote communities in Yukon. Previously, geothermal development

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primarily focused on shallow, high-temperature resources, but interest in low-temperature and deep geothermal resources has increased exploration activities as energy costs and climate change policy have evolved. We evaluated geothermal favourability in southwestern Yukon by adapting Play fairway analysis to remote regions. This spatial statistical tool uses a layered data approach to model favourability and risk assessments for resource exploration and identified two favourable areas: along the eastern Denali fault and around Carmacks. The Duke River area, along the eastern Denali fault, is of particular interest due to shallow Curie-point depth. The Burwash Landing community, near Duke River, could benefit directly from geothermal exploration. The objective of this work was to conduct a thermo-stratigraphic assessment of the Duke River area located in the Canadian Cordillera. Southwest of the Denali fault, the Duke River area is primarily composed of unmetamorphosed volcano-sedimentary rocks from the Wrangellia terrane with minor metamorphosed rocks (phyllite, marble, and meta-sandstones) from the Alexander terrane to the south. The area northeast of the Denali Fault consists primarily of Kluane Schist. A stratigraphic column is presented for either side of the fault. Reliable volumetric heat capacity and thermal conductivity data are essential for modelling subsurface heat transfer. Volumetric heat capacity (2.05 to 3.18 J $cm^{3\ -1}$ K^{-1}) was estimated for each sample based on literature. Thermal conductivity was measured at room temperature on outcrop samples using a thermal conductivity scanner (1.557 to 3.822 W mK^{-1}). The lower thermal conductivities are from intrusive igneous rocks (diorite and gabbro) followed by extrusive igneous rocks (andesite and basalt), whereas the higher thermal conductivities are associated with sedimentary (sandstone and siltstone) and metamorphic rocks (schist). The influence of temperature on the thermal conductivity of these samples was measured using FOX50 Heat Flow Sensor. These values are presented in a thermo-stratigraphic column and will be used in thermal modelling of the subsurface. Ultimately, the thermal model will be combined with a hydrogeological model to determine the deep geothermal potential of the Duke River area and explore potential for future deep geothermal exploration in fault zones.

A BAYESIAN AGE MODEL FOR THE TONIAN STRATIGRAPHY OF THE WESTERN OFFICER BASIN, AUSTRALIA: IMPLICATIONS FOR THE ORIGIN AND EARLY EVOLUTION OF THE CENTRALIAN SUPERBASIN

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The Neoproterozoic to Paleozoic Centralian Superbasin of Australia comprises a series of formerly interconnected, intracratonic sedimentary basins spanning much of central Australia and mostly buried beneath Cenozoic cover. Though displaying some stratigraphic variability, the Officer, Amadeus, Ngalia, and Georgina basins possess overall strikingly similar sedimentary successions that include Cryogenian glacial strata that can be correlated with the better exposed and more extensively studied Adelaide Rift basin in South Australia. Neoproterozoic strata of the Centralian superbasins are commonly subdivided into four 'supersequences', the lower of which is Tonian in age and separated from overlying Cryogenian rocks by a major unconformity. Although geochronological control on Supersequence 1 is poor and limits understanding of the origin and early evolution of these basins, it is widely assumed that the Centralian Superbasin initiated in the early Neoproterozoic (ca. 850–800 Ma) in response to the earliest stages of the break-up of the Rodinia Supercontinent. In order to elucidate the early history of this basin, we have developed a new Bayesian age model for Supersequence 1 (the Buldya Group) in the Western Officer basin in Western Australia. This age model is conditioned upon the identification of the global middle Tonian Bitter Springs (ca. 809–802 Ma) and late Tonian Russøya negative carbon isotope anomalies (ca. 742 Ma) in drill cores in the Western Officer basin, along with a new Ar–Ar plagioclase age of 753.1 ± 0.8 Ma on the Keene Basalt near the top of Supersequence 1. We apply this new age model, along with backstripping of the Buldya Group in two drill cores (Empress and Lancer) to perform a new subsidence analysis of the Tonian stratigraphy in the Western Officer Basin.

SEISMIC GEOMORPHOLOGY AND EVOLUTION OF MID-MIOCENE SUBMARINE FAN SYSTEMS OF THE MOKI FORMATION, OFFSHORE TARANAKI BASIN, NEW ZEALAND

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Confinement, basin slope, local topography, and sediment supply are major factors controlling the dimensions of individual turbidites and submarine lobe geometry. The same factors that control individual turbidites and lobes also influence the larger-scale submarine fan morphology, however, these dimensions can vary even within a single submarine fan. This study investigates whether basin topography and sedimentary dispersal patterns have any bearing on the spatial distribution of individual lobes within deepwater fan systems, or whether individual lobes' migration is independent of external forcing on the system. Here, we present results from an analysis of 3-D seismic data addressing the linkages between individual lobe morphology and large-scale fan morphology. The Taranaki Basin of New Zealand provides one of the best subsurface examples of a deepwater fan system. Within this basin, the Miocene stratigraphic section exhibits sinuous, leveed deepwater channel systems entrenched in the Mid-Miocene Moki fan system. Interpretation of 3-D seismic data from the Taranaki offshore basin reveals seven mappable composite lobe systems. Detailed mapping and subsequent seismic attribute analyses unravel the patterns of compensational stacking within the lobe systems. The deepwater Moki fan system exhibits an overall basin-ward progradation pattern as successive lobes are stacked vertically and subsequently entrenched by younger feeder channel systems. Correlation of Gamma-ray log patterns from drilled wells with the 3-D seismic data in the backdrop also reveals a stacked coarsening- and thickening-up pattern of the Moki fan system and subsequent lateral migration of turbidite input systems. The detailed 3-D mapping of subsurface seismic and well data from Moki Fan systems will provide a window into the sedimentological processes involved in the generation of stacked deepwater fan-lobe systems. The documentation of spatial evolution and stacking of lobes to build the bigger fan system will in turn provide a scaled measure of lateral vs longitudinal spreading of turbidity currents.

CANADA – CHINA COLLABORATIVE RESEARCH ON URANIUM DEPOSITS: A RETROSPECTION AND VISION FOR THE FUTURE

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Canada is the second largest uranium producer, whereas China, also one of the top 10 uranium producing countries, is the most rapidly growing consumer of uranium. Collaborative research on uranium deposits between Canada and China started early in this century, initially in the form of Chinese delegations visiting uranium mines in Saskatchewan, hosted by the Saskatchewan Geological Survey (SGS), and reciprocal visits by SGS to China. Over the past decade, academic collaboration between geoscientists from Canadian institutions including SGS, Geological Survey of Canada and universities and geoscientists from Chinese counterparts have significantly increased, including visiting scholarships, conferences and joint studies such as the IGCP-675 project (global comparison of sandstone-hosted uranium deposits). These collaborative studies have resulted in several publications in peer-reviewed journals including special issues on uranium deposits in Ore Geology Reviews and Journal of Earth Science. The collaborations have been mutually beneficial for researchers from both countries and have invoked interesting scientific questions through comparative studies. For example, the comparison of granite-related uranium deposits between the Beaverlodge uranium district (around Uranium City) in northern Saskatchewan and those in South China has led to the proposal that such

uranium mineralization resulted from coupled control of shallow (red-bed basins) and deep-seated (mafic magmatism) geologic processes in extensional tectonic settings. The comparison between unconformity-related uranium deposits in the Athabasca Basin (located at the base of the basin) in Canada and the sandstone-hosted uranium deposits located at intermediate to shallow depths within the Ordos and Yili basins in China has led to a model in which the hydrodynamic regime in sedimentary basins played a major role in the localization of the uranium mineralization. Chinese colleagues have learned from different government-industry relationships in addition to the unique geological characteristics and exploration models of the high-grade, large-tonnage unconformity-related uranium deposits. Canadian researchers have expanded their experiences in uranium geology from the vast diversity of as many as fifteen different types of uranium deposits in China. We believe the collaborative research between Canada and China on uranium mineralization will continue in the future based on the successful experience in the past, and the expectation that Canada will remain as one of the top uranium producing countries and China will continue to need more uranium for its energy needs. This kind of collaboration should be encouraged especially in the context of the concurrent development of United Nations Sustainable Development Goals and the United Nations Climate Action.

PHOTOCATALYSIS AS A PRE-TREATMENT FOR BIOLOGICAL DEGRADATION OF NAPHTHENIC ACIDS IN OIL SANDS PROCESS-AFFECTED WATER

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Bitumen extraction from the Athabasca oil sands involves large volumes of water known as oil sands process-affected water (OSPW). Concerns of OSPW production stems around its containment of naphthenic acids (NAs), a class of aliphatic and alicyclic carboxylic acids that can be toxic and are recalcitrant to natural attenuation. Fully passive advanced oxidation treatments via buoyant photocatalysts (BPCs) have been identified as a promising treatment for NA removal from OSPW. BPCs are buoyant microspheres that immobilize TiO_2 along the surface of waters where it can be illuminated by solar light and, in turn, oxidize NA to more-biodegradable forms (partial mineralization) or to CO_2 (complete mineralization). BPCs have been shown to have strong reactivity and recycling performance but can require impractically long hydraulic retention times to achieve full mineralization of all organics. Another promising, passive treatment for NA removal is biodegradation since NAs can act as carbon sources to drive microbial growth. Although microbes can completely degrade more simplistic NAs, studies have found that biological degradation suffers from incomplete removal once NAs have higher alkyl branching and cyclicity due to steric hindrances. It was therefore hypothesized BPCs can serve as a pre-treatment for biodegradation by breaking down complex NA structures to more simplistic forms for a post-biological treatment. To test this hypothesis, BPCs were employed as a photocatalytic pre-treatment under varying effective times (1 h, 4 h, 8 h, 1 d, and 2 d) in a solar photocatalytic bed to treat 40 mg/L of NAs in synthetic OSPW. The pre-treated waters were subsequently dosed with a mixed, indigenous consortium which were then used in a post biological degradation stage for 21 days where chemical oxygen demand (COD), ATP, protein, and optical density were monitored every 3–7 days. Inhibition tests demonstrated that long photocatalytic times (1 d and 2 d) were successful in eliminating microbial toxicity. These findings coincided with the observed protein and ATP levels in pre-treated samples as these were statistically significantly greater than that observed for raw samples. In accordance, the 2-d photocatalytic treatment time demonstrated near complete removal of COD (> 92%) which exceeded that observed for the raw OSPW samples (~32%). Overall, this study demonstrates that photocatalysis has the potential to convert toxic, recalcitrant NAs into biodegradable forms that can be metabolized by indigenous microbes to achieve near full mineralization.

UNDERSTANDING BISULPHIDE TRANSPORT BEHAVIOUR THROUGH BENTONITE UNDER DEEP GEOLOGICAL REPOSITORY CONDITIONS

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Most nuclear safety agencies around the world agree that deep geological repositories (DGRs) constructed hundreds of metres below ground in stable host rock formations are long-term solutions to safely isolate used nuclear fuel. The Nuclear Waste Management Organization is responsible for designing and implementing Canada's DGR, where used nuclear fuels will be isolated in an engineered barrier system (EBS) within a suitable host rock. The EBS includes highly-compacted bentonite (HCB) that surrounds the copper-coated used fuel containers (UFCs) located about 500 m underground. UFC corrosion, which is one concern in the DGR design, is currently being investigated. This is an interdisciplinary phenomenon that includes processes such as microbial activity, species transport through the HCB as well as corrosion dynamics. For example, under anaerobic conditions, microbiologically-influenced corrosion (MIC) could occur, where sulphate-reducing bacteria produce bisulphides (HS^-) that can transport through HCB and corrode the copper barrier. This study focuses on quantifying HS^- transport through HCB using diffusion experiments under a range of anticipated DGR conditions (e.g. temperature and ionic concentration) as well as HCB densities. Preliminary results indicate that geochemical reactions/sorption of HS^- onto HCB result in certain changes in the bentonite composition that may cause unusual diffusion behaviour. Further studies, including scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) and total sulphur analysis, are ongoing to better understand the transport dynamics. The results from these studies will aid in assessing the performance of EBS, thereby enabling safe storage of used nuclear fuel in a DGR.

NEW PROTEROZOIC PALEOMAGNETIC DATA FROM THE REHOBOTH BASEMENT INLIER, NAMIBIA, INDICATING 30° CLOCKWISE LOCAL ROTATION DURING DAMARAN OROGENESIS

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The Rehoboth Basement Inlier (RBI) lies along the edge of the Kalahari craton at the southern margin of the Pan-African Damara Orogen, Namibia. Knowledge of its location during geologic time will aid future supercontinent reconstructions. Within the RBI, paleomagnetic data were collected from the Bitterwater volcanics and quartzites in the Opdam Formation, the Swartkoppies mafic dykes that presumably feed Opdam basalts, the Uisib River mafic dykes, dolerite dykes intruding the Opdam Formation outside the town of Rehoboth, mafic dykes from the Klein Aub region, and redbeds and volcanics of the Doornpoort Formation. The majority of the Swartkoppies and Klein Aub sites were strongly affected by lightning strikes. The Bitterwater sites and the Doornpoort Formation sites displayed stable remanent directions, with fold tests indicating the occurrence of syn-folding magnetizations. The shallow inclinations observed in the samples indicate that the folding event occurred prior to the Damara folding event that took place at mid-latitudes, and could be related to a similar syn-folding event observed in the Aubures Formation in the adjacent Konkiep subprovince. The Bitterwater and Doornpoort sites produced two poles estimated to be ca. 1100 Ma in age, although they are rotated 30° clockwise from the well-established ca. 1100 Ma paleopole for the Kalahari craton. One dyke from each of the Swartkoppies and Uisib swarms produced a virtual geomagnetic pole with similar location to those of the Bitterwater and Doornpoort sites. Our results indicate that the Rehoboth Basement Inlier underwent a rotation of approximately 30° clockwise relative to the rest of the Kalahari craton. Previously published data suggested that this rotation affected magnetization as young as ca.

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500 Ma. Three Swartkoppies dykes and one Rehoboth dyke produced directions that follow previously compiled Kalahari/Gondwana apparent polar wander paths at 1030–1000 Ma and 545–525 Ma, after the 30° correction. Ages for these dykes need to be obtained to confirm the origin of these directions. It is possible that the rotation occurred due to the final closure of an ocean basin between the Congo and Kalahari cratons, although the exact kinematic history will require further study. Our study recognizes the importance of paleomagnetic constraints on supercontinent reconstructions that must take into account regional-scale structural histories.

TRACE ELEMENT GEOCHEMISTRY OF BIOTITE FROM THE SCRAG LAKE AND NEW ROSS PLUTONS OF THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA, CANADA: IMPLICATIONS FOR CRITICAL METAL BEHAVIOUR DURING MAGMA DIFFERENTIATION

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The South Mountain Batholith (SMB) is a 7300 km², peraluminous, felsic intrusion occurring in SW Nova Scotia. The batholith consists of 13 plutons emplaced in two different phases between ~385 Ma (Phase 1) and ~368 Ma (Phase 2). Previous research revealed that samples from Phase 2 plutons show significant trace element variability in biotite compared to Phase 1 plutons. Since Phase 2 plutons tend to be more geochemically evolved, it is not clear if this difference arises due to sampling bias or is an intrinsic property of the second stage of batholith emplacement. Therefore, the goal of this work is to better characterize biotite compositions across a broad compositional range of representative Phase 1 and Phase 2 plutons. Here we present results of analyses of samples from the Phase 1 Scrag Lake pluton (SGP) and the Phase 2 New Ross pluton (NRP). An electron microprobe and laser ablation ICP-MS have been used to collect major and trace element spot analyses and compositional maps on biotite from a suite of 5 samples from each pluton covering a compositional range of ~68 to ~75 wt.% SiO_2. Data for 34 trace elements were obtained, with the current focus on the critical metals Nb, Ta, Sn, and W. Preliminary results show continuous zoning in trace elements from core to rim in biotite grains in both pluton phases. The concentrations of Nb, Ta, Sn, and W all increase from core to rim, while the Nb/Ta ratio decreases from core to rim, which is expected with the crystallization of the assemblage biotite-quartz-plagioclase-K-feldspar. For similarly-sized grains and similar whole-rock wt.% SiO_2, Phase 1 samples show within grain variation from 10s–100s µg/g, while variation within Phase 2 biotites is 10s–1000s µg/g. This indicates that the more extreme extent of trace element variation is an intrinsic property of Phase 2 plutons. As both Phase 1 and Phase 2 samples show similar trace element concentrations in the cores of biotites, the difference in variability implies the existence of more highly evolved melts, and not due to differences in initial compositions. Such highly evolved melts could arise by the addition of fluxing agents, such as Li or F, serving to lower the solidus, and increasing the temperature interval over which crystallization occurs. This is supported by higher concentrations of Li and F in both whole-rock and biotite from Stage 2 plutons, although the origin of such enrichment is unclear.

MAGMATIC EVOLUTION OF THE UPPER BEAVER INTRUSIVE COMPLEX AND ITS IMPLICATIONS FOR COPPER-GOLD MINERALIZATION

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The rarity of large Archean magmatic-hydrothermal Cu-Au deposits has limited study on the processes controlling the metal endowment of these deposits (i.e. fertility). As such, it is uncertain whether such scarcity is solely attributable to erosion or if processes controlling the fertility of Archean magmatic-hydrothermal systems are different from Phanerozoic systems. The Archean Upper Beaver magmatic-hydrothermal Cu-Au deposit of the southern Abitibi greenstone belt represents a rare opportunity to investigate these processes. This exceptionally well-preserved deposit is located approximately 8 km north of Larder Lake (Ontario), and approximately 5 km north of the Larder Lake-Cadillac break along the northern limb of the Spectacle Lake regional anticline. It is hosted within tholeiitic volcanic rocks of the lower Blake River assemblage (ca. 2704–2701 Ma) near the unconformity with the underlying upper Tisdale assemblage (ca. 2706–2704 Ma). The volcanic rocks of the Blake River assemblage are intruded by the multi-phase Upper Beaver Intrusive Complex (UBIC). The Cu-Au mineralization is hosted by the volcanic, volcaniclastic, and sedimentary rocks of the Blake River assemblage, and by the intrusive rocks of the UBIC with which it is spatially and temporally associated. The UBIC is formed by distinct amphibole ± plagioclase bearing phases later crosscut by at least three events of plagioclase ± amphibole ± quartz dykes. The Cu-Au mineralization is spatially associated with a series of apophyses and southwest-trending plagioclase ± amphibole ± quartz porphyritic dykes locally named crowded porphyry. The intrusive rocks of the UBIC have a large variety of igneous textures including equigranular, porphyritic, and rare cumulates. Both plagioclase- and clinopyroxene-dominated cumulates are present within the UBIC. Compositionally, the intrusive complex is intermediate to felsic (from 53 to 65 wt.% SiO_2) and calc-alkaline to slightly alkaline. Samples range in aluminum saturation from metaluminous to weakly peraluminous (A/CNK= 0.67–1.07). The chemical signature of the magmatic rocks, with moderately to strongly fractionated REE patterns, small Eu anomalies, elevated Sr/Y values, negative Dy/Yb versus SiO_2 fractionation trends, and primitive mantle-normalized trace element patterns (enriched LILE and depleted Nb, Ta), are indicative of melting of a hydrated mantle source and that differentiation is mainly driven by amphibole without plagioclase fractionation. On a A/CNK, Na_2O/K_2O, FMSB ternary diagram, the rocks forming the UBIC define a trend from sanukitoid to TTG-type magmatism that can be either be interpreted as an effect of the magmatic differentiation or as mixing between two different magma sources.

MULTIPLE SULPHUR ISOTOPE AND TRACE ELEMENT COMPOSITION THROUGH PYRITE-PYRRHOTITE METAMORPHIC DEVOLATILIZATION OF THE ARCHEAN PONTIAC SUBPROVINCE, QUEBEC: IMPLICATIONS FOR OROGENIC GOLD SOURCE

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There is a consensus that sulphur is released to metamorphic fluids at the pyrite (FeS_2)–pyrrhotite ($Fe_{(1-x)}S$) transition during prograde metamorphism (~375–575°C). During sulphide-involving prograde metamorphic reactions, transition elements that may occur as micro and nano-inclusions in pyrite (e.g. Zn, Cu, Pb, Ag, Mo, Au) are removed, while metals that are structurally bound in pyrite lattice (e.g. Co, Ni, As, Se, Te, Bi) usually are preserved and even enriched in the recrystallized pyrite. Thus, in addition to sulphur, the reaction $FeS_2 = FeS + ½S_2$ could also result in the liberation of gold that becomes available for transport in aqueous metamorphic fluids as sulphide complexes. Moreover, the fractionation in $\Delta^{33}S$ and $\Delta^{36}S$ between pyrite and released sulphur is preserved and can be used to track sulphur sources, and Archean MIF thought the opening up pyrrhotite. Here, we utilize state-of-the-art in situ techniques (Secondary Ion Mass Spectrometry, Laser Ablation- and Time of Flight-ICP-MS) to document the multiple sulphur isotope (^{33}S, ^{34}S, and ^{36}S) signatures and trace element composition through the pyrite-pyrrhotite devolatilization reaction of metasedimentary rocks from the Pontiac Subprovince (PS) – a Neoarchean metasedimentary terrain tectonically juxtaposed to the world-class orogenic gold-bearing Abitibi greenstone belt. Metasedimentary rocks with a maximum depositional age of ca. 2682 Ma comprise turbiditic sequences metamorphosed at greenschist to amphibolite facies, with increasing grade from north to south; from biotite, garnet, staurolite, kyanite, to sillimanite metamorphic zones. Samples were selected across this Barrovian-like metamorphic gradient, from the biotite to sillimanite zones. While pyrrhotite is present in all zones, pyrite is rare in the kyanite and sillimanite-bearing rocks. Both sulphides are often associated with chalcopyrite, displaying overgrowth texture, where pyrrhotite surrounds pyrite. Preliminary results indicate that pyrite yields positive $\delta^{34}S$ (0.85 ± 0.39‰) and $\Delta^{33}S$ (0.04 ± 0.03‰) values for biotite zone, and slightly higher $\delta^{34}S$ (1.95 ± 1.73‰) and $\Delta^{33}S$ (0.17 ± 0.14‰) values for the staurolite zone. Pyrrhotite yields a more pronounced range for $\delta^{34}S$ (0.00 ± 2.21‰) and near-zero $\Delta^{33}S$ (-0.02 ± 0.07‰) values from biotite zone, being isotopically heavier in the staurolite ($\delta^{34}S$ = 2.57 ± 1.12‰ and $\Delta^{33}S$ = 0.44 ± 0.29‰ and kyanite ($\delta^{34}S$ = 1.16 ± 0.28‰ and $\Delta^{33}S$ = 0.26 ± 0.02‰) zones. Preliminary data indicated that $\delta^{34}S$ values from Fe-sulphides increase with metamorphism, while the positive $\Delta^{33}S$ signature is mostly preserved during pyrite desulphidation, which is concordant with experimental studies. Future work includes tracking the

fractionation in $\Delta^{33}S$ and $\Delta^{36}S$ in pyrrhotite overgrowing and replacing pyrite crystals in different metamorphic grades.

THE CRITICAL ROLE OF WATER FOR GENERATING CONTINENTAL CRUST

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It is increasingly recognized that active continental arcs, the sites of juvenile continental crust production, are transcrustal magmatic systems containing 'cool' silicic magmas. However, the origin of these systems is not well understood. We suggest that the role of water is critical, but greatly under appreciated. In this presentation, we track the effect of water from slab to surface in subduction zones, highlighting the impact of hydrous basaltic arc magmas (≥ 10 wt.% H_2O) saturating at ~1100°C near the Moho. There, as these hydrous basaltic magmas cool to the regional geotherm (750–800°C), they fractionate and crystallize as dioritic underplates and exsolve water, thereby driving strongly endothermic melting reactions in older overlying underplates to produce voluminous calc-alkaline, low-K silicic melts. These Cordilleran-type magmas rise as a low-temperature, diatexitic slurry of melt and residue, and recrystallize into silicic mush during adiabatic decompression. Episodic injection of more mafic (hotter) magmas facilitates ascent. Chemical diversity is controlled by the removal of residual hornblende and plagioclase, not by fractional crystallization. Repeated underplating induces repeated melting of previous underplates, efficiently producing the juvenile granitoid infrastructure of continents.

ASSESSMENT OF GEOTHERMAL RESOURCES IN ONSHORE NOVA SCOTIA

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Emerging technologies in the geothermal sector can be a game changer for the profitable exploitation of renewable energy resources currently underutilized in Nova Scotia. Direct use of heat can be developed to improve energy efficiency in the short term, while electricity generation is a long-term objective. Nova Scotia's businesses and energy consumers, showing a high demand for electricity and heat, can benefit from the development of such geothermal resources. For example, businesses in the agricultural sector have a growing interest in exploring the viability of using geothermal energy to support greenhouse operations and improve food supply chain sustainability. Nova Scotia's deep geothermal resources were identified and evaluated for direct use of heat, electricity generation, and heating and cooling from abandoned and flooded mines in this context. 119 temperature measurements recorded at depths ranging from 52 to 4536 m were compiled, analyzed and filtered, mostly from old petroleum and mining exploration wells. Available data on the porosity and permeability of deep aquifers and seismic data were also used. A methodology was then established in order to identify and rank the geothermal potential of Nova Scotia's onshore sedimentary basins based on five criteria (temperature of potential reservoirs; depth of potential reservoirs; lithology of potential reservoirs; temperature uncertainty in the zone; geological uncertainty in the zone). A methodology was also developed to estimate the amount of energy available from the mine system for space heating and cooling with the help of geothermal heat pumps, considering a 25-year use. The evaluation of mine systems was based on the volume of ore extracted for 287 abandoned mines (coal: 206, metals: 55, industrial minerals: 26), both underground and open pit. Findings indicate that most of the province's sedimentary basins have a significant geothermal potential for direct use of heat. Select areas in Hants and Cumberland counties were identified as having potential for geothermal electricity generation. Finally, the province's legacy of coal mining offers opportunities to use abandoned mines for space heating and cooling.

GEOLOGY AND GEOCHRONOLOGY OF THE GRAND LAKE OPHIOLITE COMPLEX AND ITS OVERLYING COVER ROCKS IN WESTERN NEWFOUNDLAND: EVIDENCE FOR EARLY FORE-ARC MAGMATISM IN THE BAIE VERTE OEANIC TRACT

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The Glover Island and Grand Lake area in western Newfoundland is predominantly underlain by a series of Cambrian to Ordovician ophiolitic rocks and associated cover rocks, which have been correlated with the Tremadoc (490–483 Ma) Baie Verte Oceanic Tract (BVOT) and associated cover rocks of the Snooks Arm Group on the Baie Verte Peninsula. The BVOT formed in a forearc setting in the Humber Seaway, a narrow tract of ocean between the Laurentian continental margin and the Dashwoods microcontinent. This presentation provides the results of a detailed field-based studies of the Grand Lake Ophiolite Complex (GLOC) and overlying Glover Group. The GLOC comprises an almost complete ophiolite sequence, and geochemical analysis of basalts and mafic tuffs from the top of the GLOC show boninitic and primitive island-arc tholeiitic (IAT) characteristics. The GLOC is overlain by mafic to felsic tuffs of the Kettle Pond Formation at the base of the Glover Group. Geochemical analyses of mafic tuffs indicate predominantly IAT characteristics, while felsic units are classified as Type IV rhyolites believed to have formed due to shallow melting of depleted tholeiitic basalt in juvenile arc. A new U–Pb zircon age of 492.6 ± 0.6 Ma from a QFP rhyolite in the Kettle Pond Formation show that it overlaps in age with the GLOC (490 ± 4 Ma). The island-arc volcanics of the Kettle Pond Formation transitions upwards into a thick (> 3 km) sequence of massive to pillow N-MORB basalts (Tuckamore Formation). The top of the Glover Group is marked by the Corner Pond Formation, a variable cover sequence of epiclastic siltstones to conglomerates, calc-alkaline basalts and graptolite-bearing black shales that yields a mid-Floian (477.7 to 470 Ma) age. This study shows that rocks of the Glover Island and Grand Lake area can be directly correlated with the BVOT, with early forearc magmatism dominated by boninitic to IAT magmatism (equivalent to the Betts Cove ophiolite), which formed basement to a sequence of volcanic and sedimentary cover rocks with MORB to calc-alkaline signatures (Snooks Arm Group). However, new geochronology from the Kettle Pond Formation shows that arc-type magmatism on Glover Island began by at least 492.6 ± 0.6 Ma, earlier than the onset of magmatism on Baie Verte (ca. 490 Ma). This shows that subduction must have initiated in the Humber Seaway soon after obduction of the earlier Lushs Bight Oceanic Tract at ca. 495 Ma.

INTEGRATION OF HYPERSPECTRAL CORE SCANNING INTO MINERAL DEPOSIT STUDIES OF OROGENIC GOLD SYSTEMS: A CASE STUDY FROM THE GLOVER ISLAND, WESTERN NEWFOUNDLAND

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Hyperspectral alteration mapping is effective in characterizing alteration zones in hydrothermal ore deposits, including orogenic gold deposits. These zones are related to fluid flow during the formation of these deposits, with variations in mineral chemistry likely due to variations in fluid P-T-X conditions. This study identifies alteration zones associated with orogenic gold occurrences on Glover Island in western Newfoundland, integrating geological and geochemical data with infrared spectrometry collected from high resolution hyperspectral core imaging and Terraspec spot sampling. Glover Island is host to numerous orogenic gold occurrences, including the Lunch Pond South East deposit (178,800 oz Au at 1.79 g/t). It is located on the boundary between the Humber and Dunnage lithotectonic zones in the Canadian Appalachians, which is marked by a major crustal scale fault zone known as the Baie Verte-Brompton Line-Cabot Fault Zone (BCZ). Gold mineralization is associated with second and third order faults parallel to the BCZ, and is hosted predominantly in strongly deformed and altered Cambro-Ordovician volcanic and sed-

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imentary rocks of the Kettle Pond Formation. Detailed drillcore logging, field mapping and lithogeochemical data show the nature of gold mineralization and associated alteration is strongly dependent on host-rock rheology and chemistry. Conglomerate-hosted gold mineralization is restricted to massive quartz veins in the hinges of F2 folds, and associated with broad (10s of metres) alteration halos with pervasive carbonate-sericite-chlorite ± fuchsite alteration of the surrounding conglomerates. Volcanic-hosted occurrences are hosted by strongly altered and deformed felsic to mafic tuffs, with a well-developed schistosity and the local development of mylonitic fabrics. In aphanitic felsic tuff and quartz-feldspar-porphyritic-rhyolite, proximal alteration zones are marked by intense quartz-albite-sericite-carbonate ± chlorite alteration, with mafic volcanic-hosted mineralization characterized by strong chlorite-carbonate ± sericite alteration. Hyperspectral data from high-resolution core scanning shows systematic shifts in mineral chemistry in alteration zones surrounding mineralized intervals. Proximal alteration zones are associated with shorter wavelength white mica and a shift to more Ferich chlorite, irrespective of the host rock types or style of mineralization. High resolution hyperspectral core imaging is able to discriminate between mineralized and unmineralized volcanic rocks on Glover Island, based on the alteration mineralogy and mineral chemistry. In addition, hyperspectral data is able to identify potential new mineralized zones, with characteristic alteration mineralogy, that were overlooked during initial core logging and assaying.

FLUIDS AND ORE FORMING PROCESSES IN OROGENIC GOLD DEPOSITS OF NEWFOUNDLAND: EVIDENCE FROM FLUID INCLUSIONS AND STABLE ISOTOPE STUDIES

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Newfoundland is a major emerging gold district containing numerous gold occurrences associated with Paleozoic crustal-scale fault systems. These include the Valentine Lake (3.14 Moz Au measured and indicated resource) and Cape Ray (0.84 Moz Au measured and indicated resource) gold deposits, as well as numerous recent discoveries along the northern margin of Ganderia in central Newfoundland Appalachians (e.g. Queensway and Moosehead prospects). These occurrences have characteristics typical of orogenic gold deposits, such as association with crustal-scale faults, syntectonic rock sequences, and lower greenschist to amphibolite facies metamorphism. However, there are significant variations in mineralization styles and settings between individual gold occurrences, including host lithologies, metal contents, and inferred mineralization depths. This study of some of these gold occurrences in central Newfoundland investigates variations in mineralizing fluids and ore forming processes. Herein, we present preliminary fluid inclusion results from a number of gold occurrences representing a diverse range of geological settings. Fluid inclusions have been studied in > 100 vein samples from > 10 deposits, with detailed petrographic analyses carried out using the fluid inclusion assemblage (FIA) approach. The majority of samples proved unsuitable for fluid inclusion analysis, due to multiple generations of overprinting FIA or strong deformation of samples resulting in post entrapment modification of FIA. Where suitable FIA related to gold mineralization events have been identified, the mineralizing fluids appear to be variable in composition, with carbonic, aqueous-carbonic, and aqueous fluid types identified (XCO_2 ranging from 0.03 to 1). The carbonic phase ranges from pure CO_2 to rare CH_4-dominated, and fluid salinities are generally low (< 10 eq. wt.% NaCl). These variations in fluid compositions are likely related to fluid unmixing and the geochemical influence of the host lithologies. Fluid inclusion homogenization temperatures range from 250 to 350°C, and isochore modelling indicate trapping at epizonal to mesozonal pressures (1 to 2.5 kbars). Future research will include more fluid inclusion studies (including a more complete geochemical characterization of mineralizing fluids) along with in situ sulphur isotope and trace-element analysis by LA-ICP-MS of sulphide phases associated with gold mineralization. These data will be used to better constrain the ore fluids and gold precipitation mechanisms in individual gold occurrences and identify factors responsible to the variations between orogenic gold occurrences in the central Newfoundland gold district.

PALEOSTRESS ANALYSIS OF MESOSCALE NORMAL FAULTS AND EARLY CRETACEOUS SHEET INTRUSIONS OF NORTHERN NEW ENGLAND: EVIDENCE FOR POSTRIFT EARLY CRETACEOUS EXTENSION WITHIN THE EASTERN NORTH AMERICAN MARGIN

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Postrift Early Cretaceous normal faulting occurred in association with the New England-Quebec igneous province (NEQ) magmatism in western Vermont and eastern New York. Paleostress analysis of dyke trends and fault-slip data indicates two episodes of extension related to magmatism: N-S and NW-SE. Each episode is associated with a change in extension direction from a regional NE-SW extensional stress field, and each coincided with and outlasted an episode of NEQ magmatism. Evidence for N-S extension consists of normal and oblique-slip normal faults, including normal fault conjugate systems, extension fractures, and the dominant trend of dykes within the ~140–130 Ma Burlington lobe of the NEQ. Evidence for NW-SE extension consists of normal and oblique-slip normal faults, many of which reactivate cleavage, extension fractures, and the dominant trend of dykes within the ~110–100 Ma Taconic lobe of the NEQ. Crosscutting relationships between the faults and Early Cretaceous dykes indicate a maximum Early Cretaceous age for the N-S and NW-SE extensional events. Coeval extension, magmatism, and faulting is supported by the compatibility of dyke-trend and fault-slip paleostress results and the geographic overlap of magmatism and normal faulting. The magmatism of the Burlington and Taconic lobes of the NEQ and the associated normal faulting are interpreted as the crustal expression of edge-driven convection (EDC) and potentially small-scale delamination driven by EDC. The close geographic proximity and repeating sequence of events over a time span of ~35 Ma are consistent with the periodic nature of EDC. The normal faulting and perturbations to the regional stress field are consistent with the recovery phase of small-scale delamination. Previous workers have recognized the significance of EDC beneath the eastern North American margin today and have suspected that this process may have operated along the margin in the geologic past. This investigation supports the idea that EDC was likely operating along the eastern North American margin as early as the Early Cretaceous. In addition, the results provide insight into the crustal expression of EDC within a passive margin setting shortly after rifting and establishment of the margin.

EARLY AND MIDDLE JURASSIC PALYNOEVENTS OF THE LUSITANIAN BASIN (PORTUGAL) IN THE PROTO-ATLANTIC CONTEXT

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The Lusitanian Basin is located in central western Portugal and is mainly composed of Jurassic sedimentary rocks. The macro and microfossil biostratigraphy of this depocentre is well studied, but palynological works are scarce. We address this with a high-resolution palynostratigraphic study of a Lower and Middle Jurassic succession of the Lusitanian Basin, based mainly on dinoflagellate cysts. We analyzed 301 productive samples of palynomorphs from eight outcrops. The resulting biostratigraphic scheme identified 28 significant palynomorph bioevents in the late Pliensbachian–earliest Bathonian interval, which includes: the Toarcian Oceanic Anoxic Event (T-OAE, or Jenkyns Event); the Global Boundary Stratotype Section and Point (GSSP) for the Toarcian Stage at Peniche; the GSSP for the Bajocian Stage at Cabo Mondego; and the Auxiliary Boundary Stratotype Section and Point (ASSP) for the Bathonian Stage at Cabo Mondego. This high-resolution dinoflagellate cyst record documents the first known appearance of this group of palynomorphs in the Lusitanian Basin at the base of the late Pliensbachian, with first occurrences (FOs) of four species. It also reflects the dramatic changes occurring during the T-OAE among marine organisms, including the extinction of taxa. In the Lusitanian Basin,

the beginning of the T-OAE occurred at the base of the *Hildaites levisoni* ammonite biozone and is marked by the extinction of *Luehndea spinosa*, the temporary disappearance of *Nannoceratopsis* spp., and a general reduction in dinoflagellate cyst abundance; an increase in prasinophyte abundance also occurs. These bioevents correlate with the negative carbon ($\delta^{13}C_{carb}$) and oxygen ($\delta^{18}O$) isotope excursion records previously established for the Lusitanian Basin. The increase in dinoflagellate cyst FOs during the early Bajocian to earliest Bathonian documents the Middle Jurassic radiation of this planktonic group. Despite their relatively long stratigraphic ranges, the spore *Kraeuselisporites reissingeri* and the pollen *Classopollis* spp., *Araucariacites australis* and *Callialasporites* spp. are good local additional stratigraphic indicators. As expected, the dinoflagellate cyst assemblages suggest that the Lusitanian Basin is an intermediate area between the Boreal and Tethyan realms, with taxa characteristic of both. It thus represents a transition between northern and southern Europe during the early phases of opening the North Atlantic Ocean. Comparison of the Lusitanian Basin Early to Middle Jurassic age assemblages with those from the Orpheus Graben and southern Grand Banks, offshore eastern Canada will be of great interest as the two areas were at equivalent paleolatitude and only a few hundred kilometres apart across the nascent Atlantic Ocean and precursor rift at the time.

PRIMARY CRITICAL METALS DEPOSITS AND THEIR PATHS TO DISCOVERIES IN MINERAL SYSTEMS FORMING IOCG DEPOSITS

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Metasomatic iron and alkali-calcic (MIAC) mineral systems precipitate a variety of critical metal associations with current deposit resources and potential by-products in 24 of the 31 critical metals on the Canadian list. The billion tons of resources in some global MIAC districts provide a strong reminder that the discovery and mining of iron oxide-copper-gold (IOCG), iron oxide ± apatite (IOA) and affiliated deposits are key to secure a long-term supply of critical metals for Canada and its partners. An alteration (paragenetic) model relates the alteration facies of MIAC systems to their distinct metal associations and deposit types, e.g. skarn, IOA (REE, Ni), iron-rich Au-Co-Bi-Cu, IOCG (± PGE, REE, U), iron sulphide Cu-Au (ISCG), and albitite hosted U-Au-Co or Mo-Re. It also links the magnetic susceptibility and density of the mineralization to rock composition and mineral assemblages. The alteration facies approach to establish vectors to mineralization within MIAC systems stems from extensive alteration mapping of Canadian MIAC systems and global comparisons. Yet vocabularies for mapping and logging MIAC alteration facies are scant and the collective ability to identify metasomatic (alteration) vectors to ore during regional mapping and exploration is fledgling. Available geochemical datasets are likely to lack non- or cryptically mineralized alteration zones; a caveat that can be mitigated by assessing what is present and then use the mineral system framework to prognosticate what might be present but remains to be recognized or drilled and to vectors to mineralization. Plotting molar barcodes (e.g. Na-Ca-Fe-K-Mg) or metals from bulk-rock composition on geochemical discriminant (AIOCG) and magnetic susceptibility-density (Henkel) diagrams helps assess system prospectivity for critical metals. Case examples include the critical metal endowment of the Olympic Dam deposit (AU), the Great Bear magmatic zone (NT) and its NICO Au-Co-Bi-Cu deposit and Terra polymetallic mineralization, the Central Mineral Belt (NL), the Labrador Trough (QC, NL), the Josette REE deposit (QC), the Scadding Au mine (ON), and the Appalachian orogen (NB, NL, NS). As datasets are processed, tools are refined. Refinements include means to highlight alteration facies and their metal endowment within albitite-hosted U and Au-Cu ± Co prospects and distinguish high and low temperature components when plotting samples within the AIOCG diagram. The plots of elements contents and new barcodes on Henkel plots help assess the impact of distinct heavy minerals on mineral system geophysical footprints.

GENESIS OF THE PALEOPROTEROZOIC HUZYK CREEK POLYMETALLIC GRAPHITE DEPOSIT, AND THE POTENTIAL BENEFITS OF HIGH-GRADE METAMORPHISM OF METALLIFEROUS BLACK SHALES

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Metalliferous black shales have long been recognized as potential sources for a number of critical metals including Ni, Mo, Zn, Cu, Co, V, Cr, U, and PGE. Many of these metals are considered essential for green technologies and transition to a low-carbon economy. However, these deposits are rarely mined because of relatively thin bed thickness, sub-economic ore grades, and/or difficult metallurgy related to ore mineralogy and fine grain size. The effects of metamorphism have the potential to change the economics of metalliferous black shales by transforming their organic carbon content into graphite, thereby creating graphite deposits with metals as value-added byproducts. Chalcophile elements that were contained in organometallic compounds, or fine-grained pyrite, can be partitioned into economically important ore minerals. With increasing metamorphic grade, both sulphides and graphite can recrystallize to progressively coarser grain size making beneficiation more efficient. The Huzyk Creek polymetallic graphite deposit is located in the Trans-Hudson Orogen of Manitoba. The deposit occurs within Paleoproterozoic Burntwood Group turbidite deposits of the Kisseynew domain, which are overlain by Ordovician limestone and sandstone of the Western Canadian Sedimentary Basin. The Burntwood Group rocks were metamorphosed to lower granulite-facies conditions during the Trans-Hudson orogeny. The Huzyk Creek deposit consists of 14–17 m-thick intervals of graphite schist enclosed by orthopyroxene- and garnet-bearing, wacke-derived gneiss. The graphite schist is enriched in V, Mo, Zn, Cu, and U. A model has been proposed where redox-sensitive elements were leached from the adjacent Flin Flon arc-collage during oxidative weathering. The metals were transported by oxidized surface run-off draining the arc-collage and discharged into the Kisseynew basin. Although oxygenated and likely biologically productive at shallow depths, the basin shelves were likely euxinic. Mixing of metal-enriched oxygenated water with organic matter and euxinic water resulted in reduction and fixing of redox-sensitive metals with organic material, which accumulated during a period of low-stand or tectonic quiescence. Burial and metamorphism resulted in transformation of the organic material into graphite, while Mo, Cu, and Zn were partitioned into molybdenite, chalcopyrite, and sphalerite, respectively. Determining the mineral hosts for V and U will be part of future investigations. This model could apply worldwide to basins of similar age and tectonic setting.

SOURCE TRACING OF A REE-RICH GRANITIC PEGMATITE DYKE INJECTED IN WABASH PARAGNEISS (GRENVILLE)

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The Grenville province, a Mesoproterozoic orogenic belt mainly exposed in Quebec and Ontario, has a great potential for rare earth elements (REE) exploration. This potential is shown by high number of recognized REE showings (more than 100 showing with concentration >1800 ppm) in Quebec. These REE showings are mostly associated with alkaline complexes and granitic pegmatites, and few with carbonatites and Iron Oxide Copper Gold mineralization (IOCG). The sources and the processes leading to the formation of the REE-rich granitic pegmatite in the Grenville province is debated. Recent studies on REE-rich pegmatite in the Lac Okaopéo region proposed that they were generated by the partial melting of fertile Paleoproterozoic–Archean metasedimentary rocks. However, in the central Grenville, REE-rich pegmatites display a spatial association with REE-rich alkaline complexes, suggesting a plausible genetic link between them. A better understanding about the formation of the REE-rich pegmatites is needed to help futures REE explorations in the Grenville. This study is focused on the Blanchette-1 showing located 25 km northwest of La Tuque. The REE mineralization is contained in a 2 m-wide, allanite-bearing pegmatite dyke hosted by Mesoproterozoic paragneiss (Wabash complex). Chosen grab samples show REE enrichments > 2% (mostly

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light REE) with > 0.4% neodymium. To better understand the source of this REE enriched pegmatite, four samples were selected for zircons U–Pb dating and Hf isotopic analysis by LA-ICP-MS: (i) the REE enriched pegmatite dyke (ii) an alkaline syenite intrusions (Toad Syenite) outcropping a few kilometers away, and (iii) two granitic dykes connected to the leucosome of the migmatitic paragneiss of the Wabash Complex. Preliminary treatment of the zircon U–Pb data indicate an emplacement age around 1005 ± 4 Ma for the syenite and from 1060 to 1080 Ma for the pegmatite and granitoïd dykes. The age of the syenite is coherent with the documented alkaline magmatism affecting this part of the Grenville, dated between 1000 and 1040 Ma. The fact that the REE-enriched pegmatite bodies are older and shows a similar age to granitoid dykes connected to the leucosomes of the migmatitic paragneiss suggest that the REE enriched pegmatites may be sourced from the differentiation of melts produced by the migmatization of the nearby paragneiss.

DETERMINING MAXIMUM ACCEPTABLE PUMPING RATES IN AN ISLAND FRESHWATER LENS CONSIDERING PARAMETER, OBSERVATION, AND CLIMATE UNCERTAINTY

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Pumping optimization under uncertainty techniques are powerful tools to support groundwater management, but their implementation remains limited in coastal and island aquifers. This is because of the long simulation times associated with seawater intrusion numerical models, and because of challenges associated with coupling different sources of uncertainty. A highly reproducible framework was developed to optimize pumping rates in an island freshwater lens considering parameter, observation, and climate uncertainty. The method was implemented in an island aquifer in the Magdalen Islands archipelago (Québec, Canada). A seawater intrusion model with fast simulation times was developed using MODFLOW-SWI2. History matching and uncertainty quantification were then performed using PESTPP-IES. Model predictive uncertainties were coupled with climate uncertainties, including recharge uncertainty (derived from various global circulation models and emission scenarios) and sea-level rise uncertainty. Using PESTPP-OPT, the pumping rates in the freshwater lens were maximized while avoiding well salinization and considering parameter, observation, and climate uncertainty. Sets of maximum acceptable pumping rates were obtained for different risks of well salinization. Ultimately, selection of the final pumping scenario is dependent on the groundwater manager's attitude towards risk. This framework could be used to support groundwater management in other islands or coasts.

THE RADIOGENIC ISOTOPE RECORD OF CENOZOIC CONTINENTAL ARC MAGMATISM ACROSS THE PHANEROZOIC–PRECAMBRIAN TERRANE BOUNDARY IN NORTHERN NEVADA, USA

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Northern Nevada and northeastern California include a phenomenal record of continental arc magmatism from ca. 40 Ma to 3 Ma that progressed southwesterly across Nevada into eastern California, presumably due to rollback of the subducting Farallon Plate. Over the last two decades, over 800 samples of igneous rocks from Lake Tahoe east to the Nevada-Utah border have been collected to characterize mantle and crustal sources of these arc rocks and to test the influence of basement age and composition on magmatism. Here, we report radiogenic isotopic data (Sr, Nd, Pb, Hf) from this dataset. Arc magmatism was primarily mafic (basalt to andesite) in the younger western arc but was more felsic in the older, eastern arc that includes the numerous caldera complexes of the Ignimbrite Flare-up event. Compared to the modern south Cascades Arc, all mafic igneous rocks of the Eocene–Pliocene arc required a more enriched mantle source, which we propose to be the lithospheric mantle that was refertilized (hydrated) during flat-slab subduction prior to the onset of arc activity. The 0.706 and 0.708 Sr-isotope lines pass through central Nevada and separate Precambrian lithosphere to the east from Proterozoic lithosphere to the west, with the Transition Zone in between. Mafic igneous rocks west of the 0.706 line generally have $^{87}Sr/^{86}Sr < 0.7055$. Within the Transition Zone, mafic rocks have highly variable initial isotopic compositions (e.g. $^{87}Sr/^{86}Sr = 0.7055$ to 0.708) suggesting that both Phanerozoic and Precambrian mantle lithosphere exists at the base of the Transition Zone. Rare mafic igneous rocks east of the 0.708 line do have $^{87}Sr/^{86}Sr < 0.708$. Thus, mantle sources vary in isotopic composition from west to east depending on basement age. Felsic igneous rocks broadly follow the same west-east variation in isotopic composition as the mafic rocks. Felsic igneous rocks west of the Transition Zone commonly have isotopic compositions and Th/La that overlap with coeval mafic rocks, possibly due to similarities in mantle and crustal isotopic compositions, but felsic rocks emplaced within the eastern Transition Zone and especially on Precambrian basement show a distinct Pb isotopic signature and higher Th/La ratios that are likely derived from Precambrian crust. We conclude that crustal contamination is a contributing petrogenetic process in magmas traversing Phanerozoic basement and crust, but is of major importance in felsic magma evolution in the eastern Transition Zone and on Precambrian basement.

THE RADIOGENIC ISOTOPE RECORD OF MIOCENE ARC VOLCANISM IN THE NORTH ISLAND, NEW ZEALAND

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Mid to Late Miocene continental arc volcanism on the North Island of New Zealand is found in the Coromandel Peninsula, the Kiwitahi volcanic chain on the west side of the Hauraki Gulf, and the Taranaki Basin (Kora volcano) offshore of the western margin of the North Island. Coeval oceanic arc volcanism is also found along the offshore Colville Ridge and the Kermadec Ridge (CKR) north of New Zealand. This Pb-Sr-Nd-Hf isotopic study aims to evaluate mantle sources and potential crustal contaminants along these sections of the Miocene arc system. The sample set includes 50 new on-land samples, ten core samples from the Kora Volcano (Kora-1, -2), and 35 archived samples from the University of Auckland. Whereas the oceanic arc rocks are mostly basalt-basaltic andesite with rare dacite, the continental arc samples are basalt (rare) to dacite. All lavas have $(Gd/Yb)_N < 1.7$, indicating melting in the spinel peridotite field in the mantle wedge. The CKR oceanic lavas have high Ba/La, indicative of a dominant fluid component in the mantle wedge, and fall in two isotopic groups with different sources: average Pacific upper mantle and an EMI-type mantle composition that is strongly evident in Pb isotope ratios. The on-land mafic ($SiO_2 < 57\%$) Coromandel and Kiwitahi arc lavas have consistently lower Ba/La than the oceanic lavas, and all isotopic data indicate that 2–5% subducted Pacific sediments were added to the mantle wedge beneath the North Island. The EMI component observed in the oceanic CKR lavas is not observed in any mafic on-land arc lavas. High Th/La and excellent correlations with isotopic ratios indicate that evolved ($SiO_2 > 57\%$) Coromandel and Kiwitahi magmas include a crustal component, likely derived by variable partial melting and assimilation of Waipapa metasedimentary rocks. The Kora Volcano intrusions are distinctly different from the oceanic CKR and on-land Coromandel/Kiwitahi groups: although Ba/La is extremely high as in CKR lavas, Sr-Nd-Hf isotopes indicate a more depleted mantle source for the Kora intrusions. Pb isotope ratios are unique and are like those of Indian Ocean MORB. Either (1) the western Taranaki Basin was underlain by Indian Ocean mantle, (2) unusual Pacific MORB crust was subducted beneath this part of the arc only, or (3) rifted Gondwana lithospheric mantle of the Western Province with low Pb-isotope ratios (exemplified by young volcanic rocks from Queensland) has contributed to western Taranaki Basin magmas.

REINTERPRETING BIOMAT-ASSOCIATED ICHNOGENERA

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Organism-microbial mat (also known as biomat) interactions are commonly used to track the evolution and the diversification of early animals, especially during the

timeframe from the late Neoproterozoic to the Early Paleozoic where important geobiological revolutions appear in the Earth's story. This includes, for instance, the replacement of Proterozoic-style microbial biomats by Phanerozoic-style bioturbated mixgrounds. In the rock record, some trace-fossil occurrences are best explained as exploitation of biomats for their oxygen production as opposed to their food value. In that context, we reinterpret some characteristic Ediacaran and Lower Palaeozoic trace fossils, which are commonly observed in association with biolaminated sediment. Hypothesized oxygen-exploitive trace fossils have some of the following characteristics: (1) the burrow was connected to the sediment (or biomat) – the water interface was maintained as an open living chamber and shows optimization of burrow surface area or volume beneath biomat zones (for example, *Chondrites*); (2) the burrow is situated at the base of biomats but has no connection to the sediment-water interface; or (3) the trace fossil is preserved immediately beneath fossil biomats and was subsequently back-filled during trace-fossil emplacement. This study reports the taxonomic range of reported Ediacaran and Cambrian trace fossils that exemplify these characteristics (e.g. *Oldhamia*, *Chondrites*, *Planolites* and *Trichichnus*) and sheds light on the interpretation of biomat-associated trace fossils as self-contained underwater breathing apparatus (or SCUBA) for the seafloor ecospace colonization and the organism-biomat interactions by the earliest invertebrates.

IS LONGER BETTER? PROTRACTED MAGMATISM AND VMS ORE-FORMING SYSTEMS IN FELSIC-SILICICLASTIC PROVINCES: GEOCHRONOLOGY OF THE FELSIC VOLCANISM IN THE NEVES CORVO DEPOSIT, IBERIAN PYRITE BELT

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Volcanogenic massive sulphide (VMS) deposits occur in a variety of geotectonic and lithostragraphic settings. In some VMS provinces, the relation between ore-forming systems and mafic magmatism is indisputable. In settings where mafic magmatism is less voluminous or absent (e.g. felsic-siliciclastic provinces like the Iberian Pyrite Belt, IPB), the development of hydrothermal systems may be triggered by other heat sources, possibly crustal-derived magmatism. To further understand this relationship, we report zircon U–Pb geochronology data from thirteen samples from footwall felsic volcanic rocks of the Neves Corvo VMS deposit. All dated samples comprise coherent and poorly sorted clast- and matrix-supported breccias, with gradational contacts, representing the coherent cores and in-situ quenched auto-breccias of felsic cryptodomes. These occur at similar lithostratigraphic positions, and therefore, represent the same effusive volcanic episode in the footwall stratigraphy. The U–Pb data shows occasional evidence of U–Pb system disturbances, with variable amounts of Pb-loss (discordant and younger than extrusion dates) and intra-grain Pb-gains, revealed by older rims than cores. The filtered U–Pb data exhibits a multi-peak age spectrum, indicating the presence of several magmatic zircon populations, all displaying typical magmatic CL textural features (e.g. oscillatory zoning) and Th/U ratios. Inherited zircon grains span from the earliest Devonian, Ordovician, Cambrian to the Neoproterozoic, suggesting a source area with Laurussia affinities. Besides the eruption age (362 ± 1 Ma; avg. Th/U = 0.5), the zircon cargo of the felsic effusive volcanic rocks is characterized by abundant Early Devonian zircon, some overlapping with the age of felsic volcanism in other IPB sectors (375 ± 2, 382 ± 5 and 390 ± 2 Ma; avg. Th/U = 0.39, 0.65 and 0.40, respectively). The zircon cargo of the felsic effusive volcanism in the Neves Corvo VMS deposit footwall thus record the remobilization and extrusion of a silicic crystal mush which shows evidence of multiple recharge and felsic melt storage episodes. Considering the protracted zircon U–Pb record of the Neves-Corvo footwall felsic effusive volcanic rocks, and of other felsic volcanic rocks that host giant VMS deposits in the IPB, we suggest that the thermal gradients generated from cooling of upper-crustal silicic reservoirs enhance and promote efficient upper crustal-scale fluid flow, and consequently the formation of giant VMS deposits in settings where mafic magmatism is not significant. Further work will combine zircon U–Pb and trace element data, to constrain the melts' thermal evolution and thus contributing to the improvement of regional and/or local exploration criteria. This work is supported by FCT(PD/BD/142784/2018) and FCT/UIDB/50019/2020 – IDL.

CHARACTERIZING A ROCK FRACTURE ROUGH SURFACE USING SPATIAL CONTINUITY AND KRIGING: FROM SEMI-VARIOGRAMS AND AN UPSCALED SURFACE

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Fluid flow through low permeability rocks is mainly accomplished through fractures. Coupled thermo-hydraulic-mechanical-chemical (THMC) numerical models rely on representation of fracture surfaces to construct a distribution model of the empty space (aperture) between the two. The generally used statistical representations of fracture surfaces often overlook directionality which may result in a poor representation of the aperture distribution and thus a poor model. Semi-variograms are used as spatial continuity methods in areas such as ore deposits and geological facies prediction but few studies have applied these techniques to fracture face characterization. The aim of this study is to investigate the possibility of characterizing a fracture surface roughness using semi-variograms and heavily upscaled fracture surface. Comparing the kriging originated fracture surface to the original offers a measurement of methodological quality. A statistical analysis was performed in greywacke in order to acquire the semi-variograms' parameters necessary to describe the spatial continuity of the fracture surface topography. The surface will then be interpolated using simple (SK) and ordinary (OK) kriging techniques. A reasonable match between the kriged and original surfaces is expected to be achieved and the fit quantified by analyzing the residuals between the two. These results may provide a new alternative to current storing and computing solutions for fracture representation, especially in aperture distribution calculation for coupled THMC numerical models and simulations. To verify the applicability of this work in coupled processes, the comparison of results and computing time of models using apertures derived from original versus kriged surfaces must be made.

HYFLEX TEACHING AND LEARNING: WHAT IS IT AND WHAT ARE THE PROS AND CONS?

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The Covid-19 pandemic has changed many aspects of college and university-level education, including whether instructors deliver online course material synchronously (in-real time) or asynchronously (e.g. via pre-recorded lectures). In the Department of Geoscience at the University of Calgary, one of the things that students reported that they liked most about online learning was the ability to go back and re-watch recorded lectures. Thus, the department encouraged (but did not require) instructors to record their synchronous lectures and post them on the course learning management website. Now that campuses are heading back to in-person learning, making lectures available to students who prefer to be online may be the next step in the evolution of geoscience education. HyFlex refers to a course design whereby the material is Hybrid (offered in both face-to-face and online formats) and Flexible (students can participate synchronously or asynchronously). In HyFlex courses, students can choose to: participate in face-to-face class sessions, participate in class sessions via video conference (e.g. Zoom), or participate fully asynchronously. Students can change their mode of attendance weekly or by topic, according to need or preference. Lecture and lab materials are available such that students can access them online or in-person, during or after class sessions. It is clear that this model offers a high level of flexibility and accessibility for today's students, who have busy and complicated lives. However, questions arise regarding increased instructor workload, how to maintain equity in assessment, and the technology available at post-secondary campuses. This presentation explores the pros and cons of HyFlex teaching and learning in the context of a post-secondary geoscience curriculum.

INDIGENOUS CONTRIBUTIONS TO PALEONTOLOGY IN ALBERTA: WHOSE BONES ARE THEY?

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Who owns the fossilized remains of plants, animals, or human ancestors found on Indigenous land? Who gets to profit from displaying fossils in museums? Since antiquity, the pattern has been the same: after local people discover a spectacular fossil, outsiders arrive to remove the object for "safekeeping" and "proper" interpretation, as defined by non-Indigenous authorities. In the U.S., millions of dollars worth of fossils have been removed from reservations by scientists, federal agencies, and museums, who commonly rejected local ownership and cultural traditions. For example, in 1942, after a Navajo man discovered a rare double-crested *Dilophosaur* skeleton, Sam Welles, the famous fossil-hunter for University of California, Berkeley, arrived. Welles dug up the fossil in a record ten days and took it to Berkeley, where it remains as a prize specimen in the museum's collection. The Navajo tribe has requested the return of this fossil, which was denied, even though a multimillion-dollar museum where the fossil could be the main attraction was built by the tribe. In Alberta, there is abundant evidence that First Nations people discovered bones prior to the arrival of Europeans. Fossils from Alberta can now be found in Ontario, New York, and Natural History Museum in London. The *Alberta Historical Resources Act* (HRA) of 1972 (fossils included in 1978) states that all fossils within the province belong to the Crown, but this does not apply to First Nations land. Fossils found on First Nations land are the property of the First Nations and, as such, they are not bound by the restrictions that the HRA places on excavation, modification, and sale of fossils. Recently, in southern Alberta, a mosasaur skeleton was discovered on the Blood Tribe Reserve while mining for ammolite in the Upper Campanian Bearpaw Formation. An agreement was established between the Tribe and the Alberta Government for the Royal Tyrrell Museum to excavate the specimen and curate it for as long as it is of scientific value, but the specimen remains property of the Blood Tribe. A cast of the specimen was made and donated to the Blood Tribe, and is on display at the reserve. This presentation will describe historic fossil finds by Indigenous people in Alberta and showcase collaborations between Indigenous groups and scientific organizations.

P-T-T CONSTRAINTS ON HIGH-GRADE METAMORPHISM FROM CA. 1.95 GA INCIPIENT COLLISION OF SLAVE AND RAE CRATONS

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Incipient collision between Rae and Slave cratons was a key stage in the final assembly of the composite Laurentian craton. The Great Slave Lake shear zone (GSLsz) represents the locus of the Slave craton indentation into the Rae craton; however, the timing and kinematics of this event have been thoroughly overprinted by subsequent ductile transform motion. As such, the timing of initial Rae-Slave collision remains unconstrained. We have applied phase-equilibria modelling and Lu–Hf garnet and U–Pb accessory phase petrochronology to supracrustal rocks along the GSLsz to precisely constrain the conditions and timing of peak metamorphism associated with crustal thickening along the central segment of the western Rae cratonic margin. We document a series of nested P-T paths for six samples all with similar peak conditions of 0.8–1.0 GPa and 750–800°C. Lu–Hf garnet geochronology of two samples constrains the timing of peak conditions to have occurred from 1932–1917 Ma within a protracted high-temperature metamorphic interval, synchronous with monazite and zircon (re-)crystallization. At lower crustal depths, high temperatures persisted until at least ca. 1900 Ma. Based on our results and the typical lag between collision and crustal thickening, we propose that the Slave craton first indented the western Rae margin at ca. 1950 Ma. Taken together with constraints on the timing of metamorphism elsewhere along the western Rae margin, we propose that incipient closure of the intervening basins between Slave and Rae was followed by northwards zippering of the margins and ~500 km of dextral translation of Slave craton along the Great Slave Lake shear zone after ca. 1900 Ma.

TECTONIC SETTING AND PROVENANCE OF PLUTONIC ROCKS HOSTING THE GREAT SLAVE LAKE SHEAR ZONE FROM MICROANALYTICAL ZIRCON U–Pb GEOCHRONOLOGY AND OXYGEN AND HAFNIUM ISOTOPES

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The initial amalgamation of the composite Laurentian craton occurred along the western margin of the Rae craton, which is subdivided into three main segments from north to south: the Thelon tectonic zone, Great Slave Lake shear zone (GSLsz), and Taltson magmatic zone. Based on U–Pb zircon and whole-rock major, trace element and isotope geochemistry, the Thelon (2.07–1.96 Ga; $\delta^{18}O$= 6–9 ‰) and Taltson (1.99–1.92 Ga; $\delta^{18}O$= 8–12 ‰) magmatic suites are commonly attributed to a continental arc and intra-continental setting, respectively. The plutonic rocks along the GSLsz occupy a key position at the transition between the two plutonic belts and at the locus of the proposed Slave-Rae craton collision and has been previously attributed to the Taltson suite. Nevertheless, the age and isotope signature of the GSLsz rocks are as yet unconstrained. To address this gap in tectonic constraint along the western Rae margin, we have carried out a detailed U–Pb geochronology and isotope geochemistry study of plutonic rocks hosting the GSLsz that span the range of observed lithologies. The rocks along the western Rae margin experienced a multi-stage history, including primary pluton crystallization, granulite-facies metamorphism associated with Rae-Slave collision at 1930–1900 Ma, and retrograde metamorphism during a major phase of transform motion at < 1900 Ma. To circumvent any secondary alteration and to target the primary magmatic signature of the rocks, we have applied a micro-analytical approach to zircon, including U–Pb geochronology and Hf-isotopes analyzed by LA-ICP-MS and O-isotopes analyzed by SIMS. These results will allow for the confident interpretation of whether the rocks hosting the GSLsz 1) reflect derivation from a mantle source or to what degree they may have interacted with continental crust or sedimentary rocks; 2) are similar to either the Thelon or Taltson magmatic rocks or whether they represent a mixture/transition between the two; and 3) evaluate the changes in magmatism and tectonics along the western Rae margin.

EVALUATING THE CASE FOR MAGMATIC LOADING IN THE COAST-CASCADE OROGEN

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The burial of rocks in orogenic belts is typically attributed to imbrication of thrust sheets during convergence. However, in regions of voluminous plutonism, crustal thickening and attendant metamorphism may also be the result of magmatic loading, which involves sequential emplacement of sheet-like intrusions and the forced burial of country rocks to depths of up to 40 km. The Harrison Lake area of the Coast-Cascade Orogen may provide a natural example of such a process. The rocks in this area experienced peak metamorphic pressure and temperature (P-T) conditions typical of mid-crustal depths, but the record of this metamorphism is highly localized to the country rock immediately interstitial to the plutons and there is no evidence for post-metamorphic structural juxtaposition. There are precise age constraints for the three voluminous plutonic suites that may have caused the observed metamorphism, thus providing a framework for testing the feasibility of magmatic loading as the primary mechanism for the peak metamorphism. To do so, we constrained the P-T evolution of the lowest (greenschist facies) and highest-grade (upper amphibolite facies) metapelitic rocks using phase-equilibria modelling and dated the timing of garnet growth associated with peak burial using Lu–Hf garnet geochronology. Both samples experienced initial low-P heating to conditions of < 4 kbar and < 575°C, consistent with contact metamorphism due to initial plutonism at shallow depths. A second phase of metamorphism is preserved in the high-grade sample, which underwent burial along a steep dP/dT path to 7–8 kbar and 625°C. Garnet

growth in the high-grade sample occurred during minor heating at maximum burial depths and is dated to 94.2 ± 0.2 Ma. The timing of garnet growth corresponds to a lull in magmatism and the cessation of deformation in the area. We use these P-T-t constraints to constrain calculations of the evolving thermal field in which the effects of magmatic emplacement are investigated. Results will provide insight into which plutonic suite is responsible for the mid-crustal burial and, more broadly, will inform on the effects of pluton emplacement on the thermal conditioning and burial of the crust in orogenic belts.

LINKING CLINOFORM TRAJECTORY ANALYSIS AND SEQUENCE STRATIGRAPHY: IMPROVED STRATIGRAPHIC UNDERSTANDING OF THE LABRADOR MARGIN, OFFSHORE EASTERN CANADA

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The concept of a clinoform has been around for decades, but has received renewed attention in its application to stratigraphic studies. These morphological features develop in different depositional settings, including shorelines, subaqueous deltas, and shelf-edges, with a clinothem corresponding to the body of rock bounded by successive clinoforms. The passive margin of Labrador began forming during rifting in the Cretaceous, with subsequent seafloor spreading starting in the Maastrichtian and ceasing in the earliest Oligocene. The resultant stratigraphic record includes a number of Late Cretaceous through Pleistocene clinothem units that we have identified and mapped. Focusing on the Hopedale Basin, where sufficient well and seismic data exist, we combined paleoenvironmental interpretations, biostratigraphic constraints, and seismic data to produce paleogeographic maps and seismic profiles that delineate seven shoreline, five subaqueous delta, one shelf-edge, and three shelf-edge delta clinothems. Changes in paleoenvironments and clinoform trajectories (relative lateral and vertical movements) were used to define eight second-order sequences, which allowed for refinements to the Labrador margin lithostratigraphic column and to an improved understanding of tectonic, eustatic, and climatic influences throughout the region's depositional history. Upper Cretaceous shoreline clinothems of the Freydis Member (Markland Formation) developed during late rift and characterize lowstand and highstand intervals. Subsidence occurred at this time, but a global sea level low in the Cenomanian–Turonian was also likely a major factor during regression. The Gudrid Member (Cartwright Formation) represents a forced regressive and lowstand interval during the Paleocene to Early Eocene, tied to seafloor spreading, a Selandian eustatic low, and sediment supply driven by the Paleocene–Eocene Thermal Maximum. Kenamu Formation shales represent a major transgression of the margin in the Early Eocene, with a small shoreline clinothem developed during stillstand. Subsequent Middle Eocene regression formed the Leif Member shoreline clinothem and associated subaqueous delta and shelf-edge clinoforms, with the Middle Eocene Climatic Optimum possibly contributing to enhanced sediment influx. Subtle subaqueous delta clinothems developed in the Late Eocene and Early Oligocene within the Mokami Formation during highstand conditions. The Saglek Member of this formation includes three shelf-edge delta clinoform units developed during falling stage and lowstand conditions, and were influenced by the Oi2 glaciation and global sea level fall in the Oligocene, the Miocene Climate Optimum, and Pliocene–Pleistocene Northern Hemisphere glaciation. This study demonstrates the utility of integrating clinoform trajectory and sequence stratigraphy analyses at second-order scale on a margin that underwent several major regressive and transgressive events.

ORIGIN OF THE SONGPAN-GARZE TERRANE, TIBETAN PLATEAU: A VIEW FROM THE PALEO-TETHYS OCEAN TECTONIC EVOLUTION

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The Songpan-Garze terrane, located in the northern Tibetan Plateau, represents the world largest remnant flysch basin, and hosts a world-class Late Triassic rare-metal pegmatite deposit. It is separated from the Kunlun terrane in the north by the A'nyemaqen suture, from the Northern Qiangtang terrane in the south by the West Jinsha suture and from the Yangtze Block in the east by the Longmenshan fault. Most researchers agree that this basin was deposited in a remnant ocean in the Late Triassic during the Pangea supercontinent final amalgamation. However, it is hot debated about when the predecessor ocean formed and its subsequent evolution. After reviewing the Cambrian–Triassic magmatism in relevant terranes adjacent to the Songpan-Garze terrane, a few magmatism gaps were revealed in several terranes, i.e. 380–280 Ma in East Kunlun terrane, 380–340 Ma and 320–250 Ma in West Kunlun terrane, 340–300 Ma in Northern Qiangtang terrane. The long magmatic gap up to 100 Myr in East Kunlun terrane argues against there was a long ocean subducted from Cambrian to Triassic, but supports the closure of Proto-Tethys in the Early Silurian as documented by high-pressure metamorphic rocks and with the Paleo-Tethys opening later. The main Paleo-Tethys Ocean was located to the south of the Northern Qiangtang terrane and is represented as the Longmu Cuo-Shuanghu Paleo-Tethys Ocean, which was opened in Late Silurian and subducted between ~370–230 Ma. The A'nyemaqen Ocean or West Jinsha Ocean was possibly opened in 340–320 Ma via backarc extension in the upper plate of Paleo-Tethys subduction zone. It is hard to evaluate whether this ocean underwent self-subduction with available data, but the magmatic arc, if it existed, was probably short. The beginning of magmatism (~230 Ma) in the Songpan-Garze terrane was later than the closure time of the predecessor A'nyemaqen Ocean or West Jinsha Ocean and the adjacent main Paleo-Tethys Ocean, thus, it occurred in a post-collisional setting rather than subduction setting. More precise and accurate geochronological data are needed to reveal the space-time of late Paleozoic magmatism, the relationship between A'nyemaqen Ocean and West Jinsha Ocean, and their detailed tectonic evolution.

TIME-LAPSE ELECTRICAL RESISTIVITY IMAGING (ERI) FOR EMBANKMENT SEEPAGE MONITORING

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Electrical resistivity imaging (ERI) is a geophysical method that, through the injection of electrical current into the ground, is used to image electrical resistivity variations in the subsurface. In recent years measurement of resistivity variations over time i.e. time-lapse ERI, has been used to image subsurface processes, including the movement of water. The technique is of special interest for non-invasive investigation of seepage/leakage through embankment dams and levees where the resistivity of water seeping through these structures varies seasonally with both ion content and temperature. However, modelling and field trials are required to investigate the method's sensitivity and viability. Since October 2019, a time-lapse ERI system has been operating at the Mactaquac Generating Station in New Brunswick, Canada, as part of a seepage monitoring research program sponsored by NB Power and NSERC. The system, employing 123 electrodes distributed over a 70 m × 25 m area adjacent to a concrete sluiceway structure, runs autonomously each night, yielding data that are typically averaged over one-week periods and subsequently inverted to yield weekly snapshots of the 3-D resistivity distribution. Over the past year, the system's sensitivity to variations in the dam's clay-till core has been substantially improved by incorporating electrodes buried under the road along the dam crest and improved topographic modelling. These changes have proven highly effective, as illustrated by recent data collected between September and December 2021, during which time the resistivity of water in the dam's reservoir more than doubled, allowing the water to be used as a resistive tracer that highlighted regions within the core that appeared to experience preferential flow. The most strongly anomalous region was in the upper part of the core above ~8 m depth, in agreement with inferences from temperature monitoring that is ongoing in a borehole drilled into the concrete abutment immediately adjacent to the clay-till core. We anticipate that it will be possible to make order-of-magnitude estimates for seepage flux (and its spatial variation) by analyzing the time lag between resistivity changes in the reservoir and in the dam core, compensating for the fact that seasonal temperature (and hence resistivity) variations in the reservoir naturally decline with depth. This is an exciting development in embankment seepage monitoring technology. While prior time-lapse ERI studies have been conducted using 2-D imaging along a dam crest, the system at Mactaquac is novel for its 3-D coverage and application to a dam abutment region.

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NITRATE LEACHING FOR A THREE-YEAR POTATO ROTATION IN PRINCE EDWARD ISLAND, CANADA

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Intensive potato practices in Prince Edward Island, Canada, can negatively impact groundwater, the sole source of drinking water for the province, and have been associated with increased frequency of anoxic events in downgradient coastal ecosystems. In this study (2009–2015), two cycles of a three-year potato rotation (potato-barley-red clover) implemented on a field scale (2.4 ha) at the Harrington Experimental Research Farm of Agriculture and Agri-Food Canada, located 10 km north of Charlottetown, were modelled using Root Zone Water Quality Model (RZWQM), a one-dimensional model that simulates plant growth and the movement of water, nutrients and pesticides in the root zone, to better understand the nitrogen (N) dynamics and magnitude of nitrate leaching under the various rotation phases. The main inputs of N were mineral fertilizer (150 kg, 51 kg and 0 kg N $ha^{-1}y^{-1}$ for potatoes, barley and red clover, respectively) and mineralization of N from soil organic matter (60–90 kg N $ha^{-1}y^{-1}$, depending on the rotation phase). For the red clover phase, biological N fixation provided an additional input of N (40–170 kg N $ha^{-1}y^{-1}$). Plant uptake was the most important process for removal of N from soil (195–226 kg kg N $ha^{-1}y^{-1}$ for potatoes, 80–103 kg N $ha^{-1}y^{-1}$ for barley and 83–215 kg N $ha^{-1}y^{-1}$ for red clover) and was followed by leaching, which was greatest for potatoes (67–76 kg N $ha^{-1}y^{-1}$), followed by barley (31–37 kg N $ha^{-1}y^{-1}$) and clover (27–36 kg N $ha^{-1}y^{-1}$). The greatest nitrate leaching occurred in the fall after harvest when the crop cover was absent and the infiltration was high (e.g. maximum leaching of 33 kg N $ha^{-1}y^{-1}$under potato in November 2014). Elevated nitrate leaching also took place in mid-spring when residual soil N was mobilized by increased percolation due to snowmelt (e.g. maximum leaching of 23 kg N $ha^{-1}y^{-1}$ at the end of the clover phase in April 2014). The results of this research, including the calibrated plant growth models for each rotation phase can be used for developing sustainable management practices aimed at reducing nitrate leaching while maintaining agricultural yield as well as for assessing the impact of future climate changes on both yield and environmental footprint associated with potato production practices.

EDI IN ACTION: INITIATIVES AND CHANGES IN MCGILL'S EARTH AND PLANETARY SCIENCES DEPARTMENT IN COLLABORATION WITH URGE

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The Equity and Workplace Climate Committee (EWC) at the Department of Earth and Planetary Sciences in McGill University was formed in 2018 to address systemic equity issues in academia. The committee, which consists of students, faculty, postdocs, and staff, meets regularly to discuss departmental policies and implement initiatives to address issues specific to the geosciences, including hiring practices, onboarding policies, outreach, support for graduate students, and reporting policies. While the committee acknowledges that dismantling systemic racism and creating an inclusive environment within our community requires long-term action, we've focused on implementing a series of actionable changes to build toward our long-term goal. In this presentation, I will showcase our department's initiatives and reflect on their applicability in other academic institutions. As an internationally diverse department (~57% non-Canadian citizens), we supported a graduate student initiative of Culture Chats. This event allowed international students to showcase their academic journeys thus far, thereby opening a cross-cultural dialog about cultural and academic expectations in geosciences in our department context and internationally. We started an EDI-focused departmental blog that features bilingual student profiles, faculty interviews, and discusses topics focused on minority representation in Earth Sciences. Creating this blog allowed us to showcase positive changemakers, and create an inclusive environment for the members of our community. Our undergraduate student society started a department-wide EDI-focused reading group to discuss recent research on EDI in geosciences and ways to implement these findings in our department. Members of our committee and others also participated in an NSF-funded URGE (Unlearning Racism in Geosciences) program. Supported by URGE, we laid the foundations for demographic tracking, new student recruitment policies, and other department-scale structural changes which we continue to build. Examples of specific implemented initiatives are instituting a field safety committee to discuss best practices for fieldwork and updating the graduate onboarding system led by graduate students. These initiatives were also adopted by several other university organizations and departments. By listening to the concerns brought to the committee by its members, we were able to collaboratively develop these initiatives that addressed the needs of our department. Our constant engagement and discussions with the broader EPS community have been critical to the success of these initiatives. As we look towards implementing more initiatives over the coming years, we want to focus on long-term institutional changes that allow us to create a more inclusive and diverse environment within the geosciences.

INVESTIGATING DEFORMATION ALONG A PALEOMEGATHRUST: INSIGHTS FROM MICROSTRUCTURAL STUDY OF BLUESCHIST METACHERT FROM THE FRANCISCAN COMPLEX, CALIFORNIA

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Seismological evidence shows that a mixture of brittle-ductile deformation at the downdip limit of the seismogenic zone is responsible for producing slow slip and very low-frequency earthquakes. Structural analysis is essential to our understanding of how this deformation is accommodated at the plate boundary and how mixed-mode deformation influences the earthquake cycle. One way to address this question is to study exhumed rocks that provide us the opportunity to make direct geological observations for structural analysis. Our goal is to study these exhumed rocks to determine the deformation mechanisms hosted in the dominant mineral phases and derive the background stress estimates at the source region of slow slip and low-frequency earthquakes. In this study, we present preliminary field and micro-scale observations from an exhumed paleomegathrust in the Franciscan Subduction Complex. The Franciscan Subduction Complex represents a Mesozoic subduction zone and consists mostly of underplated clastic sediment-rich terranes that are metamorphosed from prehnite-pumpellyite to blueschist facies. Angel Island, in the San Francisco Bay, is composed of blueschist facies metasedimentary and metabasic rocks containing potential paleo-megathrust faults that correlate to the source depths of slow slip earthquakes. Subduction-related faults and shear zones crop out in sea cliffs around the perimeter of the island and enable us to observe deformation features in characteristic subduction zone lithologies. We used both field and microscopic techniques to understand the mineralogy and structural fabric development of the meta-sedimentary and metabasic rocks across a paleo-megathrust fault on Angel Island. Centimetric-scale field maps showing crosscutting relations between fabric sets are reinforced with microstructural thin section mapping and shear stress estimates from quartz paleopiezometry. We focus on a shear zone in blueschist-facies metachert, where the main deforming mineral phases are sodic amphiboles, phyllosilicates, and quartz. Amphiboles and phyllosilicates define the foliation of these rocks whereas quartz records ductile fabric and exhibits dynamic recrystallization. The microstructures reveal a progressive increase in the intensity of structural fabric and proportion of blueschist mineral assemblages. Pressure solution processes are seen in the matrix of the rocks. We also observe overprinting between thin brittle shear zones and intracrystalline plastic deformation in quartz. Using EBSD-derived phase maps and quartz paleopiezometry, we try to determine the deformation mechanisms and deformation gradients hosted in the quartz-rich and stilpnomelane-rich units across the paleo-megathrust. Our study highlights this complexity while presenting evidence for possible deformation mechanisms and stress conditions witnessed at slow slip depths.

TROPICAL CYCLONES AND THEIR EXPRESSIONS AND IMPACT ON SHALLOW-MARINE SEDIMENTATION; A CASE STUDY FROM THE TAIWAN STRAIT

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Tropical cyclones drive the transfer of massive sediment volumes to Earth's oceans through extreme precipitation and associated runoff. These sediments are then partly reworked by tides and waves (fair-weather processes). Distinguishing between sediments deposited during extreme events and those redistributed by fair-weather processes can be approximated by determining the proportions of terrestrial- vs. marine-sourced carbon in the sediment using delta-^{13}Corg values and C:N ratios of organic matter. Terrestrially sourced carbon is delivered dominantly during extreme events that erode organic material from land, and marine-sourced carbon, such as plankton and marine particulate matter, settles on the seafloor and is incorporated into the sediment when fair-weather processes persist. In Pliocene strata of the Western Foreland Basin, Taiwan, marine-sourced carbon comprises 40–60% of all organic matter in marine mudstone deposited at water depths estimated to exceed 35 m. In sediment deposited at 10–35 m water depth, organic carbon is effectively 100% terrestrially sourced. The overwhelming contribution of terrestrially sourced organic carbon reflects the dominance of tropical cyclones on sedimentation in shallow marine settings and in settings where preserved physical expressions of these storms are limited. In the Taiwan Strait, the emergence of Taiwan and associated erosion is preserved by a marked shift in delta-^{13}Corg values and C:N ratios towards terrestrial values, and in clay mineralogy and magnetic susceptibility. This drastic shift in sediment character records emergence of the island and the overwhelming impact of tropical cyclone-induced sedimentation in the shallow-marine realm.

A COMPARATIVE STUDY OF THREE ARCHEAN CRATONS EMPLOYING SEISMIC TOMOGRAPHY, ANISOTROPY, AND THERMOCHEMICAL MODELLING

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In the past, cratons have rifted apart (African and South American plates), modified by mantle plumes (kimberlite eruptions), or recycled by plate subduction (India-Asia collision). We examine these processes of delamination and rejuvenation in three Archean cratons and gain an understanding of the various geotectonic mechanisms (plumes, subducting slabs, mantle convection) interacting with the craton and with each other employing seismic tomography, anisotropy, and thermochemical modelling. Wyoming craton experienced episodes of decratonization during the Laramide orogeny due to underlying flat slabs which hydrated and weakened the lithospheric root. The latest phase of decratonization is related to the encroaching Yellowstone hotspot. We will discuss results from seismic shear wave velocity and radial anisotropy models showing that the combination of flat-slab subduction, small scale convection, and hotspot activity can lead to massive destruction of the cratonic lithosphere. To further the characterization of these mechanisms, we will compare these models with those of the Tanzanian craton since it has not yet suffered complete keel removal and may be in its early stages of erosion. Seismic tomography and anisotropy models provide important constraints on the velocity structure of the cratonic lithosphere. However, knowledge of the present-day thermal and compositional structure of the lithosphere and sub-lithospheric upper mantle is key to understanding the relationships between internal Earth dynamics, surface observables, and the location of mineral and energy resources (e.g. diamondiferous kimberlites).We look at the new thermochemical models of the lithosphere and upper mantle beneath the Superior craton and surrounding regions and discuss several robust features that carry important geological and geodynamical implications for this region.

A MANTLE CONTINUUM FOR TYPE IIB BLUE DIAMONDS GROWTH ENVIRONMENT

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Blue diamonds are of type IIb because of the presence of boron (≤ 10 ppm) and the absence of noticeable nitrogen. They are among the rarest diamonds and mainly found at the Cullinan Mine, South Africa, and at the Kollur mine, India. Recent studies suggest that blue diamonds formed at the transition zone or even deeper in the lower mantle, in subduction-related settings. Here we present a detailed study of multi-phased synchronous and epigenetic solid and fluid inclusions trapped in five specimens of type IIb diamonds from the Cullinan Mine, using Raman and FTIR and X-ray diffraction and fluorescence. Inclusions of graphite, Fe-Ni-Cu native metallic alloys, sulphides of the pyrrhotite group, but also Ni-rich oxide were found together with a common fluid containing H_2O + CH_4. Two breyite examples (Ca_3SiO_3) were identified in two diamonds as primary inclusions, one of them closely associated with larnite (Ca_2SiO_4). It is recognized that breyite stability ends at 10 GPa and the breyite-larnite assemblage is stable around 4 to 9 GPa. The remnant pressure of the breyite was measured by micro-Raman spectroscopy and micro-X-ray diffraction allowing the calculation of residual trapping pressures. Both breyite samples indicated a trapping pressure of 4.9 to 5.6 GPa (between 900 and 1400°C) corresponding to a depth of formation between 160 and 180 km in the lithosphere. The breyite-larnite assemblage and pressure measurements support a lithospheric depth of formation for the hosting diamonds. Hence, it is proposed that type IIb diamonds may form in a mantle continuum, from lithospheric to sub-lithospheric depths. These diamonds likely grew in water-dominated supercritical fluids associated with metallic melts, a growth environment characterized by low oxygen fugacity buffered by the association of the fluid and the metallic alloys. Finally, type IIb diamonds contain a few ppm of boron and even less nitrogen. This suggests that a contribution from a subducting plate (bringing lithophile B and N) is possible but not specifically required: the mantle itself is sufficiently enriched in boron to supply it to the blue diamonds, while metallic alloys in the growth environment would prevent the incorporation of nitrogen reducing drastically its amount in the gem.

NOBLE GASES IN FLUID INCLUSIONS OF FIBROUS AND COATED DIAMOND: FIRST DATA FOR DIAVIK MINE, CANADA

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Fibrous and coated diamonds are enriched in fluid inclusions, which record diamond growth conditions and provide excellent clues to monitor interactions between mantle and crustal reservoirs. Further, fluid micro-inclusions can provide pristine information on mantle volatiles sources. Noble gases (He, Ne, Ar, Kr, and Xe) are chemically inert and thus can be excellent tracers of those sources and their interactions. Indeed, the sources of noble gases, namely the atmosphere, the crust and the mantle, show distinctive isotopic signatures. Noble gas studies of diamonds from the Slave Craton, Northwest-Territories are rare and were restricted to Ekati kimberlite pipes. Here, we report the first noble gas results on diamonds collected at the Diavik kimberlite, also located in the central Slave Craton. A total of eleven samples were provided by the Diavik Diamond Mines: 1 fibrous and 10 coated diamonds, which are those generally containing the largest volume of fluid inclusions. Micro-FTIR spectroscopy at University of Alberta in Edmonton, Canada, identified micro-inclusions of carbonate, liquid H_2O, O-H, and solid inclusions of pyroxene and another silicate phase. Fibrous coats displayed low degrees of N aggregation, identifying these diamonds as type IaA (medium N of 1360 ppm and average N aggregation of

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5% B). Noble gases were extracted by crushing under vacuum (500 strocks), purified and analyzed using a Thermo Helix MC-Plus at Geotop, Montreal, Canada. First results show a $^{3}He/^{4}He$ ratio (R) normalized to that of the atmosphere (Ra = 1.384×10^{-6}) ranging from 4.82 ± 0.26 for the fibrous diamond to 7.65 ± 0.21 for coated ones. The higher value is close to that expected for a depleted mantle source (R/Ra = 8 ± 1, as measured in MORBs) and higher than sub-continental lithospheric mantle (SCLM), which has typical R/Ra values of 6.1 ± 0.9. The R/Ra values measured in the Diavik fibrous diamond are in the range of those previously measured for diamonds from Ekati kimberlites (R/Ra from 4 to 6) whereas Diavik coats have distinctly higher values (7.65 ± 0.21), which might preclude a SCLM source for the diamond-forming fluids but suggest a convective depleted mantle source instead. The $^{40}Ar/^{36}Ar$ ratios are highly variable from 300 ± 1 for fibrous diamond (practically indistinguishable from the atmospheric argon ratio of 295.5) to 7761 ± 129 for coated diamond, distinctly lower than those measured at Panda (20,000–30,000) but still indicating a large addition of terrigenic Ar.

CHEMICALLY ABRADING ZIRCON BEFORE LASER ABLATION ANALYSIS: WHAT IS THE EFFECT ON THE U–Pb AGE AND ZIRCON CHEMISTRY AND IS IT WORTH THE HASSLE?

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Chemical abrasion (CA) is a methodology that is usually applied to zircon prior to high precision U–Pb dating to reduce the effects of Pb loss and therefore improve the accuracy of U–Pb ages. This technique involves thermally annealing zircon crystals at 900–1000°C for ~48 hrs, and then partially dissolving them in HF acid in a pressurized digestion vessel for 6–18 hrs. This CA pre-treatment to zircon crystals prior to high precision U–Pb dating has resulted in zircon ages that are significantly more accurate and reproducible than without the treatment. Although annealing is already used quite frequently before laser ablation analysis, CA has rarely been used. Here we evaluate whether this chemical abrasion treatment is beneficial in the context of laser ablation dating. To investigate the effects of CA on laser ablation analysis, we tested a range of reference materials that had been chemically abraded for 3, 6, and 12 hrs. We monitored the laser induced elemental fractionation (LIEF), U–Pb age, and trace element and Hf isotope compositions of the grains. In general, LIEF was less pronounced in grains that had longer CA times (meaning that the differences in ablation behaviour between the primary reference and unknowns was reduced). U–Pb ages became more concordant, more accurate and also recorded less scatter with longer CA. Trace element concentrations were similar to previously measured values, and the measured Hf isotopic compositions were identical to the published values. Following the successful reference material tests, we investigated the use of CA on a suite of Precambrian detrital zircon grains. Zircons were separated and divided into two aliquots, one of which was treated with CA for 6h and the other not. Both aliquots were analyzed for U–Pb ages and trace elements using a split-stream approach. The CA aliquot showed a factor of ~3 greater concordance than the non-chemically abraded batch, as well as significantly lower concentrations of non-stochiometric cations, indicating that much less altered zircon was measured. As a result, for the same number of analyses, about 3 times more data are useable after CA than without it. In conclusion, CA adds multiple extra steps to the laser ablation U–Pb workflow but results in more consistent and reproducible data and significantly reduces the number of analyses rejected due to Pb loss. This technique is therefore recommended for samples with Pb loss problems or large ranges in zircon age.

BRINGING SOUTHERN ONTARIO'S LOCAL GEOLOGY INTO THE CLASSROOM

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The Covid-19 Pandemic forced us to bring our teaching to our student's homes. Over the past two years, instructors faced immense difficulties, particularly regarding field-based instruction of students. Important hands-on skills such as outcrop investigations, field mapping, rock and thin section description were suddenly virtual. We were forced to reimagine teaching approaches and find ways to integrate local and field-based geology in a virtual classroom setting, while still facilitating active and experiential learning. The new "Virtual Petrographic Atlas of Southern Ontario" is a collaborative project of the University of Toronto and is part of the open access eCampus Virtual Learning Strategy initiative by the Government of Ontario. Our team has collected field data from dozens of classic Southern Ontario geological sites, including 3-D LiDAR scans of outcrops, structural measurements, rock samples, and thin sections. The project created several paid experiential learning opportunities for students to collect and analyze geological data, all of whom are listed as authors on this presentation. This Atlas is a growing virtual resource that offers digital materials on field sites located in Southern Ontario. We continue to add to this resource. Anyone can view the atlas' information and resources in freely accessible Pressbooks, which are linked to the eCampus website. To ensure usability of the resources for student learning assessments, more detailed field site descriptions and materials are withheld from the public site and made available only upon request for instructors. We will present two of the Virtual Atlases: The Central Gneiss Belt and The Central Metasedimentary Belt. The combination of virtual resources, including virtual 3-D outcrop models, hand sample models, images and virtual thin sections via weblinks, allows instructors to design custom assignments and virtual field trips. These free and accessible resources can be easily integrated in any Learning Management System.

SHORELINE GEOMECHANICS AND GEOTOURISM AT HOPEWELL ROCKS PROVINCIAL PARK, NEW BRUNSWICK, CANADA

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Natural shoreline rock formations such as sea stacks, arches, and cliffs are unique geotourism destinations in Canada and globally. These formations, such as at Hopewell Rocks Provincial Park in New Brunswick, Canada, form when the rock-mass erodes and becomes prone to partial or complete structural failure. Many geotourists visiting these formations (> 250,000 per year at Hopewell Rocks) elevate the potential for failure events to cause casualties. Failure events always raise questions about the duration and extent of safety zone delineation and access control. This research aims to evaluate public safety risk of exposure to failure of these rock formations at the park. This research draws on perspectives from rock mechanics, structural geology, and engineering geology to understand the geohazards and their instability behaviours, as well as insight from psychology and sociology that drive geotourism and human risk perceptions. To date, we have investigated two rockfall events at the park: the 14 March 2016 Elephant Rock failure and the 5 September 2021 cliff rockfall near Lover's Arch. The 2016 failure was a partial collapse of the popular Elephant Rock where the "forehead" detached along with a significant part of the seaward face. The 5 September 2021 rockfall occurred in the main cliff and the debris covered a major pedestrian access trail. Luckily, there were no casualties as a result of these two failures. We have also analyzed the stability of the Sentinel sea stack using geomechanical numerical models, with input from UAV-based photogrammetry and erosion records, to predict when this formation may become unstable. Lastly, we conducted a public survey and interviews with park visitors to understand how they value the Hopewell Rocks, and risk perceptions on rock instability. Preliminary data analysis of the survey results (a total of 248 responses) shows support for the idea that New Brunswickers have a strong positive connection to the Hopewell Rocks. In addition, there is a distinct range of risk perception from survey respondents between end-member desires to (i) remove all safety barriers and allow full exploration of the site, and (ii) restrict all close interaction to the formations from a combined perspective of safety and preservation of nature. There were also intermediate responses in support of implementing safety barriers around high-risk areas and safety-based operating hours (e.g. close the Park after significant storms). This presentation will present a summary of these investigations and how future work aims to evaluate risk in geotourism.

CONSTRAINTS ON THE PRE-ERUPTIVE METAL AND VOLATILE CONTENT OF MAGMAS ASSOCIATED WITH ARCHEAN VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS FROM ZIRCON-HOSTED MELT INCLUSIONS

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Archean volcanogenic massive sulphide (VMS) systems in the Abitibi Subprovince of Canada differ greatly in metal tenor, in particular in Au endowment. In this first study of silicate melt inclusions (SMI) in such environments, primary melt inclusions in zircon hosted in pre-, syn-, and post-VMS ore volcanic lithologies will provide compositional constraints on the initial metal and volatile chemistry of the magma before eruption, allowing a comparison of the precursor metal budgets of magmas that actively degassed, and/or were passively leached, to supply metals to the deposits. Primary methodologies in progress include (i) SMI petrography (inclusion and host zircon origin, preservation, accidentally trapped phases, etc.); (ii) SEM-EDS for determination of bulk inclusion compositions on exposed SMI; and (iii) LA-ICP-MS to quantify major/trace element composition of SMI (including metals) and host zircon chemistry. Magmatic zircons from volcanic rocks hosting VMS deposits in the Abitibi Subprovince contain accidentally trapped mineral inclusions (e.g. apatite, biotite, amphibole; 50% of all inclusions), SMI (40%) and sulphide (melt and/or mineral) inclusions (~10%). SMI (up to 35 μm diameter) occur as microcrystalline (recrystallized), and monomineralic to polymineralic. They are composed of quartz, alkali-feldspars, biotite, pyroxene, amphibole, and apatite daughter phases in varying proportions. Sulphide inclusions (1.5–15 μm) are composed of chalcopyrite and/or pyrite, and in some lithologies host zircons bearing inclusions containing silicate melt together with sulphide, indicating sulphide saturation. SEM-EDS data show that bulk inclusion compositions range from sub-alkalic rhyolite to alkalic compositions (trachytic to tephritic); notably this is prevalent within single lithologies indicating that zircons preserve melt aliquots along a variety of possible evolutionary pathways involving fractionation, contamination and/or magma mixing. Preliminary LA-ICP-MS data of SMI from regional volcanic assemblages of different ages, tectonic affinity and metal endowments (e.g. Porcupine, Kidd-Munro) show a large range in alkalinity that is not reported in the literature for the bulk host rocks. Some inclusions have very high Na+K content (up to 9.41 wt.%; trachytic, shoshonitic) content, consistent with SEM-EDS data for homogenized SMI from the same samples. In general, distinct variations in metal contents are recognized within different assemblages. For example, the Zn+Pb contents of SMI from felsic volcanic rocks in the Porcupine assemblage (2690 to 2687 Ma; up to ~2000 ppm) samples are notably higher than in felsic flows from the older Kidd-Munro assemblage (~2718 Ma; < 180 ppm). The Cs and Rb contents are higher, and Sr lower, in the SMI from the Porcupine volcanic rocks, consistent with more evolved melts.

AUTOMATED MINERALOGY USING OPTICAL MICROSCOPY IN A GEOMETALLURGICAL CONTEXT: A PRELIMINARY COMPARATIVE STUDY ON DUMONT-NICKEL PROJECT

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Nickel (Ni) is nowadays one of the critical metals worldwide, particularly in Canada. The Dumont Nickel mine project, located in the Abitibi region of Quebec, intends to become the fourth largest nickel mine in the world once in operation with a 1.028 Mt reserve at 0.27% Ni grade. The Dumont sill which hosts the deposit consists of an ultramafic intrusion which contains a large zone of Ni-bearing metadunite. The partitioning of nickel mineralization seems to be largely controlled by the degree of the serpentinization of a dunite protolith. The metallurgically recoverable Ni in the resource therefore consists of disseminated blebs of pentlandite ($(Ni, Fe)_9S_8$), heazlewoodite (Ni_3S_2) and awaruite ($Ni_{2.5}Fe$) in serpentinized dunite. Nevertheless, the weakly and partially serpentinized portions of the deposit are characterized by higher nickel content in the silicate minerals, which is considered as unrecoverable. The challenge in developing Dumont-type deposits lies in mapping the degree of serpentinization of the sill and the abundances of recoverable phases through a geometallurgical approach. To do so, it becomes essential to propose an affordable and cost-effective mineralogical quantification method to assess the economic value of mineralization. This present study proposes an innovative way to quantify relevant mineralogy for the future mining operation using automated optical microscopy with image analysis. To reach this goal, four samples, which represent the geometallurgical domains of the deposit, have been characterized by two automated mineralogy devices: optical and scanning electron microscope (QEMSCAN©). The modal composition results obtained with the two techniques have then been compared with a focus on Ni deportment within opaque sulphide minerals. These results provide very similar modal composition determinations (less than 5 wt.% opaque mineral difference) and Ni recoverable content (< 0.5% Ni content) between the two devices for the first two geometallurgical domains studied (EXP_440 and EXP_390). The difference of results obtained for the other samples (EXP_498 and EXP_466) has been related to polishing quality, misclassification of optical procedures and/or the difference of mineralogical quantification method between the two devices. These features are being improved through work in progress. This preliminary comparative study has proven the effectiveness of automated optical microscopy for mineralogical quantification purposes as applied to Dumont Nickel Project ores. The ultimate goal of this work is to demonstrate that mineralogical quantification provided by automated optical microscopy and image analysis are feasible for geometallurgical purposes, including mine planning and production grade control, of the future mining operation.

TIME SERIES ANALYSIS FOR TEMPERATURE ANOMALY DETECTION AT THE MACTAQUAC DAM, NEW BRUNSWICK, CANADA

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Seepage monitoring is an important element of dam safety programs. Statistical analyses indicate that 50% of embankment dam failures in the world before 1999 were due to internal erosion. Heat is transported through porous media primarily by conduction and convection, with convection being enhanced in regions with concentrated seepage flow. Thus, heat can be used as a tracer and temperature analysis can be used as a method for seepage detection and monitoring. Mactaquac generating station is a hydroelectric facility completed in 1968 on the Saint John River 20 km upstream of Fredericton, New Brunswick. A fibre optic distributed temperature sensing (DTS) system installed in a 50 m long borehole drilled into the concrete structure that abuts the earth embankment has been used to monitor temperature along the interface between the concrete and the embankment's clay till core at half-hour intervals since 2014. To date, plots of temperature versus elevation along the interface (and its seasonal variation) have been used to identify temperature anomalies. This approach has been effective for identifying more prominent anomalies but does not lend itself to detecting the onset of new ones nor to quantifying changes over time. We have recently started to analyze temperatures as a function of time at selected elevations, using data collected over the past 7 years. Temperature time series in the borehole resembles a sinusoidal cyclic seasonal waveform with an amplitude that decreases with increasing depth. Visual inspections have identified five types of short period anomalies (lasting days to months), occurring at shallow depths (within 5 m of the typical 40 m reservoir elevation), during the colder months between November and May. The first is represented by a step-like increase of temperature over ~0.5 m of borehole from January to April 2019. The second is visualized as a step-like drop in temperature that propagated down the borehole in April or May of three years at a rate of 0.04 m/day. A more oscillatory anomaly, propagating uphole much faster (~3.1 m/day) was also observed. The fourth and fifth anomalies are short (typically 5 day) pulse-like rises or falls in temperature with amplitudes up to 0.6°C. They appear simultaneously across a wide range of depths and are either unipolar or bipolar (i.e. having depth dependent polarity). The time-depth behaviour of these anomalies offers clues to their possible origins, which could include transient water flow near or into the borehole associated with fracture development in the concrete.

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INITIATING TRANSFORMATIVE GEOSCIENCE PRACTICE AT THE GEOLOGICAL SURVEY OF CANADA: CANADA IN 3-D

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Application of 3-D technologies to the wide range of knowledge domains in Geosciences is well underway. These have been operationalized in the workflows of the hydrocarbon sector for a half-century, and now in mining for over two decades. In Geosciences, algorithms, structured workflows, and data integration strategies can support compelling Earth models, however challenges remain to meet the standards of geological plausibility required for most geoscientific studies. There are also missing links in the institutional information infrastructure to support operational multi-scale 3-D data and model development. Canada in 3-D (C3D) a vision and road map for transforming the Geological Survey of Canada's (GSC) work practice by leveraging emerging 3-D technologies. Primarily the transformation from 2-D geological mapping, to a well-structured 3-D modelling practice that is both data-driven and knowledge-driven. It is tempting to imagine that advanced 3-D computational methods, coupled with artificial intelligence and big data tools will automate the bulk of this process. To effectively apply these methods there is a need, however, for data to be in a well-organized, classified, georeferenced (3-D) format embedded with key information, such as spatial-temporal relations, and earth process knowledge. An additional key challenge for C3D is the relative infancy of 3-D geoscience technologies for geological inference and 3-D modelling using sparse and heterogeneous regional geoscience information, while preserving the insights and expertise of geoscientists maintaining scientific integrity of digital products. In most geological surveys, there remains considerable educational and operational challenges to achieve this balance of digital automation and expert knowledge. Emerging from the last two decades of research are more efficient workflows, transitioning from cumbersome, explicit (manual) to reproducible implicit semi-automated methods. They are characterized by integrated and iterative, forward and reverse geophysical modelling, coupled with stratigraphic and structural approaches. The full impact of research and development with these 3-D tools, geophysical-geological integration and simulation approaches is perhaps unpredictable, but the expectation is that they will produce predictive, instructive models of Canada's geology that will be used to educate, prioritize and influence sustainable policy for stewarding our natural resources. On the horizon are 3-D geological modelling methods spanning the gulf between frontier or green-fields and deep crustal characterization. These are key components of mineral systems understanding, integrated and coupled hydrological modelling and energy transition applications, e.g. carbon sequestration, in-situ hydrogen mining, and geothermal exploration. Presented are some case study examples at a range of scales from our efforts in C3D.

GEOTHERMAL POTENTIAL OF NEW BRUNSWICK: IS THERE A SALT CHIMNEY EFFECT?

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The goal of geothermal energy is a clean source of reliable electricity which can provide energy security and reduce CO_2 emissions. The economical application of geothermal electricity requires sufficiently elevated subsurface thermal gradients to minimize costs associated with industrial development and production. Recently, there has been renewed attention to evaluating the potential for sedimentary basin geothermal production in Atlantic Canada, and subsurface thermal-gradient contour maps have recently been updated for the southeastern half of New Brunswick. These updated maps show a low-potential provincial average geothermal gradient of around 20°C/km, but areas of anomalously high thermal gradients are mapped in areas with known subsurface Mississippian (Carboniferous) evaporites of the Gautreau Formation and the Windsor Group. Where subsurface thermal gradients appear most prospective, exceeding 30°C/km, their values were further assessed for their validity. This work utilized thermal conductivity (k) of the units experimentally determined, using southeastern New Brunswick rock samples of different lithologies and reported in earlier work. Adjusted geothermal gradients were constructed for 20 boreholes, accounting for temperatures at lithostratigraphic unit contact points. These temperatures were calculated using the equations T1 = - [(q × L1 / k1 × A) - Ti] for the lower-most contact T1, and for all remaining contacts Tx = - [(q × Rx) - T1)], where q is heat flow through the stratigraphic column, L is unit thickness, A is a cross-sectional area of the units taken as a constant, and Ti is the bottom-hole temperature (BHT). The adjusted geothermal gradients, taking lithologies into account, were plotted against the provincial average gradient down to 4 km. Preliminary findings suggest some evidence for thermal conduction and possible "salt chimneys" in the Windsor Group halite where geothermal gradients are below 25°C/km. However, the halite-bearing wells with gradients above 30°C/km have reported BHTs which appear excessively elevated compared to provincial background temperatures. To reconcile with the regional thermal gradient at greater depth would require very thermally conductive rocks beneath the halite, which are not supported by the most likely underlying sandstone and mudstone stratigraphies of the Sussex and Horton groups. This may indicate problematic recording of BHTs in several of the original drilling reports that were not filtered out when compiling the updated geothermal map.

FOSTERING A DIVERSE AND INTEGRATED WORKFORCE IN GOVERNMENT GEOSCIENCE

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The Geological Survey of Canada, with a current workforce of over 400 individuals, is a major government employer of geoscientists in Canada. Almost 40% of these employees are research scientists, and another 45% fill other technical and scientific roles. Demographically, 40% of our staff will be eligible to retire within 5 years. This creates both a challenge and an opportunity as we look to rejuvenate our workforce. The value of incorporating different views, ideas and approaches to achieving research excellence is well-recognized, but the path to achieving this is not always clear. Equity, diversity and inclusion (EDI) are a big priority in the federal public service, to ensure that the needs of a diverse Canadian population are effectively represented in the public service. This past year has seen the launch of several initiatives aimed at creating the workforce of the future. These include proactive staffing measures, with targeted recruitment from under-represented groups; self-identification opportunities to accurately reflect the current workforce; and workplace measures that embrace inclusivity. Many other organizations, including industry, will be competing for members of the same talent pools, and organizations will benefit from proactive approaches to recruitment and hiring. The Pan-Canadian Geoscience Strategy (PGS), launched earlier this year, brings together the federal, provincial and territorial geological surveys through enhanced collaboration in order to address challenges of common interest. These include setting goals for growing the next generation of geoscientists, addressing the challenges related to EDI, and identifying opportunities for developing next generation skill sets and hiring.

USING MINERAL CHEMISTRY FOR CHARACTERIZING THE NATURE AND EVOLUTION OF AN IOCG SYSTEM

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Iron oxide-copper-gold (IOCG) deposits are globally important sources of Cu, Au, and critical commodities, including U, Co, and REE that are essential to sustain a carbon-neutral society. Despite their relevance, IOCG deposits remain an ill-defined clan, with a range of characteristics that has complicated development of the general genetic model needed to guide exploration for new deposits. Herein we focus on the use of mineral chemistry for characterizing the nature of the Candelaria IOCG deposit, looking into its hydrothermal fluid source(s) and temporal evolution. We use the mineral pyrite and evaluated in-situ chemical and isotopic variations at the grain scale in a set of samples collected throughout the Candelaria-Punta del Cobre district, integrating synchrotron micro-X-ray fluorescence, electron microprobe analysis, laser ablation ICP-MS, and secondary ion mass spectrometry. We also used, for the first time, the mineral actinolite – a ubiquitous alteration phase in IOCG

deposits—for temperature estimation at the mineral scale. We constructed novel grain-scale temperature images by computationally inverting compositional data from X-ray wavelength dispersive spectrometry (WDS) maps. This technique allowed visualization of inferred temperature gradients at a micro-scale within individual actinolite grains. Results show that Candelaria formed by a magmatic hydrothermal fluid, and by the superposition of at least two mineralization events with a late Cu-rich fluid (~550–700°C) overprinting an early, iron oxide-apatite (IOA) type mineralization event (675–800°C). These distinct events were caused by episodic injections of magmatic-hydrothermal fluids from crystallizing magmas at depth. Our data provide the first empirical evidence of grain scale temperature gradients in an IOCG system, and supports the use of mineral chemistry as a proxy for understanding the formation and evolution of IOCG systems.

DEVELOPMENT OF GEOENVIRONMENTAL MODELS IN EARLY MINE LIFE PHASES TO PROMOTE RESPONSIBLE MINE WASTE MANAGEMENT

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Mine waste management is a sensitive issue associated with mining operations. Due to the large volume of waste produced, and its mineralogical, chemical and hydrogeological properties, environmental risks can arise during mine operations and after decommissioning. The most common environmental issue related to mine waste is acid mine drainage generation (AMD), but metal leaching (ML) in neutral drainage is also worrisome. Engineers and geoscientists have access to different tools to identify and predict these environmental risks, such as static and kinetic tests for AMD assessment. However, these tools can require significant amounts of mine waste, several hundreds of grams to several kilograms, which are not available at the early stages of a mining project. Indeed, environmental assessments are required before mine construction, when waste rock and tailings samples are not readily available. Geoenvironmental modelling has been recently developed to bridge the gap between exploration data and environmental assessments, and can be further expanded to model waste rock and tailings management scenarios. Inspired by the geometallurgical concepts of domains and variability, geoenvironmental modelling can help to piece together the puzzle of environmental behaviour prediction at different steps of the mine life cycle. This presentation showcases a four-step geoenvironmental characterization protocol developed by Vermette 2018, which identifies the type of information that can be gathered from exploration data to inform the prediction of AMD and ML risks from mine waste. For each step of the protocol, case studies [most from the Research Institute on Mines and the Environment (RIME) research group at Université du Québec en Abitibi-Témiscamingue (UQAT)] are provided to illustrate the application level and type of information that is produced. The first stage is a preliminary environmental risk assessment based on rapid and non-destructive tests and observations of drill core samples. Both non-invasive techniques and database interpretation methods are presented. The second stage involves the definition of geoenvironmental domains and typical AMD tests required for prefeasibility purposes. The third stage corresponds to more detailed geochemical behaviour assessments, from which waste management options can be investigated. The final stage of the geoenvironmental characterization protocol involves a spatial visualization of the environmental attributes of the orebody and hydrogeochemical modelling of the resulting waste rock and tailings under different management scenarios, from typical storage in waste rock piles and tailings storage facilities to more complex co-disposal options. Finally, advantages and limitations of geoenvironmental modelling are presented.

HYDROTHERMAL ALTERATION AND REPLACEMENT-STYLE MINERALIZATION IN THE ABM DEPOSIT, FINLAYSON LAKE VMS DISTRICT, YUKON, CANADA

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The ABM deposit is a bimodal-felsic, replacement-style volcanogenic massive sulphide (VMS) deposit (19.1 Mt grading @ 6.6 wt.% Zn, 0.9 wt.% Cu, 2.0 wt.% Pb, 1.4 g/t Au and 156 g/t Ag) that is hosted by back-arc affinity rocks of the Yukon-Tanana terrane in the Finlayson Lake VMS district, Yukon, Canada. Massive sulphide mineralization in the ABM deposit sits immediately below the contact between two felsic sequences with distinctly different geochemical signatures. The contact is marked by a continuous argillite layer that is interpreted to represent a period of volcanic quiescence during which mineralization likely precipitated. The massive sulphide mineralization occurs as a series of stacked and stratabound lenses that are subparallel to the stratigraphy and dip shallowly (20–30°) to the NNE. The massive sulphide lenses have sharp contacts and are surrounded by pervasive sericite and/or chlorite alteration both in the hanging wall and footwall. Remnant clasts and preserved bedding occur within the massive sulphide lenses and indicate that mineralization formed through replacement of pre-existing strata below the seafloor. Mineral chemistry of phyllosilicates (white mica, chlorite) is more Mg-rich proximal to massive sulphide mineralization, and illite-chlorite thermometry indicates elevated precipitation temperatures proximal to the core of the deposit. The widespread moderate sericite ± chlorite assemblage records temperatures ~215 ± 15°C, pervasive sericite assemblage surrounding the mineralization records temperatures ~250 ± 15°C, and pervasive chlorite assemblage associated with the mineralization records temperatures ~350 ± 50°C. These alteration temperature relationships and association of pervasive alteration assemblages with mineralization suggest mineralization was deposited during peak hydrothermal fluid temperatures. Massive sulphides present in the ABM deposit occurs in two major assemblages. The first assemblage comprises the core of the ABM deposit and consists of pyrite-pyrrhotite-magnetite-chalcopyrite-sphalerite with minor Ag-rich tetrahedrite, Se-rich galena, and trace clausthalite and Bi- and Sb-rich minerals, with chlorite and carbonate as gangue. The second assemblage surrounds the first assemblage at the core of mineralization and comprises pyrite-sphalerite-galena (Se-poor) with lesser chalcopyrite, arsenopyrite, tennantite-tetrahedrite, and trace Sb-As-rich minerals, and contains carbonate, barite, quartz, and white mica as gangue minerals. Microanalytical work is ongoing to understand the origins of mineralization, physiochemical conditions of formation, and sources of Pb and S involved in their genesis.

JURASSIC AND CRETACEOUS BOTTOM-CURRENT RECORD ALONG THE SCOTIAN MARGIN, AND POTENTIAL IMPACTS ON THE DISTRIBUTION AND STYLE OF DEEP-WATER RESERVOIRS

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The onset and evolution of bottom-current-related features provide important information about the development of newly-minted continental margins and of ocean circulation pathways, as connections between different water masses are made and broken. Reflection seismic datasets off New England and Nova Scotia reveal the important role bottom-currents played in shaping Cretaceous and, to a lesser extent, Jurassic sediments. Recent wells improve age-control for post-Bajocian strata along the western Scotian Slope, and 3-D seismic volumes provide higher-confidence linkage to the lower slope. In this study, we seek to understand the temporal and spatial distribution of seismic-scale bottom-current indicators on the shelf to the abyssal plain, and to better understand their potential impact on deep-water reservoirs. Jurassic strata seaward of the primary salt basin off SW Nova Scotia record the earliest evidence for the persistent action of bottom-currents. Here, layer-cake strata above seaward-dipping reflections (SDRs), give way to shingled reflections and up-slope migrating sediment waves in Bathonian to Tithonian strata. They are limited to the area southwest of a system of strike-slip faults that define the northeast limit of well-developed SDRs. The absence of Jurassic bottom current indicators farther north could indicate these deposits are products of an early circulation gyre off the northeastern United States that had not yet propagated northward. Lower Cretaceous (Berriasian to Valanginian?) bottom-current indicators are widely absent across the study area. Hauterivian(?) to Campanian sediment waves, erosive scours, thick aggradational mounded drifts flanked by erosive moats, and very large unidirectionally-migrating channel-levee systems, mark the return of bottom currents along the lower slope and abyssal plain. We document four large hybrid contourite-turbidite channel-levee systems, each with 25 to 45 km wide channel belts (potentially sand-prone) that formed gradually as narrower channel-axes migrated to

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the NE, flanked by highly asymmetric, mud-prone levees. They were fed by a converging dendritic network of narrower 4–10 km wide U-shaped channel systems flanked by asymmetric overbank deposits. Like the more distal accumulations, the axes of these U-shaped channels and their flanking deposits migrated exclusively towards the NE, resembling stacked sediment waves on strike-oriented profiles. Their unidirectional migration is interpreted to reflect the persistent action of SW-flowing bottom currents, with periodic interruptions from down-slope turbidity currents and mass transport deposits. We show that sand distribution on the slope, including within salt-withdrawal minibasins, is strongly controlled by the relief and morphology of depositional bottom current indicators like mounded drifts, particularly in Aptian to Campanian deep-water strata.

THE 'M-MARKER' ALONG THE CENTRAL AND WESTERN SCOTIAN MARGIN – IS IT A REFLECTION MOHO?

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Deep crustal seismic reflection markers are recognized along most passive margins, and are variously interpreted as reflections from the crust-mantle interface, top of lower-crustal bodies, lithospheric shear zones, or intra-mantle serpentinization fronts. The M-marker is a moderate- to high-amplitude coherent deep crustal reflection, or top marker in a series of reflections, originally recognized in the 1990s on Lithoprobe profile 88-1/1A beneath Nova Scotia's central Scotian Shelf and Slope. In this study, we aim to document its regional distribution, look at variations in its character, and test its origin. The M-marker is widely distributed across the central and western Scotian margin. Its travel-time-depth varies between 8 and 12 sec (twt). It has been imaged and correlated through an extensive grid of 2-D reflection seismic profiles and three large 3-D seismic volumes – over an area covering > 62,000 km^2. It is most clearly recognized in two domains: (i) landward, beneath necked continental crust; and (ii) in the distal domain seaward of the primary salt basin, where it underlies seaward-dipping reflections (SDRs). The marker is less clearly defined where complex salt bodies ranging from tall stocks to salt sheets overlie the crust. In depth, it is shallowest beneath landward parts of the primary salt basin, forming a complex elevated region with distinct right-stepping segments. We use a combined 3-D gravity and inversion technique to independently determine Moho depth (MGI) and compare it with the M-marker. MGI matches well with the landward and seaward parts of the M-marker, suggesting that the M-marker corresponds to a reflection Moho beneath continental and oceanic crust, respectively. However, MGI is significantly deeper than the M-marker beneath the landward parts of the primary salt basin. The discrepancy suggests that the lithosphere beneath the M-marker here comprises lower density material than unaltered mantle. Interestingly, both the shape and distribution of the mismatch coincide closely with the negative magnetic anomaly located immediately landward of the ECMA. It also coincides with an apparent seaward change from decoupled crust, with clear middle-crustal shear zones separating brittle and ductile components, to coupled crust lacking vertical changes in its reflection seismic character. We explore a number of potential explanations for these observations, but conclude that the M-marker probably forms two separate, but overlapping, surfaces. ML corresponds to a landward continental Moho; MS corresponds to the seaward oceanic Moho. Where these surfaces overlap beneath the primary salt basin, MGI follows the deeper MS marker, which rapidly loses reflection coherence.

THE ROLE OF IUGS-IFG IN THE GLOBAL ADVANCEMENT OF FORENSIC GEOLOGY AND A REVIEW OF PROVENANCE DETERMINATION METHODS FOR THE TRACKING OF MINERALS AND METALS IN THE GLOBAL SUPPLY CHAIN

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The International Union of Geological Sciences (IUGS), Initiative on Forensic Geology (IFG) was established to promote and advance the applications of geology to help solve crimes as part of police and law enforcement investigations. This paper provides an overview of the advancements made in the past decade including: (a) geological crime scene examination, (b) the collection and analysis of geological trace evidence, (c) ground searches for burials associated with homicide, organized crime and counter-terrorism. In particular, there is a focus on search and the presentation of the Geoforensic Search Strategy (GSS). This was developed over a period of 25 years by blending conventional law enforcement search methods with geological exploration and ground investigation approaches. The new and innovative search strategy that resulted is particularly applicable to open areas searches and cold case searches. The paper also provides a review of the methods and techniques for the tracking of minerals and precious metals in the global supply chain. This may be required to deter or detect the illegal trafficking, theft and trade in minerals and metals, which is reported in some parts of the world. A distinction is provided on those methods that are potentially commercially applicable, such as the use of mineral profiling and isotope profiling and those methods that are in the early stages of research and development, such as the use of microtaggant identification practices (MIP). Operational case studies are provided throughout, where applicable, although for some these have been anonymized.

POST-OLIGOCENE EVOLUTION OF SLOPE CANYON-CHANNEL SYSTEMS OFFSHORE NORTHERN TANZANIA (WESTERN INDIAN OCEAN): A TAPE RECORDER FOR THE TECTONIC HISTORY OF PEMBA AND ZANZIBAR ISLANDS

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The Tanzania margin is dissected by the islands of Pemba and Zanzibar, which represent unusual structures for a passive margin. Their stratigraphic and tectonic history have long attracted the interest of the scientific community, yet their formation is still a matter of debate. The lack of high-quality seismic data in this sector of the west Somali basin has so far represented the main challenge for a better understanding of the margin. In this study, we use 2-D seismic reflection profiles recently acquired for O&G exploration to generate "pseudo-3-D" reconstructions of the pathways of slope canyon-channel systems from the Oligocene to present day, using chronological constraints from five exploration wells. Our results indicate a net decrease in the number of slope canyon-channel systems during the Mid-Late Miocene which is interpreted to reflect the onset of the uplift of Pemba Island. Tectonically driven seafloor deformation, caused by the extensional regime established since Early Miocene (which is still ongoing), reduced sediment supply to the lower slope, progressively disconnecting turbidite channels from their feeding systems. Offshore Zanzibar, which is located ~35 km south of Pemba, slope channels were still active at that time, thus indicating that the uplift of this island occurred later.

Well-to-seismic tie of key horizons confirmed that the uplift of Zanzibar started in the Late Miocene–Early Pliocene. Furthermore, the reorganization of the slope physiography promoted the formation of two newly discovered giant canyons that represent the main source of sediments for this sector of the western Indian Ocean during the last 30 Myr. Supported by these results, which show how changes in submarine drainage network acted as a tape recorder for the different tectonic events leading to the formation of the islands, we proposed a new conceptual model for the post-Oligocene stratigraphic evolution of the northern Tanzania margin that also contemplates a potential relationship between the islands and the East African Rift System.

GEOCHEMICAL CHARACTERIZATION OF QUARTZ VEINS FROM THE BALLS LAKE FORMATION OF THE MARITIMES BASIN, SAINT JOHN AREA, NEW BRUNSWICK, CANADA

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Quartz veins are important harbingers of fluid chemistry in tectonically active systems. Importantly, we can use the geochemistry of quartz veins to not only evaluate the sources of the fluids that led to vein formation but also provide some insight into the various generations of veins based upon similarities in their geochemical signatures. We performed laser-ablation inductively coupled plasma-mass spectrometry on one-inch diameter epoxy specimen pucks to evaluate the composition of various quartz veins from outcrops of the Carboniferous Balls Lake Formation near Saint John, New Brunswick. The present-day location of Mispec Beach, New Brunswick occurs in the Pennsylvanian Balls Lake Formation of the northern Appalachians with the formation of extensive quartz veins representing a component of a transpressive flower structure that formed at the termination of the Cobequid-Chedabucto Fault following an Appalachian (northeast-southwest) trend through the Maritimes Basin. The samples analyzed in this study were collected from two locations: Mispec Beach and the Fundy Sand and Gravel Quarry. The Mispec Beach veins follow a northeast-dipping cleavage with pronounced crenulation overlaying a shallow south-dipping cleavage. In contrast, the Fundy Quarry veins show transition of thrust trends at the approach of the Baxter Mountain Fault running southeast-northwest, represented as reverse faults dipping 10–15° southeast. Our results demonstrate multiple compositionally distinct sources that can be paired with cross-cutting relationships. Coupling between aluminum and lithium concentrations also allows for relative determination of fluid pressure which in turn control crystal growth rate. In the absence of cross-cutting relationships, these compositional groups can assist in providing a relative temporal framework for understanding the fracturing patterns and fluid systems that occurred during and after Appalachian orogenesis. This protocol can be applied to other units in southern New Brunswick such as the Tournaisian Albert Formation that have suffered several phases of tectonism and veining events throughout the Carboniferous.

AN EXPERIMENTAL STUDY OF THE EFFECT OF PRESSURE ON THE FORMATION OF CHROMITE DEPOSITS

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Despite extensive research on Bushveld Complex chromitites, the mechanism(s) that form such anomalous chromite segregations remains uncertain. Recent work applying the MELTS thermodynamic model proposed that reduction of pressure upon magma ascent shifts the silicate-in temperature to lower values, with the chromite-in temperature remaining unchanged, resulting in chromite-alone crystallization and formation of massive chromitites. We are evaluating this hypothesis through laboratory phase equilibrium experiments conducted at 0.1 MPa, 0.5 GPa, and 1 GPa, employing two bulk compositions. Composition 1 (C1) corresponds to a widely accepted parental magma of Bushveld chromitites, termed B1. Composition 2 (C2) is the same used in the MELTS modelling study, which contrasts with C1 most significantly in Al_2O_3 (17.4 wt.% vs 11.8 wt.% in C1), MgO (6.7 wt.% vs 11.9 wt.% in C1), and Cr (680 μg/g vs 970 μg/g in C1) contents. Experiments were conducted at 0.1 MPa by equilibrating synthetic starting materials on Fe-Ir alloy wire loops over the temperature interval of 1170–1300°C in a vertical-tube, gas-mixing furnace for 12–48 hours, at FMQ and FMQ-0.4. Experiments at 0.5 GPa and 1 GPa were conducted with a piston-cylinder apparatus using Fe-Ir alloy capsules to buffer $f(O_2)$ at FMQ-0.4 at 1230°C and 1280°C for 4–12 hours. Results indicate that there is no significant change in Cr content of the melt at chromite saturation with pressure. For C1, the average Cr content of the melt over the pressure interval studied is 439 ± 22 μg/g at 1230°C and 799 ± 100 μg/g at 1280°C. The average Cr content for C2 is 417 ± 17 μg/g at 1230°C and 704 ± 48 μg/g at 1280°C. Results from C1, where pyroxene crystallizes at all pressures, show modal abundance and Cr content of pyroxene increasing with rising pressure. Using pressure and temperature trends for Cr content at chromite saturation and $D_{Cr(px/liq)}$ from experiments, chromite-in temperatures were modelled for different total Cr contents in the melt. Chromite-alone crystallization between 0.1–0.3 GPa occurs in C1 only for above average total Cr levels for this composition (> 1100 μg/g). In C2, results predict a higher chromite-in temperature and therefore, larger interval of chromite-alone crystallization at low pressure compared to MELTS. For the same total Cr content as the initial MELTS model, our results show that chromite is dropped from the C2 assemblage above 0.5 GPa due to appearance of pyroxene, which differs from MELTS as Cr is not included in their pyroxene model.

A RECORD OF BRITTLE-DUCTILE DEFORMATION AND HYDROTHERMAL ALTERATION ASSOCIATED WITH ARCHEAN TRANSPRESSION IN GRANITOID PLUTONS OF THE WABIGOON SUBPROVINCE, SUPERIOR PROVINCE

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The microstructure and macrostructure of twelve granitoid plutons within the Wabigoon subprovince of the Superior Province demonstrate evidence for coeval brittle-ductile deformation in the amphibolite facies of metamorphism consistent with regional scale Archean transpression, with brittle shear fracturing and alteration likely continuing into exhumation. Each pluton records evidence of amphibolite facies metamorphism through solid-state dislocation creep textures within quartz and feldspars. Feldspars have undulose extinction, subgrains, serrated grain boundaries, intragranular microfractures and deformation twins. Evidence for dislocation creep in feldspars indicates that the metamorphic grade is consistent with the onset of amphibolite facies metamorphism. Brittle deformation features common to all plutons include chlorite ± epidote infilled shear fractures that show a conjugate strike-slip relationship in the field with dips ranging from 15° to 90° and an average and median dip of 70° ± 10° for each pluton. Infilled shear fractures are commonly seen with sub-horizontal slickenlines with pitches ranging from 00° to 33°, highlighting an oblique strike-slip displacement. Although a conjugate strike-slip relationship is noted in the field, the strikes of the shear fractures across outcrops and plutons are variable, possibly as a result of non-coaxial strain in which the rigid and competent granitoid plutons have undergone a component of rigid body rotation, resulting in a shifting trend of the maximum elongation direction. Six of the twelve plutons show evidence for ongoing brittle deformation during regional amphibolite facies metamorphism in the form of ductilely overprinted tensile quartz veins and/or the presence of chlorite ± epidote infilled shear fractures within ductile shear zones. The alteration of the plutons is directly related to brittle fracturing, with alteration minerals such as chlorite, epidote, biotite, white mica, titanite, calcite and hematite. The degree of alteration is most notable near the margins of the plutons where strain is concentrated. The δD_{fluid} and $\delta^{18}O_{fluid}$ values of the hydrothermal fluid calculated from measured δD and $\delta^{18}O$ values of six chlorite infilled shear fractures in two plutons range from -30 to -45‰ and 5.6 to 7.1‰, respectively, recording a metamorphic water signature that likely stems from the devolatilization of the surrounding greenstone during regional Archean metamorphism.

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NANOGEOLOGY: A NEW APPROACH TO DECODING THE SECRETS OF THE EARTH

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Correlative analytical approaches involving high-spatial resolution microscopy techniques allow for the compositional measurements and spatial imaging of materials at the near-atomic scale. By combining electron backscatter diffraction (EBSD) mapping, electron channeling contrast imaging (ECCI), scanning transmission electron microscopy (STEM) and atom probe tomography (APT) on various geological materials such as minerals and glasses, we have successfully documented element mobility regulated by structural defects. Although these techniques were initially developed in the materials sciences, they are now being applied to a broad range of applications within many subdisciplines of geosciences including geochemistry, geochronology, and economic geology. In one set of experiments, we applied a correlative approach on naturally deformed pyrite from an orogenic gold mine in northern Canada to assess the impact of crystal-plastic deformation on the remobilization of trace elements. This study has led us to propose a new paragenetic model for metallic ore deposits in which deformation creates nanostructures that act as traps for base and precious metals. By applying our approach on pyrite that is rich with fluid inclusions, we have also documented two processes that led to proposing a new fluid inclusion-induced hardening model, which is in contrast to the more commonly reported weakening effect of fluids on minerals. To broaden the applications of our approach, we have applied the same suite of analytical techniques to a synthetic andesitic glass to assess whether nanoscale chemical heterogeneities can act as nucleation sites for gas bubbles. The combined results demonstrate the existence of nanoscale chemical heterogeneities within the melt and at the bubble-melt interface supporting the hypothesis that homogeneous nucleation could in fact be a variety of heterogeneous nucleation. The interactions between trace elements and structural defects plays a vital role in determining the mechanical properties of minerals, particularly in fluid-rich environments. These sub-nanometre scale exchanges consequently control meso- to tectonic-scale geological processes. Our research work not only demonstrates the latest advancements in analytical microscopy resolving long-standing geological problems but also brings us closer to bridging the gap between the fields of materials sciences and geosciences.

THE ORIGIN OF PYRITE-SPHALERITE BANDING IN METAMORPHOSED VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS

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Volcanogenic massive sulphide (VMS) deposits are commonly metamorphosed to greenschist or amphibolite facies conditions after their formation and can exhibit mm to cm thick pyrite-sphalerite banding within the (semi-)massive sulphide lens. The origin of this banding is commonly assumed to be epigenetic, forming as a result of metamorphic remobilization and recrystallization. However, processes resulting in this banding and excluding a syngenetic origin have not been investigated yet. Here we present detailed textural, microstructural and compositional results from pyrite-sphalerite bands in massive sulphide lenses from six VMS deposits metamorphosed to greenschist to lower amphibolite facies: Kidd Creek, ON; Flin Flon, MB; Kristineberg, SWE; LaRonde-Penna, QC; Ming, NL; Mount Morgan, AUS. Textural observations show that pyrite occurs in various textures in these massive sulphide lenses including: (1) as disseminated, subhedral, recrystallized grains with concave grain boundaries within massive sphalerite (i.e. caries texture); (2) as annealed aggregates of several mm to cm thickness forming triple junctions with neighboring pyrite grains; and, albeit minor, (3) as subhedral grains overgrowing a primary, inclusion-rich pyrite core. The microstructure of pyrite in these textures is analyzed using electron-back scattered diffraction. Misorientation angles between pyrite grains in annealed aggregates (texture 2) show a narrow range of 35–45° and the absence of (creep or climb) dislocations within grains that are commonly developed at higher metamorphic facies. Electron microprobe analyses on pyrite and sphalerite from textures (1) and (2) show a wide range of FeS content in sphalerite between locations (LaRonde and Ming: < 5 mol% FeS; Flin Flon and La Ronde: 5.50–7.5 mol% FeS; Kid Creek: > 10 mol% FeS) displaying original redox fluid compositions. Rim-core analyses of neighboring pyrite and sphalerite grains show increasing concentrations of Zn and Fe towards the rim of pyrite and sphalerite, respectively. Microtextural, microstructural and compositional results indicate that pyrite-sphalerite bands formed as result of greenschist to amphibolite facies metamorphism in which pyrite recrystallized and aligned within a preferred direction in anhedral sphalerite. Although, original fluid conditions were responsible for sphalerite and pyrite formation, metamorphism caused chemical diffusion of Fe and Zn between both phases. Therefore, metamorphism and deformation caused the formation of pyrite-sphalerite bands in the studied locations due to physical (recrystallization) and chemical processes (remobilization).

DISTRIBUTION OF VISEAN EVAPORITE ROCKS BENEATH THE GULF OF ST. LAWRENCE, EASTERN CANADA

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Visean evaporite rocks, in association with relatively thin but laterally continuous marine carbonate rocks, record numerous transgressive-regressive (TR) cycles in eastern Canada. Cyclic repetitions of limestone, anhydrite, halite and variable thickness of redbeds provide repeated density and velocity contrasts on a vertical scale of tens (exceptionally hundreds) of metres. The manifestation of these cycles on seismic reflection data was studied through the calculation of synthetic seismograms (synthetics) from deep petroleum wells, borehole data and measured stratigraphic sections from key onshore areas. Analysis of the synthetics, in concert with an extensive grid of offshore 2-D seismic reflection data, facilitates the development of seismic facies that can be mapped over large areas beneath the Gulf of St. Lawrence. The Visean rocks, assigned to the Windsor and Codroy groups, can be subdivided into lower, middle and upper seismic units. The lower seismic unit comprises high amplitude basal reflections, which correspond to limestone and overlying anhydrite. These are overlain by a variable thickness of chaotic reflections interpreted as halite; locally, the halite is overlain by fine-grained clastic rocks. The middle unit generally consists of 3 to 5 high-amplitude reflections representing as many as 15 TR cycles. The upper seismic unit varies from high-amplitude to low-amplitude seismic facies, which are interpreted as evaporite and clastic dominated TR cycles, respectively. Seismic facies maps provide context for the distribution of onshore Visean rocks. Carbonate beds can be correlated hundreds of kilometres onshore between seemingly disparate structural sub-basins. Consideration of onshore lithostratigraphy with offshore seismic facies may aid in the reconstruction of Visean paleogeography in the Maritimes Basin. For example, juxtaposition of interpreted similar facies across the Cobequid-Chedabucto Fault may be used to construct a Late Visean palinspastic map.

THE ROLE OF MAGMA DYNAMICS IN THE CONCENTRATION OF GRANITE-HOSTED CRITICAL METALS

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High-silica (> 70 wt.% SiO_2) granites are critical carriers of Sn, Cu, and other incompatible elements. Despite the significant role that high-silica granite formation has played in the chemical evolution of the crust, much remains unknown about the mechanisms responsible for its formation. One of the remaining questions is the apparent lack of evidence for crystal-melt segregation (e.g. modal layering), without which little can be inferred about the dynamics (or lack thereof) of crystallizing high-silicas granites. Here, I examine the crystallographic orientation relationships of clustered quartz crystals from the 300 m-thick Bobbenjaankop sill, Bushveld Complex. There is a marked inwards increase in both the frequency and size of quartz clusters towards the central horizon of the sill, coinciding with a significant increase in concentrations of Sn, Cu, and W. The majority of crystal pairs within each cluster not only involve similar sized grains, but exhibit coincident site lattice orientation relationships, representing low grain-boundary energy configurations. These clusters must have formed by synneusis in a magmatic environment where crystals could have moved freely, rotating into low-energy orientations on contact. I argue that this not only demonstrates that 100 m-scale crystal-poor and liquid-rich regions can be present in bodies of high-silica granite, but also that such bodies can undergo long-

lived convection during crystallization, driven by downwards movement of crystal-rich plumes at the roof, without significant crystal-melt segregation. This dynamic behaviour provides a mechanism to homogenize major element distribution across highly silicic plutons and to concentrate highly incompatible and economic elements into central mineralized horizons.

THE EFFECT OF CORE FORMATION ON SURFACE COMPOSITION AND PLANETARY HABITABILITY

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The melt productivity of a differentiated planet's mantle is primarily controlled by its iron content, which is itself approximated by the planet's core mass fraction (CMF). Here we show that estimates of an exo-planet's CMF allow robust predictions of the thickness, composition and mineralogy of the derivative crust. These predicted crustal compositions allow constraints to be placed on volatile cycling between the surface and the deep planetary interior, with implications for the evolution of habitable planetary surfaces. Planets with large, terrestrial-like, CMFs ($\geq$ 0.32) will exhibit thin crusts that are inefficient at transporting surface water and other volatiles into the underlying mantle. By contrast, rocky planets with smaller CMFs ($\leq$ 0.24) and higher, Mars-like, mantle iron contents will develop thick crusts capable of stabilizing hydrous minerals, which can effectively sequester volatiles into planetary interiors and act to remove surface water over timescales relevant to evolution. The extent of core formation has profound consequences for the subsequent planetary surface environment and may provide additional constraints in the hunt for habitable, Earth-like exo-planets.

IS ZIRCON IN EQUILIBRIUM DURING METAMORPHISM?

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Trace element concentrations in metamorphic zircon are frequently used to determine the timing of zircon formation relative to other metamorphic minerals such as garnet. Heavy rare earth elements are used as a proxy for the presence of garnet and europium anomalies are commonly used to infer if plagioclase was part of the peak metamorphic assemblage. Linking trace element compositions of zircon to the major mineral assemblage operates under the assumption that zircon is in equilibrium with other minerals in the system. The limited data available on matrix diffusion rates of rare earth elements under subsolidus conditions restricts the applications of these zircon analyses. Zircon-rich granulite facies metamonzogranite from the Muskoka Domain in the Grenville Province presents a unique opportunity to evaluate the extent of equilibrium of zircon in sub-solidus metamorphic rocks. The sample contains a mineral assemblage of plagioclase + alkali feldspar + quartz + clinopyroxene + garnet + magnetite + ilmenite + amphibole + zircon. We present in situ LA-ICP-MS analyses of metamorphic zircon and other metamorphic minerals present in the rock to show how proximity to other minerals affects the trace element composition of zircon. We test this against thermodynamic models of zircon growth and trace element modelling to assess if an equilibrium approach to understanding zircon behaviour in metamorphic rocks is a reasonable approximation. This work further develops our understanding of the growth of metamorphic accessory minerals and their applications to petrochronology.

TRACKING THE CRUSTAL THICKNESS AND ISOTOPIC VARIATION DURING THE PAN-AFRICAN OROGENY (ANTI-ATLAS BELT, MOROCCO)

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Crustal thickness and magma isotopic signature changes are key phenomena for understanding orogenic belts. To track this variation in the Pan-African orogen (830–541 Ma) of the northwestern margin of the West African craton (WAC), we compiled 723 whole-rock geochemical analyses and 250 whole-rock Nd isotopes of magmatic rocks along the Anti-Atlas and the Meseta covering this period. Our results show that during the formation of the long-lived intraoceanic arc (760–660 Ma), the arc crustal thickness evolved from 25 km (averaged value estimate) and εNd = +8 at 760 Ma to a maximum thickness of 45 km and εNd = +6 at 660 Ma. The maximum thickened crust (45 km) in this period probably represents the time of the WAC-oceanic arc collision marking the tectonic amalgamation of the Meseta block with the WAC. After this collisional event, compiled data suggest that the northwestern WAC orogenic assemblage experienced a period of high magmatic productivity localized in central-eastern Anti-Atlas and Meseta regions, synchronously with a crustal thinning regime between 640 and 620 Ma with a crustal thickness of about 28 km and depleted isotopic composition (εNd = +8). This period coincides with the post-collision extension in the eastern-central AA, marked by the deposition of the Saghro Group turbidites containing MORB and OIB basalts. The period 620–600 Ma records the emplacement of a calc-alkaline magmatism with adakitic signature in the central-eastern Anti-Atlas and Meseta domains. Geographic distribution of this magmatism shows southward-younging ages and overthickened continental crust of about 54 km and enriched isotopic signature (εNd = -4 to -1), which is concomitant with the deformation of the Saghro Group. The period between 590 and 540 Ma is characterized by a normal crustal thickness ca 35 km and the emplacement of two distinguished magmatic suites: (i) 590–570 Ma suite with the emplacement of high calc-alkaline plutonism with enriched isotopic features (εNd = -1 to -4 in average) and (ii) 570–550 Ma suit with calc-alkaline to transitional magmatism with depleted isotopic data (εNd = 0 to +3. Considering these results, the southward younging age, the calc-alkaline-adakitic nature of plutonism, and the thickened crust (~50 km) at 620–600 Ma in the NW margin of the WAC may be the result of south-dipping subduction during the closure of the Saghro Group basins. The abrupt transition from overthickened crust at 620–600 Ma to normal crust at 590–540 Ma may be the result of crustal delamination with mantle uplift allowing the onset of the extensional period leading to Cambrian rifting.

FROZEN GROUND PERFORMANCE OF ENGINEERED BIORETENTION SYSTEMS IN SOUTHERN ALBERTA, CANADA

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Stormwater managers in urban settings are increasingly adopting low impact development (LID) strategies that mimic natural hydrological systems to reduce adverse impacts, such as flooding and water quality degradation. This study focuses on bioretention systems, a form of LID technology that uses engineered, planted depressions to process stormwater by providing natural filtration and stormwater retention at a local scale. These systems have been successfully installed throughout Alberta and across Canada, but frozen ground conditions and mid-winter melt events create unique challenges that have not been fully explored. The objective of this research is to quantify year-round water movement and storage for 24 constructed bioretention cells at a facility in Okotoks, Alberta. In addition to ongoing growing season experiments, a simulated spring meltwater event containing a conservative tracer was applied to cells with varying soil type, vegetation, and impervious/pervious (I/P) ratios. Relevant hydrologic conditions, including infiltration, water retention, and tracer migration, were monitored prior to and during meltwater infiltration and spring thaw. These data provide valuable insights into water partitioning under frozen ground conditions, highlighting the role of soil media and vegetation types, and serve as a valuable comparator to unfrozen conditions. Understanding the key processes and functionality of bioretention systems will help with site design optimization and large-scale implementation of these LID features as a stormwater management strategy in cold regions.

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ANCIENT ROOTS OF TUNGSTEN IN WESTERN NORTH AMERICA

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Tungsten is a critical metal, meaning that it is essential to a wide variety of sectors but is at high risk of supply disruption. Tungsten preferentially accumulates at paleocontinental margins that form during the breakup of supercontinents, and subsequent crustal thickening and associated magmatism allows its extraction to form magmatic-hydrothermal deposits. The North American Cordillera had a protracted tectonic evolution, associated with extensive magmatism providing ideal conditions for the concentration of tungsten ores. However, the major tungsten deposits in the North American Cordillera are limited to a narrow region, the Canadian Tungsten Belt, in northwestern Canada. Therefore, the North American Cordillera provides an ideal setting to evaluate the factors that control tungsten distribution. In this study, we use neodymium isotopic compositions of the main tungsten-bearing mineral in the Canadian Tungsten Belt, scheelite ($CaWO_4$), and those of basement rocks in the North American Cordillera, as well as paleogeographic distribution of tungsten deposits in the North American Cordillera to constrain the factors that controlled tungsten distribution. In addition, parameters such as temperature of melt extraction and oxidation state of the melt, previously inferred as being crucial for the genesis of tungsten deposits, are evaluated for this purpose.

MACHINE LEARNING ALGORITHMS FOR DETERMINING NUTRIENT TRANSPORT IN RELATION TO LAND USE PRACTICES IN AN AGRICULTURAL WATERSHED

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Agricultural activities have degraded the quality of groundwater and surface water through introducing excessive amount of synthetic fertilizers and manure with high nutrient (e.g. nitrate and phosphorus) concentrations. This is one of the most crucial non-point sources of pollution in surface water and groundwater. Therefore, the protection of water resources by using best management practices for agricultural watersheds has gained much attention during the recent decades. As a result, numerical models that simulate nutrient transport in groundwater and surface water in an integrated manner play an important role in determining the optimal practices for watershed management and land use to minimize the adverse impact of nutrients on the quality of surface and subsurface water. Although several numerical models have been developed to simulate nutrient transport in groundwater-surface water interactions, most of these models have not included all the governing factors for nutrient transport processes. Many existing numerical models include a large number of parameters with high non-linearity and uncertainties (e.g. soil properties). The available watershed models for nutrient dynamics also cannot fully describe the interdependence (cause-result relationships) between transport process variables. Moreover, most of these models are limited in simulating the complex spatiotemporal distribution of nutrient concentrations in the surface and subsurface water domains. Considering these challenges, data-driven models using machine learning (ML) algorithms provide an alternative approach that can yield high performance for examining the complexity of the transport process since they can deal with complicated datasets and different scales. Also, ML models can explain the interdependence between the involved process variables because well-trained and validated ML models deal with the input (e.g. weather conditions) and output (e.g. nutrient concentrations) variables of the complex processes based on historical observations. In the current study, different classification (e.g. decision trees) and prediction (e.g. artificial neural network) ML algorithms were applied on a dataset related to an agricultural watershed in southwestern Ontario. The input variables included the weather (e.g. temperature and rainfall), hydrogeological (e.g. groundwater elevations) and hydrological (e.g. stream flow) conditions while the main output variables were the nitrate and phosphorus concentrations at specific locations in the watershed. The study results can be used by decision makers to recommend suitable fertilizer application and crop pattern practices in agricultural watersheds to minimize the degradation of groundwater and surface water quality. The results of this study can also be implemented to interpolate nutrient concentrations in the watershed from a series of point measurements.

EXTREME SUBSIDENCE AND RAPID BURIAL: IMPLICATIONS TO HYDROCARBON SYSTEMS MODELLING DEAD SEA RIFT ZONE

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In the Dead Sea Rift (DSR) Zone left-lateral strike-slip and pull-apart motion has caused drastic subsidence and burial (6 km) and a significant flaw in the hydrocarbon thermal maturation simulations with respect to disequilibrium of the organic and inorganic matter versus a short geological time, resulting in calculations of a shallower thermal maturity window. In the DSR we used a cold basin model in which Ro.55 is at 6 km versus 4 km, 0.7 at 8 km, and 1.3 at 10 km versus 8 km. Analogues to the DSR are (1) the deep basin of the Caspian, which contains a low geothermal gradient and extreme burial rates of 10 km (Pliocene), with oil onset at 10 km, and gas at 13 km, and (2) the Pliocene (5 km) of the US Gulf of Mexico offshore slope, which does not have a great impact on thermal maturity profile due to (i) rapid deposition and (ii) in flux of cold sediment. Regionally, eastern Mediterranean, Late Cretaceous source rocks occur from the Western Desert of Egypt to Turkey. In the Deep Block of the DSR the Gaharb Fm. Senonian limestone (source rock) at 6.8 km. Epigenetic diagenesis has occluded the porosity (5%) and permeabilty (1 k md) in Mesozoic carbonate rocks onshore Israel. Thus, reservoir targets would be mesodiagenetic, where the simultaneous maturation of organic matter and high pH driven connate waters have created dissolution and porosity. In the DSR, onset of mesodiagenesis for dolomites and sandstones is projected at 6 km, and H2S onset at 10 km. Petrographic evidence is found onshore in deep burial saddle and ferrous dolomitization of the Jurassic Zohar Formation. A productive analogue is in ultradeep (8 km) carbonate reservoirs (9% porosity) of the Anadarko basin. Seismic resolution at 7 to 9 km sub-salt does not reflect structural deformation in the DSR Deep Block. Analogous structural clay models of Neogene California pull-apart basins suggest recent structures forming prior to hydrocarbon generation and thus should be present in the DSR Deep Block. In conclusion, within the last million years, hydrocarbon generation, expulsion, and entrapment with the simultaneous creation of reservoir targets could exist based upon correlations between the Amiaz (4505 m) and the Sedom Deep (6450 m) wells in the (1) Judea Gr limestone (7–7.6 km), (2) Lower Cretaceous Kurnub Gr sandstone (7.6–7.8 km), and (3) Zohar Middle Jurassic Limestone (7.8 km). Limestone and sandstone older than Mid Jurassic are viable targets and justify exploratory drilling to 10 km depths.

HEAVY RARE EARTH (HREE) RESOURCES: CRETACEOUS LITHIUM RICH RHYOLITE LACCOLITH, EL PASO, TEXAS

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The Round Top Mountain rhyolite (RTMR) is a laccolith intrusion contemporaneously emplaced during Buda limestone deposition during the Early Cretaceous. Contact metamorphism has resulted in a high concentration of Be. The Texas Bureau of Economic Geology estimates the mass at 1.6 billion tons, constituting the largest HREE deposit in the United States. Regionally, the RTMR is part of the Texas Lineament, characterized by thrusting, faulting, felsic subduction-related magmatism, post-Basin and Range extension, and enriched mantle melts. The extensional tectonics and the introduction of enriched mantle melts during which late-stage magmatic hydrothermal vapor phase crystallization resulted in the partial dissolution of silicate minerals and HREE enrichment. The 2011 gravity survey maps show rhyolite as gravity lows with dykes and sills that fed the laccoliths from a buried central intrusive body. A cross-section based on core and gravity data provides an integrated geologic model with a gently sloping laccolith of red, grey, brown rhyolite layers and basal sedimentary rocks. The HREE deposits are homogeneously distributed, (NI-43-101

Preliminary Economic Assessment) reflected in 54,864 m of core, mapped with extensive gravity surveys, enriched in HREE, Y, Li, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Be, Ga, Sn, Nb, U, Th, and technology metals Be, Hf, H, Zr, and industrial metals Mn and Al. The RTMR hosts 16 of 17 rare elements and contains 13 of the 35 minerals critical deemed critical by the U.S. Department of the Interior. Lithium accounts for 32 % of the resource. Potassium feldspar, plagioclase and quartz grains comprise bulk mass. The combined Y and REE grade is 0.5% with 72% of this consisting of Y and HREE, in the range of South China ionic clays deposits, which are the most significant resource of economic HREE worldwide. USA Rare Earth plans to mine the Round Top deposit and recovery by low cost heap leach processes that are environmentally benign, with the infrastructure in place, increasing the per ton yield from $11 to $70. Significantly, the project payout (1.4 years), internal rate of return (70%) and margins (70%), are similar to and exceed risk-adjusted overall valuations for the oil and gas fields of the Permian Basin, Texas.

ULTRA DEEP HYDROCARBON POTENTIAL MESOZOIC ROCKS: NEW YORK AND NEW JERSEY, USA, EAST COAST OFFSHORE

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Exploratory drilling in the Baltimore Canyon (BC) penetrated gas condensates and dry gas within the Kimmeridgian and Oxfordian sandstone units of the prograding coastal plain and transitional marine deposits. In all the wells drilled (32) no highly mature organic rich source rocks were ever encountered. No hydrocarbon shows were present at the shelf edge Oxfordian–Lower Cretaceous porous carbonates, composed of oolitic grainstones, coral stromatopoid grainstones and boundstones. Reinterpretation of gas condensate utilizing diamondoids and carbon-13 data from the Hudson River Canyon suggest a deeper (> 6 km) Lower Jurassic hydrocarbon source, analogous to Norphlet Formation gas production in the U.S. Gulf of Mexico, sourced from the organic rich Smackover Formation. The closest onshore Jurassic potential source rocks of chronostratigraphic age equivalents occur in surface outcrops in the Newark Rift Basin, that are immature to marginally mature, whereas the Triassic are burnt-out, possibly due to the Palisades event. In the BC, a thermal maturation profile burial model of the Shell 273-1 well indicates Jurassic sedimentary rocks entered the early oil phase at 3.8 km and main gas generation at 5.2 km. Gas generation continued through the Cenozoic. Rocks younger than Early Cretaceous are not thermally mature, as supported by observed field data. A regional isopach map of probable Triassic–Jurassic rocks using seismic surveys indicates a significant volume is buried greater than 6 km, constituting a large hydrocarbon fetch area. Reprocessed seismic data (AVO analysis) indicates reflectors of widespread salt layers on the eastern flank of the Schlee Dome, 60 m thick, 40 km wide and 250 km long, constituting a potential large permeability barrier and trap. Epigenetic diagenesis associated with sea level falls are predicted and documented by reefs drilled into a shelf margin in the BC. Modern analogues demonstrating potential porosity and permeability changes due to subaerial exposure in rocks are located in the western margin of the Red Sea (Gulf of Elat/Aqaba). Ultra-deep oil and gas targets in the BC are at depths of 6–10 km created by mesodiagenesis, the simultaneous maturation of hydrocarbons and reservoir sandstone diagenetic reactions. In the BC, sandstones from the coastal-plain facies range from lithic arkoses to sublitharenites and the textural maturity increase with depth of burial reflecting the effect of feldspar alteration and porosity creation. Analogous established petroleum systems are present in the deep Wilcox and the Norphlet formations in the Gulf of Mexico from 8–9 km in depth.

MESOZOIC CARBONATE AND EVAPORITE ROCKS IN THE BAHAMAS: IMPLICATIONS TO PETROLEUM SYSTEMS

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The Bahamas contains three petroleum systems: (1) post-rift carbonate rocks in the central and northern areas, (2) the Upper Cretaceous to Oligocene southern structural belt, and (3) the underlying synrift pre-salt clastic, evaporite, and carbonate units. The Bahamas Mesozoic platform post-rift hydrocarbon system is linked to our recently discovered Cretaceous salt diapirs and is consistent with those oil/gas-field salt diapirs found offshore from the northwestern West African conjugate margin, the U.S. Gulf of Mexico (Louann Salt), and offshore eastern Canada (Argyle salt). A Bahamas salt diapir mapped 30 km to the northwest of the Long Island well appears in seismic and gravity data (-30 mgal anomaly). It is an analogue to the East Texas Fairway oil field (440 mmbo) with Lower Cretaceous carbonate lateral and vertical heterogeneous reservoirs over salt features resulting from a transgressive depositional event. The salt is overlain by porous carbonate reef-derived grainstones, shallow subtidal packstones and wackestones. The Jurassic to Lower Cretaceous lagoonal basin covering the Bahamas created ideal anoxic and hypersaline conditions for the preservation of organic matter and dolomitization with total organic carbon (TOC) 1.5 to 5 wt.%, and hydrogen index (HI) 400 to 500 mg/g TOC. The correlative source rocks are type-2 algal kerogen carbonate of the Smackover and Sunniland Formations. Evaporite units of significant thickness (3 km) occur in select wells intercalated with dolomites. The Lower Cretaceous margin is typified by the Andros Island well, which penetrated multiple zones of thick, highly porous, dolomitized reefs. Bankward petrography shows intercrystalline porosity in dolomites, anhydritic-calcitic dolomites, dolomitized mudstone-wackestone, ooid grainstones (hypersaline,semi-restricted platform and open marine environments of deposition). Lower Cretaceous reservoir rocks contain porosities of 10–25%, and permeabilities of 10–50 md. The carbonates may have been subaerially exposed correlating to U.S. Gulf of Mexico's stratigraphy and to northwestern Atlantic conjugate margin (Baltimore Canyon) connected to the Bahamas, showing one verified Cretaceous and one postulated Jurassic period of supercyclic low-stand. The second petroleum system formed as a result of the emplacement of the Late Cretaceous to Early Tertiary subduction zone. A structural belt was created, sub-paralleling Cuba. The geothermal gradients measured in the exploratory wells are extremely low, thus ultra-deep deep drilling is required to reach source–trap proximity. The third petroleum system is in the synrift, pre-salt rocks. The Great Isaac well bottomed (5 km) in synrift volcanoclastics, red beds, and evaporites, with oil and gas shows. Seismic records show a breakup unconformity correlative with Mexico's onshore Huehuetepec oil field.

SEISMIC EVIDENCE FOR CRUSTAL THICKENING CONTROLLING ASEISMIC DEFORMATION AT THE BEAUFORT SEA CONTINENTAL MARGIN, CANADA

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The Canadian Beaufort Sea continental margin of northwestern Canada has recorded several episodes of deformation from Late Cretaceous to Late Miocene time. An arcuate fold-and-thrust belt was formed in the area due to the Late Paleocene–Mid Eocene north-south compression. The lack of seismic deformation indicates that this north-south compression is accommodated by aseismic deformation due to either high crustal temperatures and/or slow deformation, and/or infrequent large earthquakes (M > 6). Here we investigate whether the Beaufort Sea margin is a newly forming convergent margin, potentially representing a rare case of incipient subduction. We develop high-resolution seismic velocity models (VP, VS, VP/VS) of the region using recordings of regional earthquakes. The velocity models reveal an anomalous low-velocity region within the crust beneath the Beaufort Sea continental margin of northern Yukon, which we interpret to reflect a hot and highly deformed crust. This is consistent with our event relocations showing that the brittle ductile transition is shallow across the study area. Furthermore, we show that localized crustal thickening, due to the stacking of sedimentary and volcanic rocks, occurs below the Arctic coast of northern Yukon. This evidence suggest that the Beaufort Sea margin of northern Yukon is a juvenile slow convergent margin, however, the limited resolution of our velocity models prevents us from confidently interpreting features offshore within the Beaufort Sea. Therefore, it is highly critical to deploy ocean-bottom seismometers on the continental shelf and offshore within the Beaufort Sea to obtain robust and reliable information about the detailed crustal structure of the area.

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ORTHOVERSION AND THE THREE-STAGE TRANSITION BETWEEN SUPERCONTINENTS

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A quasi-regular cycle of global tectonics, with a periodicity on the order of 700–500 million years, appears in numerous proxies of Earth's orogenic and stratigraphic records. Although long linked to a proposed cycle of supercontinents, the paleogeographic constitutions of those extinct landmasses are only beginning to come into focus. Kinematic transitions between successive supercontinents, which depend on accurate reconstructions defined primarily by paleomagnetism in concert with tectonostratigraphy, are even more conjectural; but endmember idealizations include (i) introversion, where young internal oceans close to assemble a new supercontinent appearing similar to its predecessor, and (ii) extroversion, where old external oceans close to reorganize the continents "inside-out." Although neither of those concepts specifies the mantle reference frame locations of successive supercontinents, if one were to imagine future closure of the Atlantic, the resulting landmass would likely have a centroid not far displaced from that of Pangea. Conversely, if the Pacific were to close, the next supercontinent would likely have a centroid closer to the antipode of Pangea. Today's long-wavelength lower mantle structure, including two equatorial large low shear wave velocity provinces (LLSVPs) surrounded by a nearly great-circle girdle of subduction, has endured since Pangea breakup and offers clues to the geodynamic context of supercontinental transitions. A three-stage model of supercontinental reorganization is proposed as follows: (1a) supercontinental breakup sends fragments toward subduction zones but they largely resist descent into the mantle, thus collisions should occur mainly in the global girdle; (1b) mantle upwelling centered over the LLSVPs prevents continents from returning to the sites of breakup, but rather (2a) confines final collisions to occur within the girdle; (2b) the new supercontinent will remain in the old global mantle convection pattern until it has attained sufficient size and duration to (3a) deflect subduction toward its margins; (3b) accordingly, the resulting girdle will be located approximately 90 arc degrees away from the prior subduction girdle; and (3c) if the geographic location of the new girdle warrants, true polar wander will migrate the entire system in latitude such that the new supercontinent is centred within an equatorial degree-two pattern shifted about 90 degrees of absolute longitude from the prior landmass's centroid. This model, first proposed nearly twenty-five years ago, has been named (iii) orthoversion and carries testable predictions of geophysical and geological proxy datasets.

A MICROSTRUCTURAL INVESTIGATION OF FLOW TEXTURE IN PSEUDOTACHYLITE

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Pseudotachylite is a fine-grained rock formed from the quenching of a frictionally generated melt along a fault's slip surface during an earthquake. They have been dubbed "fossil earthquakes" as they are the only unequivocable evidence of paleoseismicity in the rock record. It has been demonstrated in experiments that a friction-generated melt acts as a lubricant to slip once a melt layer sufficiently coats the fault surface, however, once the production of frictional heat ceases, the melt begins to quench and acts as a viscous brake until slip stops and the fault is welded shut. This brings into question how the rheology of a pseudotachylite melt affects seismic slip. A near ubiquitous feature of pseudotachylite is the presence of flow textures, namely banding and the alignment of microcrystallites parallel to the vein margins. Aside from authors noting the presence of such flow textures, they have not been extensively studied. We have studied several pseudotachylite examples from different locations to document, classify, and interpret flow textures. Petrographic and electron microscopy was used to determine their overall structure and to investigate their chemical and mineralogical make-ups to define individual flow bands. Additionally, cathodoluminescence microscopy was used to visualize features not otherwise observable, such as strain patterns. Preliminary results show that flow textures observed are the result of chemical differences in the matrix, differences in grain size and mineralogy indicating heterogeneities in the melt. Studying flow patterns in pseudotachylite provides important insight into the material properties of earthquake generating faults. Understanding these properties, especially during dynamic rupture, is helpful to understand the earthquake cycle and supports efforts to make more accurate predictions of when, where, and how strong future earthquakes will be.

IDENTIFICATION OF THERMAL REFUGES IN RIVERS BY USE OF THERMAL AERIAL IMAGERY

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Rivers in northern Québec are known for the abundance of Salmonidae. Fishing is important for local communities and bring a source of revenues. The optimal temperature range for Salmonidae growth varies according to species, but the lethal water temperature range is 25–27°C. In summer, salmonids can experience thermal stress during extreme weather conditions. This affects their growth and even threatens their survival. Some specific zones in the rivers constitute thermal refuges allowing fish to be more comfortable to grow and survive in extreme events. Extreme conditions are likely to occur more frequently in Québec rivers due to climate change. They can have a negative impact on the population of Salmonidae in rivers in the future. Therefore, identifying and understanding the process of thermal refuges in rivers is of fundamental interest. Thermal infrared (TIR) images have been used to map river water temperature, thermal refuges, surface water-groundwater exchange and more specifically to monitor thermal refuge fish habitats. This study analyzes thermal refuges as well as cooling zones in two Atlantic salmon rivers in a subarctic climate. Cooling zones of the rivers were examined, since TIR imagery can miss some thermal refuges at specific locations due to mixing of cold water patches with the main river channel. The map of thermal refuges was made by use of TIR imagery. Then, river scape hydro-morphological variables of each refuge were investigated and the mechanism affecting them was identified. The two studied rivers are the Koroc River and the Berard River. Both are located in northern Québec, Nunavik, and drain into the Ungava Bay. On the studied section of Berard River, four thermal refuges and five cooling zones have been detected. Within the thermal refuges, two are cold side channels and two are lateral seep type. Cooling zones have a total length of 8.9 km, representing 52% of the surveyed section of the river. On the 41 km section studied for the Koroc River, 70 thermal refuges and four cooling zones have been identified. Cooling zones in the Koroc River have a total length of 9.4 km, which is 23% of the studied section of the river. 89% of identified thermal refuges are groundwater-controlled. The identified cooling zones have a good match with known spawning and late/no-freezing locations on the rivers by local northern communities. This information can be used for a better planning of conservation measures to be implemented for the Atlantic salmon population.

FOLLOWING LINES OF EVIDENCE: DAVID HONEYMAN AND THE FIRST DECADE OF GLACIAL GEOLOGY IN NOVA SCOTIA (1873–1884)

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Dr. Rev. David Honeyman was an experienced international delegate of Nova Scotia geology and natural history when he became the first curator of the Provincial Museum (founded 1868) until his death in 1889. Honeyman began his glacial geology work in 1873, the same year the HMS Challenger visited Halifax Harbour during its Arctic scientific voyage. Honeyman lead an excursion for the crew to examine the glacial striations at Prince of Wales Tower. The same year Honeyman also found amygdaloidal basalt boulders among the 'drift' near Cow Bay that he hypothesized had been transported by glaciers and having originated from Blomidon, Bay of Fundy. In 1883, he produced the hand coloured and annotated "Glacial Chart Geological Map of Halifax Harbour", that he used as reference for his presentations of "Glacial Geology of Nova Scotia" to the Geologists' Association in London in June 1883, and the British Association meeting in Montreal in August 1884. Honeyman published frequently in the Proceedings of the Nova Scotian Institute of Science, which had significant international distribution. One report describes a field excursion to Point Pleasant Park with several delegates prior the British Association meeting in August 1884, including Matthew Blair, who later published 'The Surface Geol-

ogy of Paisley". During the excursion, specimens of glacially transported rocks were collected and his map was discussed. In the smaller citizen-published science publication, Canadian Science Monthly, Honeyman published a short summary of another Halifax field excursion in September 1884. This post-conference trip included British geologists such as William Blanford, then President of the Geology Section of the association and New England geologists such as Professor Richards from MIT. The trip started in Joggins, and over several days included visits to geology sites in Springhill, Parrsboro, Windsor (Newport), and finally Halifax to examine striations and basalt boulders. Honeyman had also provided a similar tour to Professor Richards and students from MIT geology the month before in July of 1884. These field trips, publications and map represent the first decade of glacial geology research in Nova Scotia. Honeyman provided evidence to support glacial origin of 'drift', contrary to others (e.g. J. W. Dawson), who supported the floating ice drift theory. By leading delegations to observe evidence of glacial geology in Halifax Harbour, David Honeyman acted as a bridge for knowledge translation between international geologists, regional scientists and citizens interested in natural history and sciences.

THE MAKING OF THE SECOND EDITION OF "THE LAST BILLION YEARS: A GEOLOGICAL HISTORY OF THE MARITIME PROVINCES OF CANADA"-WE RISE AGAIN

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The first edition of *The Last Billion Years: A Geological History of the Maritime Provinces of Canada* (LBY1) was published by Nimbus Publishing and the Atlantic Geoscience Society (AGS) in 2001. An immediate hit, the first print run sold out within weeks and reviews were enthusiastic. The success of LBY1 was sustained over the ensuing years, with over 10 000 copies printed. However, significant advances in the understanding of Maritimes geology over the past 20 years warranted a new edition (LBY2). As in LBY1, the new edition will comprise chapters and boxes, the latter being "minichapters" between the main chapters that focus on topics not fully covered otherwise. Like in LBY1, chapters 1–3 introduce general aspects of geology, with a Maritimes slant. The next five chapters describe the geological history of the Maritimes, from obscure beginnings in the late Proterozoic to the ubiquitous remains of the recent Ice Age. LBY1 included a single chapter on resources and environmental concerns; whereas in LBY2 these topics are covered by three final chapters, one each on resources (mainly mining and energy), natural hazards (such as earthquakes and landslides), and human induced problems (such as the climate emergency). Of the LBY1 boxes, a few have been omitted or encompassed in the main chapters of LBY2, and others have been updated. New boxes on rivers, building stones, remote sensing, and evaporites and limestones have been added. Several well-known geologists from the Maritimes and beyond assisted with the updates and revisions. New and revised graphics include updated paleogeographic maps from 850 to 3 Ma, revised geological maps of the Maritimes, and new figures showing the phylogeny of branches represented by Maritimes fossils. As in LBY1, LBY2 features many attractive photographs and pieces of artwork, including some new specially commissioned watercolours. A geologist, three non-geologists, and a technical editor have extensively reviewed the book. Like its predecessor, LBY2 is aimed at an interested, non-specialist audience. It is co-published by Nimbus and AGS with funding provided by the Canadian Geological Foundations, AGS, the Association of Professional Engineers and Geologists of New Brunswick, and the Association of Professional Geologists of Nova Scotia. As of mid-February 2022, the book is scheduled to go to the printer in mid-March 2022 and should be available by mid-May 2022. We hope that LBY2 will be as well received as LBY1.

PETROGRAPHIC, FLUID INCLUSION, AND EPMA STUDIES OF THE MIDWEST URANIUM DEPOSIT, ATHABASCA BASIN, CANADA

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Midwest is a classic example of an unconformity-related uranium deposit in the Athabasca Basin. The deposit contains elevated concentrations of Co, Ni, and As in addition to U. High-grade polymetallic ores are hosted predominantly along the unconformity between the underlying crystalline basement and overlying conglomeratic sandstones. Petrographic observations of ore textures and cross-cutting relationships indicate a complex, multi-stage paragenesis characterized by an initial phase of primary mineralization followed by at least two episodes of ore reworking. Three distinct generations of uraninite have been identified, with each generation separated by Ni-Co arsenide and sulpharsenide deposition. This sequence of mineral precipitation is consistent with geochemical path modelling involving mixing between an oxidizing, U-bearing fluid and a relatively reducing Ni-Co-As-bearing fluid. Bi-phase, liquid-dominated fluid inclusions from drusy quartz veins spatially related to mineralization are the target of microthermometric experiments and Raman analyses. Upon heating, those fluid inclusions suitable for analysis homogenize to the liquid phase between 105°C and 130°C. During cooling many of the inclusions show reluctance to freezing, while those that do freeze must be supercooled. First melting, ice melting, and hydrohalite melting temperatures indicate that the fluid may be characterized by the H_2O-NaCl-$CaCl_2$ system, which was checked by means of cryogenic Raman spectroscopy. Fluid salinity calculated from ice- and hydrohalite-melting temperatures vary between 22 and 29 wt.% NaCl equivalent. Electron probe microanalysis (EPMA) has been used to better determine the composition of U minerals present in the ore. A total of eighty-five analytical spots were selected across three petrographically distinct generations of U minerals. The results of the analysis show that the composition is highly variable: U content is between 60 and 80 wt.% with most analyses around 75 wt.%, Pb ranges between < 1 and 15 wt.%, Si+Ca+Fe between 1 and 5 wt.%, and Th is generally below the detection limits of the instrument. These are divided into two broad groupings: one with high Pb and low Si+Ca+Fe content, and the other with a low Pb and high Si+Ca+Fe content. The first grouping representing less-altered, primary uraninite, and the second group representing altered uraninite and coffinite. Linear correlations between chemical ages calculated from the EPMA data and Si+Ca+Fe contents suggest primary mineralization ages between 1600 Ma and 1400 Ma.

ASSESSING LATERAL AND VERTICAL HYDRAULIC CONNECTIVITY IN A MULTI-LAYERED SEDIMENTARY BEDROCK AQUIFER USING HIGH-RESOLUTION, SPATIAL-TEMPORAL MONITORING IN ERIN, ONTARIO, CANADA

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The presence, position, and thickness of aquitards within a sedimentary sequence were identified using multiple high-resolution characterization and monitoring techniques in order to parameterize distinct hydrogeologic units within the flow system at a site in Erin, Ontario. Data from continuous core, geophysical or hydrogeophysical logging, and removable pore-pressure monitoring, were collected in two bedrock boreholes (MW13A-20 and MW14A-20) to select monitoring intervals and install depth-discrete multilevel monitoring systems (MLS). The cored holes are part of a 3-D monitoring network about 430 and 380 m away, due west and south, from a permitted water supply well completed in a shallow fractured bedrock aquifer. Prior to MLS completion, the core holes were instrumented with a total of 48 pressure transducers at targeted depth-discrete intervals along the open borehole lengths (n = 26 in MW13A-20 and n = 22 in MW14A-20) and sealed behind a FLUTeTM liner to obtain hydraulically isolated, depth-discrete vertical hydraulic head (converted to equivalent water level) profiles and dynamic head responses recording at high-frequency (1 second). Water levels are sensitive to fluctuations in natural and anthropogenic forcings, such as barometric pressure, pumping, Earth tides and precipitation, which create noise in the water level and can make estimating hydraulic properties of the subsurface difficult. At this site, signals from the nearby pumping well and four municipal wells in Hillsburgh and Erin, approximately 2 and 5 km away, as well as barometric pressure and Earth tides were removed using regression with elastic net regularization in a deconvolution model. After the removal of these signals in the water levels, the loading and pumping response functions were created, and aquifer and aquitard properties were estimated. Preliminary results suggest the two bedrock MLS respond differently to the nearby pumping well. Monitoring location MW13A-20 to the west shows a classic Theis confined response in each of the monitoring depths, with distinct response times and a decrease in magnitude with depth below the pumping interval. In contrast, monitoring location MW14A-20 to the

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south displays a leaky aquifer response, suggesting lateral variability in the overlying or underlying vertical hydraulic conductivity. Separate studies show no impact to surficial features. Our study shows important insights regarding vertical hydraulic connectivity, the position and thickness of aquitards, and laterally variable confinement in a multi-layered sedimentary rock system using high frequency data in vertical detail at more than one location. This can in turn improve assessment of pumping influences within these spatially complex 3-D flow systems.

TOURMALINE BRECCIA PIPES OF THE GIANT COPPER PROPERTY, SOUTHERN BRITISH COLUMBIA, CANADA: UNDERSTANDING THE SIGNIFICANCE OF TOURMALINE AND BRECCIA PIPES AS VECTORING TOOLS IN ORE DEPOSITS

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The AM breccia is part of the Giant Copper property of southern British Columbia. Located approximately 150 km east of Vancouver, this brownfield property has high-grade Cu and Ag mineralization confined to tourmaline breccia pipes. The AM breccia, the property's better-defined tourmaline breccia pipe, has an inferred resource of 30.2 Mt at 0.72% Cu. The AM breccia shares similarities with other tourmaline breccia pipes, most notably the tourmaline breccia pipes of Chile and Peru. Additionally, similarities exist with tourmaline breccia pipes associated with PCDs in the Cascadia arc. Although tourmaline breccia pipes are known features in selective PCDs, they can also form in Sn-W intrusion-related deposits. Their occurrence in two distinct ore deposit types warrants the ability to distinguish between porphyry- and non-porphyry-related tourmaline breccia pipes. Quantifying the chemical properties and redox conditions of the intrusive suites responsible for breccia pipe formation and ore-bearing fluids can also reliably establish porphyry affiliation. A LA-ICP-MS U–Pb zircon date of 24.9 ± 0.2 Ma (2ó) for the Invermay diorite, the intrusion responsible for breccia pipe formation, is consistent with Cascadia suite porphyry-type mineralization and associated breccia pipes. Trace element concentrations of Invermay zircon, on average, have fertility indicators for redox state, water content, and fractionation that correlate well with known PCDs. Regardless of deposit association, tourmaline is a common alteration mineral in tourmaline breccia pipes. Due to its chemical diversity, thermal and mechanical stability, and boron concentrations, it is an excellent mineral reservoir capable of recording the chemistry of magmatic-hydrothermal processes. Chemical and isotopic characteristics of hydrothermal tourmaline at the AM breccia have major-element compositions aligned with tourmaline compositions from PCDs globally. Tourmaline from PCDs is alkali-rich with elevated Fe, Mg, Ti, and Ca, reflecting a metaluminous composition. Sn-W intrusion-related tourmaline is alkali- to X-site vacant-rich and contains high concentrations of Al, F, Si, Mn, and X-site vacancies compared to PCD tourmaline and reflects a peraluminous composition. Boron isotopes from AM tourmaline range from -8.1‰ to 5.6‰, indicating an unaltered MORB boron source and I-type affinity. The chemical and isotopic characteristics strongly suggest that the AM breccia is PCD-related and that the Invermay diorite has the zircon fertility characteristics of a PCD. The application of this study provides new quantitative criteria for determining the deposit affinity of tourmaline breccia pipes.

MINERALS AS RECORDERS OF EARTH AND PLANETARY PROCESSES

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Minerals are the building blocks of rocks, and they are ubiquitous across the Solar System. Mineral formation and subsequent alteration or deformation can provide a sensitive record of processes in the formation and evolution of the Earth and the Solar System. Minerals form whenever conditions satisfy their P-T-X stability fields and when kinetics allow. Thus, their presence provides the P-T of their formation and/or subsequent equilibrium conditions, recorded in their composition and structure. Differing chemical affinities of the elements during mineral formation make mineral compositions and associations useful as exploration vectors. Associated changes in crystal structure, accessible by in situ X-ray diffraction, are also potential exploration vectors, including kimberlite indicator minerals garnet, chromite, ilmenite and Cr-diopside. Minerals can be used as thermobarometers, based most commonly on chemical exchange between minerals or on structural changes within a single mineral (e.g. cation order-disorder). Solid state nuclear magnetic resonance (NMR) spectroscopy in an excellent tool for measuring cation order-disorder for use in thermobarometry - e.g. spinel ($MgAl_2O_4$) in refractory inclusions from carbonaceous chondrite meteorites records temperatures in the early Solar System. After formation, minerals can record subsequent deformation events, from tectonism, mantle flow, or meteorite impacts. Mineral deformation is accommodated by lattice strain and plastic deformation of the crystal, resulting in a mosaic spread of subdomain misorientations, termed strain-related mosaicity (SRM). Lattice strain can be measured by conventional powder X-ray diffraction (pXRD) and Rietveld refinement. Using laboratory-based micro X-ray diffraction (μXRD), mineral SRM can be measured rapidly and non-destructively to quantify plastic deformation. It can be calibrated using experimental samples from known peak shock pressures. Examples include impact-shocked minerals from chondrites, achondrites, Mars, the moon and Earth, and minerals from various tectonic stress regimes on Earth – e.g. olivine in mantle xenoliths and quartz in deformed crustal rocks. Crystal structural information obtained by laboratory XRD is an ideal complement to the more familiar microbeam methods applied to the same samples, including electron probe microanalysis (EPMA), electron backscatter diffraction (EBSD), and micro X-ray fluorescence (μXRF). Integrated in situ observations of mineral composition and crystal structure are highly desirable in the laboratory setting, and work is underway to develop a miniaturized in situ XRD instrument that would operate as part of a suite of instruments in future Mars exploration – or anywhere else a remotely operated robotic rover might be deployed, including remote regions of Earth for environmental science or resource prospecting and development.

INFLUENCE OF SURFACE PROCESSES ON SEASONAL FROST, TALIK DYNAMICS AND PERMAFROST EXTENT AT A DEGRADING LITHALSA NEAR UMIUJAQ,NUNAVIK, CANADA

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Previous work has shown how complex interactions between topography, vegetation and seasonal snow cover can influence the subsurface thermal and moisture regimes in cold regions. Yet because of the large degree of spatial heterogeneity and interseasonal variability of these surficial conditions in the discontinuous permafrost zone, the extent of the interactions between surficial conditions and seasonally- and perennially-frozen ground is not well understood. Specifically, there is only a small amount of coupled field and modelling work that has examined these interactions, as well as their implications for permafrost extent and talik dynamics, in variably saturated, mineral soil-type environments. To date, much of the current body of knowledge on this topic comes from studies that were performed in saturated environments with organic-rich soils, such as peatlands or wetlands where unsaturated conditions are highly improbable or of limited depth. As a result, there is a need for a more critical analysis of the role of saturation in permafrost environments, specifically at locations with variable topography and unsaturated soil conditions. This study focuses on evaluating the impacts of different thermo-hydraulic mechanisms occurring in the seasonally frozen layer on local seasonal frost, talik and permafrost dynamics at a degrading lithalsa, or permafrost mound, located in the discontinuous permafrost zone near Umiujaq, Nunavik, Canada. Data indicate that the surface energy balance is significantly influenced by the large degree of spatial heterogeneity and seasonal inter-variability of surface conditions, including topography, vegetation and snow cover, over the small scale of the study site. Data further indicate that the formation and closure of an isolated supra-permafrost talik at the study site are controlled primarily by the degree of saturation. As such, a cryohydrogeological conceptual model was developed to provide insight into the processes that govern local permafrost dynamics at the studied permafrost mound. The SHAW numerical model was then used to investigate the mechanisms that control the surface energy balance and the thermal and moisture regimes at the top and the side of the permafrost mound, as well as at the location of the observed ephemeral supra-permafrost talik. Improved knowledge of the site-specific thermo-hydraulic processes will be

employed to better constrain permafrost and talik dynamics in future large-scale models.

GEOCHRONOLOGY AND GEOCHEMISTRY OF THE BAY OF ISLANDS METAMORPHIC SOLE: A METAMORPHIC RECORD OF TACONIC OCEANIC CONVERGENCE

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The Bay of Islands ophiolitic complex (BOIC), located on the west coast of Newfoundland, Canada, is one of the best-preserved and best-exposed fossil subduction systems on Earth. The four BOIC massifs represent the leading edge of the upper plate during the oceanic convergence phase of the Taconic orogeny. BOIC mantle rocks are underlain by a thin sheet of metabasite and metasedimentary rocks referred to as a metamorphic sole. Metamorphic soles are composed of multiple thrust sheets off-scraped from the uppermost crust of the lower plate during intraoceanic convergence. As such, they provide a record of the subducted lower plate, from its leading edge at the site of subduction initiation (SI) to the margin over which the ophiolitic complex is eventually obducted. The BOIC thus provides a critical record of both lower and upper plates during early Taconic convergence in the Iapetus Ocean. The timing of early Taconic metamorphism in central Newfoundland west of the Baie Verte line mostly relies on a 469 ± 5 Ma $^{40}Ar/^{39}Ar$ date on hornblende from the BOIC metamorphic sole. This date is interpreted as marking cooling of the sole during the obduction of the BOIC onto the Laurentian margin. To document the pre-obduction metamorphic history, we report new in-situ LA-ICP-MS titanite U–Pb geochronology of rocks from the middle and lower sections of the BOIC metamorphic sole under the Table Mountain and North Arm massifs. Results indicate that the Hb-Pl amphibolite and metasedimentary rocks reached near peak metamorphic conditions at 485 ± 4 Ma. The nature of the BOIC metamorphic sole protoliths of the mafic and metasedimentary sections is characterized through immobile major and trace elements analyses and detrital zircon analysis. Metabasites forming the Table Mountain and North Arm Mountain soles have a dominantly N-MORB affinity consistent with formation at a mid-ocean spreading centre. Detrital zircon from the lowermost unit of the sole yielded U–Pb dates that range from Archean to Ordovician, with the youngest dates defining the most dominant peak at ca. 490 Ma. Our new titanite dates, which overlap with the available U–Pb zircon ages of the overlying ophiolite (ca. 488–484 Ma), indicate that sole subduction and accretion to the upper plate was already ongoing at the time of upper plate spreading. Geochronological analysis of the higher grade, and potentially older part of the sole in contact with the ophiolitic mantle section, is currently ongoing to further inform the timing of early Taconic metamorphism and obtain a robust minimum age for SI.

EODP: ADAPTING EXISTING DATABASE STRUCTURES TO WORK WITH SCIENTIFIC OCEAN DRILLING DATA

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Scientific ocean drilling, through the International Ocean Discovery Program (IODP) and its predecessors, has produced vast quantities of data revolutionizing many geoscience subdisciplines. Much of that data, however, is dispersed into a variety of bespoke databases. Of key importance is the lack of a resource that collates marine stratigraphy and the age, deposition, and fossil composition of the ~435 km of scientific ocean drilling cores. Having those data processed and located in a central repository would be an obvious boon to the research community, allowing for both its scientific use and as a stratigraphic nexus upon which to mount other research initiatives. Extending Ocean Drilling Pursuits (eODP) is an NSF EarthCube-funded project seeking to facilitate access to, and aid visualization of, these large ocean datasets. To do this we are leveraging two established resources, the Paleobiology Database (PBDB) and Macrostrat, and collaborating with NeptuneSandBox. Work on eODP is still ongoing. A fundamental issue impeding early progress was that scientific ocean drilling data were held within several unconnected databases, largely corresponding to which program generated the data. For example, Deep Sea Drilling Project-era data are maintained by NOAA in .html tables, whereas the current IODP database, LIMS, produces a variety of file types that are accessed via an API (application programming interface). In order to standardize stratigraphic and fossil occurrence data into a unified format, an intermediate platform (called the 'Baggage Stripper') is being built to standardize across the disparate sources, preserve the data as it was collected during cruises, and cross-walk to the PBDB and Macrostrat systems. Other efforts have been to check and correct taxonomic errors, data entry for age models, as well as hand entry of certain lithologic descriptions which had been digitally lost. Our hope is to leverage these data for exciting science. For example, from this dataset we can address questions about how and where new pelagic species evolve, or carbonate production during climate events, and the connection between biotic sediments and the macroevolution and macroecology of the organisms which produce them.

THE COMPLEXITY OF MICRO- TO CENTIMETRE-SCALE HETEROGENEITIES IN GEOLOGICAL AND GEOMECHANICAL PROPERTIES IN FINE-GRAINED DEPOSITS AND HOW TO QUANTIFY IT

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Recent studies have illustrated that the geological and compositional characteristics of fine-grained deposits, often referred to as shale or mudstone, are highly heterogeneous from the millimetre to kilometre scale. These heterogeneities are controlled by (1) the processes that deposited the sediment thereby forming sedimentary fabrics, (2) the allogenic and authigenic composition that make up the fabric, and (3) post-depositional modification by bioturbation that collectively influences the variability of elemental and geomechanical properties of mudstone deposits. However, studies have focused on the compositional and mechanical properties of mudstone deposits at the metre- to kilometre-scale despite deposits exhibiting heterogeneities down to the laminae. Therefore, the characterization of vertical and lateral sedimentary fabric and elemental variability at the millimetre- to centimetre-scale is needed to better understand how heterogeneities at this scale control the mechanical behaviour of mudstone. Eleven representative samples of three sedimentary fabrics of the Montney Formation in northeastern British Columbia (massive siltstone, stratified (light- vs. dark-dominated) siltstone, and bioturbated siltstone) were examined using a 1 cm by 1 cm grid system to determine vertical and lateral heterogeneities at a centimetre-scale. A handheld XRF machine was used for elemental composition and a HLD piccolo tool to document mechanical properties. Micro-scale analysis using an SEM was used to characterize microfacies and their respective microfabric makeup (matrix, cement, and framework grains) to better understand the elemental distribution across the sedimentary fabrics. Based on centimetre gridding and micro-scale analysis, inter- and intra-sample compositional and mechanical heterogeneities exist in the Montney Formation. Sedimentary fabric with the highest centimetre-scale aluminum content from XRF comprises microfacies that are comparatively matrix-rich, consist of mica and clay minerals (observed in SEM) and exhibit the lowest hardness values. On the other hand, sedimentary fabric with a higher elemental calcium component comprises microfacies that are matrix-poor, highly cemented by carbonate (calcite and dolomite) and quartz, and overall exhibit a positive trend with hardness measurement. Collectively, this dataset provides insight into the influence that sedimentary fabric and the distribution of elemental composition has on mechanical properties below well log resolution, which can then be applied to modelling of unconventional reservoirs and adapted to understand fracture networks in the mining industry.

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TECTONIC EVOLUTION OF THE ALLOCHTHONOUS (AMAZONIAN) CHORTÍS BLOCK OF CENTRAL AMERICA

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The Chortís block of Central America is a cratonic-type peri-Gondwanan terrane and is commonly included in Neoproterozoic-Paleozoic paleogeographic reconstructions. At present, most research has focused on the Mesozoic evolution of the Chortís block, and as a result, its pre-Mesozoic tectonothermal evolution remains poorly constrained. As a result, there is considerable debate surrounding the definition of the Chortís block as a terrane as internal complexities of the Chortís block have not been well established by geochronological and geochemical data. The Nueva Segovia group crops out in northern Nicaragua and is considered to be correlative to distinct metasedimentary formations in Palacagüina, Nicaragua and Cacaguapa, and Petén, Honduras. The Nueva Segovia group in Nicaragua is composed primarily of polydeformed sequences of greenschist facies marine clastic and chemical sedimentary rocks in conformable contact with felsic volcanic rocks. These rocks are collectively intruded by the composite Dipilto Batholith. LA-ICP-MS analysis of detrital zircon grains from the Nueva Segovia group reveal a youngest age peak of ca. 250 Ma with other significant peaks at ca. 450 Ma, ca. 950 Ma and ca. 1.2 Ga. Hf-isotope data from igneous zircons of the Dipilto Batholith suggest an older source between 1.04 and 0.57 Ga. Whole-rock geochemical data from felsic volcanic units of the Nueva Segovia group suggest a within-plate tectonic environment of emplacement which contrasts with that of the Dipilto Batholith. Taken together with field data, these data suggest: (i) a protracted tectonic history for the Nueva Segovia group, (ii) the Nueva Segovia group likely records, in part, the amalgamation of Pangea, and (iii) the basement of the Chortís block is likely of Precambrian age.

A PROCESS SEDIMENTOLOGY APPROACH TO UNDERSTANDING THE DEPOSITION OF FINE-GRAINED MIXED SILICICLASTIC-CARBONATE SYSTEMS: A CASE STUDY FROM THE ALTARES MEMBER WITHIN THE LOWER TRIASSIC MONTNEY FORMATION, WESTERN CANADA SEDIMENTARY BASIN

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Although the up to 300 m thick Lower Triassic Montney Formation predominantly consists of siliciclastic-dominated planar-laminated siltstone, a short-lived, mixed siliciclastic-carbonate interval is observed within the upper Middle Montney (Smithian), the Altares Member. This succession comprises of vertical cycles of carbonate and clastic dominated facies, suggesting recurrent paucity of terrigenous input into the basin and the establishment of carbonate factories on the shelf at this time. Overall, the Altares Member consists of centimetre- to decimetre-scale bituminous siltstone and very fine-grained sandstone, interbedded with bioclastic packstone to grainstone beds. These have been interpreted as deposited in proximal offshore to offshore transition settings, with shell material transported by storm-generated currents from more proximal settings, possibly low-relief biostromes. However, in this study detailed characterization of microfacies and depositional processes of the Altares Member document millimetre-scale grain size variability, the distribution of shell and carbonate material, sedimentary fabric, and sedimentologic heterogeneity. Within the siliciclastic-dominated beds, observed sedimentary structures include planar laminae, pinstriped laminae, wavy laminae, discontinuous planar laminae, and thin massive beds. In carbonate-dominated intervals, sedimentary structures include planar laminae, wavy laminae, current ripples, thin massive beds, scour fills, and loading structures, with concretions. Shell material mainly consists of disarticulated and fragmented clams (Claraia flat clams), terebratulide brachiopods, and rare gastropods, ammonoids, fish, and ichthyosaur bones. A complex microfacies distribution within studied samples suggests that multiple processes deposited and reworked sediment, including erosion and current reworking of the sea floor, suspension settling, bedload transport, and deposition from storm-generated flows. Microfacies are similar between carbonate-rich, mixed, and pure siliciclastic beds suggesting that sedimentary processes likely remained more or less the same throughout the deposition of sediment irrespective of the lithologies. Microscale data are then integrated with regional facies trends from core datasets and the stratigraphic framework from petrophysical logs to determine the distribution of large-scale paleoenvironmental conditions. Through this study, a better understanding of depositional processes associated with the short-lived period of carbonate deposition of the Altares Member and its larger association with the surrounding siliciclastic-rich Montney Formation can help further refine depositional models in mixed siliciclastic-carbonate systems.

PHLOGOPITE DEFORMATION FINGERPRINTS: A SYSTEMATIC STUDY OF STRAIN-RELATED MOSAIC SPREAD IN PHLOGOPITE FROM DRY-BONES BAY KIMBERLITES AND MANTLE XENOLITHS

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As the most common ferromagnesian trioctahedral mica in kimberlites, the origin of phlogopite in association with kimberlites is still debated. There are three recognized models for the origin of kimberlite-hosted phlogopite to date, including 1) xenocrysts originating from disaggregated metasomatised mantle xenoliths (e.g. peridotites and eclogites); 2) cognate phenocrysts crystallized directly from "proto-kimberlite" melts via fractional crystallization; 3) products from previously failed kimberlite intrusions that are subsequently transported by ascending kimberlite magmas, i.e. phlogopite fragments of antecrystic origin. These conclusions are drawn based on petrographic observations, geochemical analyses and experimental modelling. Kimberlitic phlogopites frequently display signs of ductile deformation in the form of kink-banding, undulatory and mosaic (patchy) extinction. Although the deformation features are an important petrogenetic recorder of kimberlite magma evolution, they are poorly quantified from a crystallographic perspective. Here we quantify the extent of plastic deformation in a suite of deformed phlogopite grains from Drybones Bay kimberlites and their entrained mantle xenoliths using in situ micro X-ray diffraction (μXRD). All the examined phlogopites show various degrees of subdomain misorientation (or strain-related mosaic spread) indicative of non-uniform strain experienced by these samples, resulting in streaking along Debye rings or chi (χ) direction in a 2-D μXRD pattern. Progressive deformation is visible in the XRD pattern, trending from discrete diffraction spots (unstrained) to streaks (non-uniform strain or bending) and sometimes showing an array of spots, or asterism (complex strain conditions), along the Debye ring dimension. This is interpreted to be proportional to increasing shear conditions. The degree of strain-related mosaic spread in phlogopite is quantified by measurement of the full width at half maximum (FWHMχ) of the X-ray streak. These results will be correlated with optical characteristics, grain size, unit cell parameters and chemical composition of kimberlite-hosted phlogopites to test whether systematic strain measurements could serve as a complementary vector to aid in discerning phlogopite paragenesis.

USING DEVIATED WELLS TO HARNESS HEAT FROM THE DEEP AQUIFERS OF THE ST. LAWRENCE SEDIMENTARY BASIN

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In Quebec (Canada), 76% of the energy consumed by residential buildings is used for heating. In its Plan 2030 for a green economy, the government of Quebec aims to increase by 25% the production of renewable energy and to reduce by 50% GHG greenhouse gases emissions related to building heating. Harnessing geothermal heat from deep saline aquifers in the St. Lawrence platform, which have not been exploited for heat until now, could help achieve these objectives. Geothermal doublets are the most common type of system worldwide for harnessing heat from deep aquifers (1–2 km depth). These systems typically consist of two wells, a producer, pumping brine from a deep aquifer, and an injector well, returning the cooled brine into the same aquifer. While most systems installed in the 1980s and earlier used vertical wells, deviated wells are now feasible and increasingly popular for geothermal heating projects. Here, the aim was to simulate and compare the performance of geothermal doublets having vertical wells 1000 metres apart or deviated wells (at 45°) that would be located in the St. Lawrence platform. At first, a homogenous deep aquifer between 800 and 1500 m depth was considered. A sensitivity analysis was

used to compare the impacts of the aquifer hydraulic conductivity (K) and fluid flow rate on their respective performances. Then this aquifer was separated into different units with varying hydraulic and thermal properties in order to assess the impact of vertical stratification on the performance of both systems. A first estimation of the heat production costs with both types of systems was made to further compare their advantages. Preliminary results, obtained with a homogeneous aquifer show the use of deviated wells would reduce the power consumption of the doublets, especially if the hydraulic conductivity is low. Indeed, with a fluid flow rate of 20 litres s^{-1}, if $K=1 \times 10^{-8}$ m s^{-1}, 61% less pumping power would be required over 30 years of operation with deviated wells, while it would be only 9% less if $K=1 \times 10^{-6}$ m s^{-1}. A doublet with deviated wells could thus be operated with a higher fluid flow rate, producing more heat. Moreover, wells designed with an inverted V configuration, allow for the wellheads to be close to each other and to the consumer, which would allow the same drilling pad to be used, as well as decrease the length of surface piping required.

QUANTITATIVE GROUNDWATER RESOURCE MANAGEMENT ON SMALL ISLANDS: THE MAGDALEN ISLANDS

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Groundwater resource management is a major issue on small islands, as it is often the only drinking water source. In these environments, fresh groundwater occurs as a lens overlying saline groundwater. Both its quality and quantity are threatened by numerous hazards, such as seawater intrusion along the coast, saltwater upconing under pumping wells, human activities, and climate change. Knowledge of the freshwater lens thickness is fundamental to support water resource management, but it is difficult to measure. Numerical models are powerful tools to assess the spatial distribution of hydraulic head and lens thickness. In the Magdalen Islands (Québec, Canada), 36 municipal pumping wells distributed on four islands are currently supplying drinking water to 11,000 inhabitants. 2-D numerical models have been developed on these islands to support groundwater management, using the MODFLOW-SWI2 program. The models were calibrated using piezometric observations, and observations of the freshwater - seawater interface when available. These calibrated models were used to inform groundwater management following three steps. Firstly, maps of piezometric head, freshwater - seawater interface elevation and freshwater lens thickness were generated, along with general water budgets, to understand the current state of water resources. The current rise of the freshwater - seawater interface under municipal pumping wells since the beginning of pumping was assessed, to evaluate when the new equilibrium will be achieved. Secondly, the models were combined with an optimization algorithm and with 2050 predictions of climate change and sea-level rise, to find sustainable groundwater pumping scenarios avoiding well salinization and anticipating climate change effects. The optimized pumping rates were compared to predictions of the 2050 water demand. Finally, the models were combined with the MODPATH particle tracking module, to identify areas that should be integrated in a groundwater resource protection plan.

TILL COMPOSITION MOSAICS

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Northern Manitoba contains areas of thin (< 5 m) to thick (5–100+ m) drift, all affected by the same 3+ glacial cycles. While modelling experiments indicate widespread cold-based conditions in the study area during the last glacial cycle, uniformly relict landscapes are not common. Instead, the glaciated landscape is palimpsest and commonly fragmented, which formed assemblages that recorded both shifting ice-flow direction through time and shifting subglacial conditions. It is now hypothesized that shifting conditions at the ice-bed interface occurred within a subglacial bed mosaic of erosion, deposition and sliding. Both ice dynamics (ice topography, subglacial water availability, temperature) and bed dynamics (existing sediment physical properties and thickness), and physical properties of the bedrock (erodability)) played a role in this mosaic – and contribute to palimpsest glacial landscape development. Herein, we provide evidence that the landscape in southwestern Hudson Bay has a high degree of landscape preservation in some areas, and strong overprinting by younger phases in other areas (patchy erosion and deposition). Based on our reconstruction, some of the subglacial remnant patches (relict-glacial terrain zones) predate the Last Glacial Maximum (LGM) and some may even predate the last glaciation. The majority of carbonate detritus transport also appears to be old, and unrelated to LGM or deglaciation. Some 'deglacial' terrain zones defined by a single time-transgressive lobate streamlined-landform flowset, actually contain different till-composition types, varying thicknesses of till and sculpted bedrock at surface. Hence, deciphering the levels of relative inheritance and overprinting can inform models of till genesis over time, and is essential for drift exploration in glaciated terrains.

DATING DUCTILE TO BRITTLE DEFORMATION BY U–Pb SMALL SCALE ISOCHRONS

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The uranium-lead (U–Pb) isotope system is widely applied for dating crystallization and re-crystallization of mineral assemblages during high temperature events in earth history. So far, the focus has been on accessory phases (zircon, monazite, titanite etc.), which, however, did not always form at the same time as the rock-forming minerals. While this method provides very good results for many magmatic and metamorphic processes, there are rocks and processes that cannot be dated in this way because suitable accessory minerals are missing and the temperatures were below the closure temperature of conventional thermo-chronometers. Examples for such rocks can be found in many shear zones, e.g. as mylonites, pseudotachylites, and tectonic cements, but also in high-P/low-T metamorphic units, or as ore mineralizations, and diagenetic to pedogenic cements. This study focusses on the application of in-situ U–Pb isotope analyses of low-U (e.g. 0.001 to 5 ppm) minerals in thin/thick sections by laser ablation inductive coupled plasma sector-field mass spectrometry (LA-ICP-SFMS). For this rock forming minerals and mineral assemblages that (re-)crystallized and equilibrated during an event, containing low but variable amounts of U and μ ($^{238}U/^{204}Pb$) will be analyzed. Instead of dating domains of single accessory phases, multiple analyses with variable U/Pb within mm- to cm-areas of a rock section will form a linear array in the $^{207}Pb/^{206}Pb$ vs $^{238}U/^{206}Pb$ space; the lower intercept with the Concordia curve is interpreted as crystallization age and the intercept at the y-axis as the initial Pb isotope composition. Over the last years this method has been applied at Goethe University/FIERCE for dating successfully various rock types (e.g. mylonites, pseudotachylites, carbonatites, calcite slickenfibres, cherts, granulites/eclogites, sheared calc-silicates, altered MORB and pedogenic sulphates) formed during Archean to Neogene time. Different examples will be shown and the results as well the standardization procedures discussed.

LATE PALEOZOIC–MESOZOIC GRANITIC ROCKS IN THE MONGOL-OKHOTSK BELT: PETROGENESIS, MINERALIZATION AND TECTONIC SIGNIFICANCE

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Abundant granitic rocks of the Late Paleozoic–Mesozoic age are widespread in Central and Eastern Mongolia and their role is important for understanding the evolution of the Mongol-Okhotsk belt, a key structure of the Central Asian Orogenic belt. The Mongol-Okhotsk belt stretches from Khangai Mountain in Central Mongolia to the Okhotsk Sea of the Pacific Ocean over 3000 km forming the concentrically zoned structure with the large Permian Khangai and late Triassic - early Jurassic Khentei batholiths in the core, the Orkhon-Selenge arc with Permian-early Triassic to Jurassic volcanic and plutonic rocks in the northwest and Permian to late Jurassic volcanic and plutonic rocks in rifts southwest of the Khentei Batholith. Granitic rocks formed during three magmatic phases: late Permian to early-mid Triassic (260–230 Ma), late Triassic to mid Jurassic (230–175 Ma), and late Jurassic to early Cretaceous (175–100 Ma). Many economically important porphyry Cu-Mo and rare metal (W, Sn, Li, Be, Ta, and Nb) mineral deposits are genetically related to the Late Paleozoic-Mesozoic granites. The majority of rocks in the batholiths (diorite-gran-

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odiorite-granite) and in a volcanic arc (diorite-granodiorite-granite) are related to I-type calc-alkaline to high K calc-alkaline metaluminous to peraluminous granitoids enriched in LILE and LREE, and depleted in P, Ti and Nb, Ta. The Sr-Nd-Hf isotopic data suggested these granitoids were derived from the depleted (juvenile) Neoproterozoic basaltic crust with the contribution of a small amount of older crustal material. Assimilation-fractional crystallization was the main process during magma evolution. Rare metal (Sn, W, Mo, Be) granites surrounding the batholiths are A-type (A2) peraluminous highly fractionated high K calc-alkaline to alkaline, predominantly peraluminous, enriched in Cs, Rb, Li, while associated alkali granites are enriched in Zr, Hf, Ta and REE, depleted in Ba, Sr, Eu, and Nb. Depletion in Nb, characteristic for volcanic arc magma reflects reworked crust and upper mantle during subduction and accretion processes. There are two tectonic models to explain the origin of granitic rocks in the Mongol-Okhotsk belt: (1) subduction and closure of the Mongol-Okhotsk Ocean, and (2) collision and raising of a mantle plume; these models are still under discussion.

NEW LA-ICP-MS U–Pb INHERITED ZIRCON AGES FROM THE GERMAN BANK PLUTON, OFFSHORE SOUTHWESTERN NOVA SCOTIA

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We conducted U–Pb LA-ICP-MS zircon analyses on a metaluminous magnetite-bearing granite sample of the German Bank pluton from offshore southwestern Nova Scotia and specifically targeted inherited cores, to investigate the nature of the basement and host rocks. The pluton may have intruded in one of the Gondwanan terranes that constitute the Appalachians of northeastern North America, or in one of the Northwest African fragments that have recently been discovered in eastern New England, and Grand Manan Island. The three Gondwanan terranes that collided with the Laurentian margin are from west to east Ganderia, which shows Amazonian affinity based on rock types, geochronology and geochemistry, Avalonia with likely Amazonian and/or Baltican affinity, and the Meguma terrane with likely Northwest African and/or Amazonian affinity. The Meguma terrane forms the southern part of Nova Scotia and does not show Precambrian rocks. Previous work on the German Bank pluton revealed a strong negative neodymium signature suggesting the presence of a ~2 Ga, possibly African, basement. Our sample was taken from core 76016-20, drilled in 1976 by the Geological Survey of Canada. Zircons from this rock previously yielded an ID-TIMS age of 300 ± 1 Ma (n=4). Zircons from this study yielded LA-ICP-MS $^{206}Pb/^{238}U$ ages between 324.1 ± 11.1 Ma and 247.1 ± 10.5 Ma, and a weighted mean of 294.5 ± 1.5 Ma (n=84, MSWD=6.1), which is reasonably consistent with the 300 Ma ID-TIMS crystallization age. Inherited zircon cores yielded $^{206}Pb/^{238}U$ ages of 673 ± 32 Ma (n=1), 444 ± 12 Ma (n=1), 361 ± 10 Ma (n=2), and 334 ± 11 Ma (n=3). Cryogenian igneous rocks are present in Avalonia and Northwest Africa, making the ~673 Ma zircon alone not diagnostic for the source. The ~444 Ma zircon is most consistent with the age of a 442 ± 4 Ma felsic tuff from the White Rock Formation of the Meguma terrane; the 361 ± 10 Ma zircons with a ~363 Ma granite exposed on Seal Island between the German Bank and mainland Nova Scotia; and the 334 ± 11 Ma zircons with a ~329 Ma granodiorite from the Mohawk well in offshore southern Nova Scotia. Therefore, these preliminary data suggest that most inherited zircon may have been sourced from local (Megumian?) rocks, whereas the Cryogenian zircon and existing neodymium data may indicate the presence of a Precambrian basement to Meguma or possibly other African (?) basement.

FLUID-STRUCTURE INTERACTION OF THE EARLIEST BIOMINERALIZING ANIMALS

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The late Ediacaran Period (~571–539 Ma) was a pivotal time in geologic history that witnessed the first appearance of macroscopic animal biomineralization particularly present within the expansion of tubular-shaped organisms. One important example is the iconic fossil *Cloudina*, which is globally distributed and a potential index fossil of the terminal Ediacaran stage. The degree of *Cloudina* biomineralization has been debated despite abundant fossil evidence, partially due to their often fragmentary individual preservation and preservation within a range of lithologies. Here we combine computational fluid dynamics (CFD) and structural mechanics to perform a series of fluid-structure interaction (FSI) analyses on idealized *Cloudina* models. Our results demonstrate large stresses near the sediment-water interface and assumed attachment location, which help explain the fragmentary nature of these fossils. This work provides key insight into *Cloudina* taphonomy and introduces new quantitative approaches for reconstructing Ediacaran paleobiology using multiphysics modeling.

DEPOSITIONAL HISTORY AND PALEOECOLOGY OF THE CALF CREEK LOCALITY (CYPRESS HILLS FORMATION) IN SOUTHWESTERN SASKATCHEWAN, CANADA

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The Eocene to Miocene Cypress Hills Formation (CHF) spans 28 million years, forming the conglomeratic caprock of the Cypress Hills plateau in southwestern Saskatchewan. The formation records one of the last significant sedimentation events in the western plains of North America at a time of major global climate fluctuations. The CHF contains the only high latitude, non-polar mammalian fossil assemblage known in Canada, spanning the Late Eocene to Early Miocene (Uintan to Hemingfordian land mammal ages). The Calf Creek Locality is Late Eocene in age (Chadronian 2) and was originally discovered in 1936 after bones were found eroding out of deposits along Calf Creek Coulee along the southeastern flanks of the Cypress Hills. This site is the most prolific Paleogene multitaxonomic bonebed in Canada, with numerous field campaigns resulting in the collection of roughly 60 fossil vertebrate families. This includes various carnivores and creodonts (ie. *Hyaenodon horridus, Hesperocyon gregarius,* and *Daphoenus* sp.), early horses and tapirs (*Mesohippus westoni, Mesohippus propinquus, Miohippus grandis, Colodon occidentalis*), small rhinos and deer *(Hyracodon priscidens, Leptomeryx* sp.), various "insectivores", brontotheres (*Megacerops coloradensis, M. kuwagatarninus*), and numerous freshwater fish, amphibians, and reptiles. This work presents a detailed sedimentologic and paleoecological study to establish a depositional framework for the Calf Creek Locality. Numerous studies of this kind are ongoing to establish a detailed regional framework to unravel the notorious complexity of the CHF, which hosts one of the most significant Cenozoic mammalian faunas in Canada.

CARBON SEQUESTRATION IN THE BAY OF ISLANDS OPHIOLITE COMPLEX, NEWFOUNDLAND

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The high reactivity and unique chemistry of ophiolites make them ideal sites for carbon mineralization. When groundwaters percolate through an ophiolite they dissolve it forming basic (Mg^{2+} rich) waters and ultra-basic (Ca^{2+}) rich waters. At elevated pH values, dissolved CO_2 in the water can dissociate to form CO_3^{2-} ions which readily bonds with Mg^{2+} and Ca^{2+} to precipitate carbonates. While this process has been proposed as a unique method to combat climate change the kinetics of these reactions and the impact they could have on the atmosphere have not been quantified experimentally. Experiments reported here were performed on rocks from the Bay of Islands Complex (BOIC) an ophiolite in Western Newfoundland. Crushed rock (< 7 mm) was combined with simulated basic and ultra-basic groundwaters in a closed batch chamber. A CO_2 analyzer was connected to the chamber headspace which monitored CO_2 concentrations over a 4-hour period. Conductivity, pH, ion concentrations, and total inorganic carbon (TIC) were measured before and after each observation. A total of 6 experiments were completed (in triplicate), one for each water type with and without the addition of crushed peridotite. In all experiments, except for the control group, the CO_2 concentration decreased in the chamber headspace over the 4-hour period. The addition of crushed ultramafic rock to deionized water had a CO_2 flux of -1.26 x 10^{-5} mol/m^2/minute (± 4.5 x 10^{-6} mol/m^2/minute, 1σ, n = 3). Basic waters and deionized water with rock had similar

CO_2 fluxes while ultra-basic waters had the greatest CO_2 flux of all experiments at -7.05 x 10^{-5} mol/m^2/minute (± 1.4 x 10^{-6} mol/m^2/minute, 1σ, n = 3). The data here suggest that ultramafic rock in the presence of H_2O can sequester carbon dioxide. At a greatly elevated pH (> 12) some of the CO_2 removed from the headspace precipitates out of solution as solid carbonate minerals. Our results indicate the potential impact this process could have on the Earth's atmosphere if this natural process were accelerated on an industrial scale.

GOLD GRAIN MORPHOLOGY AS AN INSIGHT TO GLACIAL HISTORY

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Gold grain dispersion is an extensively used exploration method in glaciated terrain. Tracking grain dispersion along the dominant ice-flow direction has enabled the discovery of various gold source(s) with a very high success rate over most of the Canadian Shield. If the area experienced a complex glacial history, palimpsest dispersion fans can modify the overall ribbon-like dispersion expected from dominant glacial flow, decreasing the success rate. However, evidence of complex sediment reworking can be cryptic, and in these areas the efficiency of the method remains elusive. Industry practice traditionally classified gold grain shapes according to the intensity of erosion on their surface in order to evaluate distance from the source. With the advent of Scanning Electron Microscope (SEM)-based automated gold grain counting, including systematic acquisition of high resolution Back-scattered Electron (BSE) image, a replicable shape classification protocol has been developed, and accurate proportions of "pristine", "modified" and "reshaped" grains are calculated and weighted according to grain size and "fragility". Based on images from almost a quarter of a million grains recovered from glacial sediments over the Canadian Shield, it was determined that "pristine", "modified" and "reshaped" grains typically occur in similar proportions in the regional background. Contribution from local dispersion trains is typically restricted to "pristine" grains that are added to the background signal. However, some areas of the Canadian Shield such as the northeastern part of the Abitibi sub-province and the Ashuanipi Complex, have abnormally high abundances of grains affected by intense wear despite proximity of abundant gold occurrences. These discrepant counts are typically found in genuine lodgement till in areas with clear dominant ice-flow. These sediments also have abnormal clay-silt-sand ratios that do not fit the usual trend seen in tills. Abnormal grain size distribution is considered as evidence that the till incorporated reworked sediments. The abnormal abundance of "reshaped" gold grains in such sediments supports the evidence of sediment recycling. Abundance of recycled gold grains explains the low success rate of the method in these areas. The issue is circumvented by using only "pristine" gold grain counts, conditional to sufficiently low detection limits and accurate classification. Gold grain morphologies can hence be used to highlight the existence of former cryptic glacial events.

POLYNORMALIZATION: A DETERMINISTIC-STOCHASTIC APPROACH TO GEOCHEMICAL SURVEY DENOISING

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Geochemical dispersion in the secondary environment, more notably hydromorphic dispersion, is notably difficult to interpret because interactions between active chemical processes are extremely complex. Consequently, the mineral industry usually limits its interpretation of surveys to statistical modelling, although such statistics can be quite refined. This leads to the issue that any survey has anomalies, which should be considered dubious. Subsequent geological verification rarely relates these anomalies to metallic deposits, meaning that most of these anomalies are likely false anomalies. Sorting these false anomalies from true ones remains the nemesis of geochemical exploration. Metal availability is not the only factor controlling metal concentration in a soil, stream sediment, ground water or any other medium susceptible to record hydromorphic dispersion. The concentration in the secondary environment is significantly influenced by the capacity of the material to fix the metals, which itself is controlled by the various equilibrium-induced physicochemical conditions and composition of the material. Hence, a series of dominant parameters can be identified, and which differ for material type and metals of interest. As abundance of the various constituents of the material is usually not measured, proxies must be selected to estimate their effect. As example, the cationic exchange capacity of humus can be approximated from loss-on-ignition (LOI) measurements. Abundance of these constituent is however dependant on pH-Eh conditions since their equilibrium reactions typically controls their abundance and trace metal scavenging capacity. Examples includes the Fe^{++} $Fe(OH)_3$ or the CO_2HCO^{3-} reactions. Consequently, the effect of acidity or redox potential on metal abundance is a discontinuous function and specific for each metal species. Variations of these controlling parameters are the prime cause of metal abundance variance, and need to be corrected in order to obtain the residual signal that relates to metal availability. Since these parameters are discontinuous and interdependent, they cannot be deciphered by sole statistical analysis. A procedure to remove these causes of variability, involving cascading normalizations, is presented here. The effectiveness of the method is supported by results obtained from various types of geochemical surveys where true anomalies were effectively discriminated from false ones.

RESOLVING THE ARCHITECTURE AND EVOLUTION OF A FOREARC BASIN: LOWER NANAIMO GROUP, GEORGIA BASIN, CANADA

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Recent studies indicate that the lower Nanaimo Group in the Georgia Basin, Canada comprises multiple depositional phases with distinct depocenters. Basal coarse-clastic strata (Benson and Comox Formation equivalents) are preserved in paleotopographic depressions, mainly in the northern Georgia Basin, Canada and grade upwards into coal-bearing coastal plain and shallow marine deposits. These strata are overlain in turn by mudstones and turbidites (Haslam Formation) that are regionally extensive and contain a glauconitic sandstone bed that is interpreted as a condensed section and disconformity that developed during deposition of the lower Nanaimo Group. A second major pulse of coarse-clastic sediment occurs 100s of metres above the glauconite bed and occurs in the central Georgia Basin; it comprises mainly continental facies that are equivalent to the Extension, Pender and Protection formations. The shift in sedimentation from the northern Georgia Basin to the central Georgia Basin is interpreted to represent the emergence of an island in the central Georgia Basin that acted as a major sediment source to the adjacent depocenter. Emergence of the island occurred contemporaneous with drowning of the northwest clastic source that debouched into the northern Georgia Basin. The distinctive stratigraphic disconnect between the coarse-clastic and coal-bearing strata of the northern Georgia Basin and the significantly younger coarse clastic and coal-bearing strata of the central Georgia Basin suggests that the lower Nanaimo Group was deposited in distinct depocenters that amalgamated into a single, large basin during regional transgression. Additionally, the absence of the younger phase of coarse-clastic deposits in the northern Georgia Basin suggests that syntectonic activity (i.e. uplift, erosion) extensively influenced deposition of the lower Nanaimo Group. These results demonstrate that the temporally long-ranging lower Nanaimo Group records a complex depositional history with multiple sedimentation events and evolving sediment sources that were affected significantly by syn-depositional tectonism.

EVALUATING TECTONIC MODELS FOR THE FORMATION OF THE CANADIAN CORDILLERA USING MULTIVARIATE STATISTICAL ANALYSIS OF CONODONT FAUNAS AND OXYGEN ISOTOPE GEOCHEMISTRY

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The Canadian Cordillera is a composite of crustal terranes with various stratigraphic and tectonic histories. The relationships between these terranes, and their relative positions throughout the late Paleozoic and Mesozoic, are an ongoing field of research. In British Columbia and southern Yukon, the oceanic Cache Creek terrane is structurally juxtaposed between the island arc Stikine and Quesnel terranes. Previous studies have concluded that the Quesnel and Stikine terranes were originally part of the same arc and were emplaced in their current configuration either through

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rotation ("entrapment" hypothesis) or by strike-slip faulting ("shearing" hypothesis). These tectonic models are mutually exclusive. The "shearing" hypothesis requires that the Stikine terrane was originally located to the south of the Quesnel terrane, before being moved northward by strike-slip faulting. In contrast, the "entrapment" hypothesis requires that the Stikine terrane was originally located to the north of the Quesnel terrane, before moving southward due to rotation. The present study utilizes two complementary methodologies to discriminate between these models. Multivariate statistical analysis of conodont faunas has allowed the degree of similarity between faunas of the Quesnel and Stikine terranes, and the northern and southern parts of the North American margin, to be determined during the late Carnian – early Norian interval. This is prior to the time when both terranes are thought to have accreted to the North American margin in the Early–Middle Jurassic. The conodont faunas of the Stikine terrane are more similar to those from the southern part of the North American margin than those of Quesnel are, suggesting that the Stikine terrane was further to the south during the late Carnian – early Norian, in accordance with the "shearing" hypothesis. Oxygen isotope ratios are primarily controlled by sea-surface temperature and therefore analysis of the oxygen isotope ratios preserved in early Norian conodonts of the Quesnel and Stikine terranes, as well as the northern part of the North American margin, allows the determination of relative temperatures of each of these tectonic entities at this time. The temperatures recorded by both the Stikine and Quesnel terranes are notably higher than those of the northern North American margin, suggesting that these terranes were to the south of their present location prior to accretion.

AN EVALUATION OF MAGMATIC PROCESSES RESPONSIBLE FOR TUNGSTEN ENRICHMENT IN THE CANADIAN TUNGSTEN BELT: EVIDENCE IN MELT INCLUSIONS OF GRANITOIDS ASSOCIATED WITH THE CANTUNG W-Cu DEPOSIT

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An important metal enrichment mechanism for many critical mineral deposits associated with granitic magmas (e.g. W, Mo, Sn), is their enrichment during protracted fractional crystallization. However, there is a lack of melt inclusion studies on these systems to i) evaluate whether these metals behave incompatibly during crystallization, and ii) that melts are enriched in these metals relative to the crust. The major and trace element abundances of apatite-hosted silicate melt inclusions (SMI) from two highly fractionated peraluminous monzogranite plutons (the Mine stock and Circular Stocks) as well as genetically related aplitic dykes associated with the world-class Cantung W-Cu skarn deposit, Northwest Territories, Canada are determined in this study. These data are used to evaluate the behaviour of W during fractional crystallization and determine the concentrations of W in the melt relative to the whole rock. The trace element abundances of homogenized and non-homogenized SMI via laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) shows higher average metal concentrations in the aplitic dykes compared to the Mine Stock, as expected for more evolved melts: W (28 ppm ± 19; 1σ vs 13 ppm ± 7; 1σ), Cs (126 ppm ± 130 vs 107 ppm ± 158), Ta (45 ppm ± 37 vs 9 ppm ± 7), Nb (32 ppm ± 17 vs 12 ppm ± 9) and lower B (847 ppm ± 526 vs 1242 ppm ± 1139). A correlation between Ta and Rb indicate fractionation into biotite. The Nb/Ta ratios are much lower in the aplite dykes (0.9 ± 0.7) compared to Mine Stock (2 ± 2), indicating preferred incorporation of Nb over Ta in biotite during fractional crystallization. However, no correlations between W and incompatible elements like Cs and Ta values were observed suggesting fractional crystallization is not a key factor in W enrichment. Future work includes the analyses of homogenized SMI from the Mine Stock and aplite dykes via electron probe microanalysis (EPMA) for the determination of their major element compositions to classify the tectonic environments of these magmas. The data from this study will also be used in batch crystallization calculations to model the trace element behaviour during fractional crystallization by using published mineral-melt partition coefficients of the modal minerals present. A comparison to other melt inclusion studies from other intrusion related W deposits, porphyry deposits and barren environments will allow us to further constrain the controls of W enrichment in these granitic systems.

TESTING CONCEPTUAL MODELS OF ATLANTIC CANADA ICE DYNAMICS

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Hypotheses and conceptual models regarding interpretations of ice dynamics and onshore and offshore stratigraphy in Atlantic Canada since the mid-2000's Atlantic Canada Ice Dynamics (ACID) workshops by and large have remained untested. In addition to the paucity of generous outcrops of pre-Illinoian stratigraphy onshore, a major limitation to progress is the lack of geochronology and application of new tools for investigating regional ice dynamics. I will present a summary of different approaches from collaborative studies in the past two decades to address key ice dynamical questions using examples from Atlantic Canada. (i) The concentration of ^{10}Be in quartz versus depth through the Hartlen Till reveals that the top of the Hartlen Till has a higher concentration, confirming that there was an ice-free 'exposure' period between the deposition of Hartlen and Lawrencetown tills. (ii) The concentration of ^{10}Be in quartz in the Lawrencetown Till is much lower than in the Hartlen Till, supporting the notion that the stratigraphically older Hartlen Till is composed of residuum from a much longer period of weathering than the Lawrencetown Till, supporting the regolith hypothesis. (iii) ^{10}Be exposure dating of boulders in Nova Scotia and Newfoundland show a collapse during the Bolling-Allerød warming after 15.6 ka, supporting the dominantly offshore (and lacustrine) radiocarbon minimum-limiting chronology—a collapse that is concomitant with other sectors of the Laurentide and Cordilleran ice sheet. (iv) Here, the nunatak hypothesis has been refuted in all but the highest coastal peaks (e.g. Cumberland Peninsula and Torngat Mountains), giving way to a 'maximum' ice dynamics model that explains the high inheritance concentrations of ^{10}Be and ^{26}Al in resistant bedrock in regions of cold-based ice (low erosion) compared to moderate and low concentrations in tills and bedrock in warm-based or ice-stream zones. (v) Those concentration distributions in tills also support the quasi-stationary ice divides in conceptual models inferred from landform and striae records for Atlantic Canada, and support the interpretation of the distinction between local tills (e.g. Stony Till) and long-transport tills (e.g. Hartlen Till) as a function of basal thermal regime. (vi) The hypothesis that parts of the Atlantic shelf may have been subaerially exposed for a short time during initial emergence prior to deglacial transgression is being tested (with N. King, GSC-A) using barnacle-covered cobbles from the Grand Banks seafloor that reveal ~1 kyr exposure ages with multiple isotopes.

CATASTROPHIC LAKE BREACH FLOODS AND THE EARLY MARS LANDSCAPE

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The early Mars environment, > 3.7 Ga, saw a surface host to large lakes and the formation of branching fluvial systems. The majority of identified lakes from this time period filled with water to the point of breaching, leading to the incision of outlet canyons. These paleolake outlet canyons represent some of the largest individual fluvial valleys incised during this era of early Martian history. However, at the global scale, it is often assumed that Martian valley systems, or valley networks, represent a signal of erosion occurring throughout early Mars history, at least episodically, as an integral part of the distributed hydrological cycle. In contrast to protracted valley incision, paleolake outlet canyons are interpreted to form rapidly due to high-discharge, catastrophic lake breach floods. Here we assess the contribution of lake breach flood erosion to the incision of fluvial valleys on early Mars. We use global Mars Orbiter Laser Altimeter (MOLA) topography and a progressive black top hat transformation to estimate and compare cumulative eroded volumes of 'classic' branching valley networks and paleolake outlet canyons. We find that paleolake outlet canyons have a cumulative eroded volume of ~1.4 x 10^{13} m^3, compared to a volume of ~4.3 x 10^{13} m^3 for valley networks. Our results indicate that catastrophic lake breach floods were an important geomorphic process for shaping the early Martian landscape, responsible for at least 24% of valley erosion. We propose that the

prominence of lake breach floods for valley incision on early Mars is a consequence of the topographic structure of the Martian surface, which is dominated by impact crater basins. Furthermore, we suggest that lake breach floods were likely an important influence on the topographic form of many Martian valley systems. As lakes breached and rapidly carved large outlet canyons, valleys on the surrounding landscape would have responded to this drop in local base level; one commonly observed example of this response is hanging tributaries flowing into paleolake outlet canyons. Past workers have often interpreted similar convex longitudinal valley profiles as a signature of a formative Martian climate and hydrologic cycle that was unable to supply long-lived runoff. Instead, we propose the alternative hypothesis that the convex topography of many Martian valley systems is the result of influence by catastrophic lake breach floods. We conclude that the influence of lake breach floods should be carefully considered when evaluating the evolution of fluvial valley systems on Mars.

MINERALOGY AND CHEMISTRY OF VANADIUM-BEARING SHALES AT THE VAN PROPERTY, MACKENZIE MOUNTAINS, NORTHWEST TERRITORIES

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The Van property in the Mackenzie Mountains, Northwest Territories, is a shale-hosted vanadium prospect from which seven samples were collected for mineralogical and compositional analyses. The collected samples are from the Lower Cherty Mudstone Member of the Lower Ordovician to Devonian Duo Lake Formation, Road River Group in the Selwyn Basin. Six shale samples are very fine-grained, dominated by quartz and clay with small patches of organic matter and finely disseminated traces of sulfides and oxides, show thin laminations, and can have mm- to cm-thick bedding-parallel carbonate veins. One sample of a calcareous concretion is made of relatively coarse-grained calcite with minor fine-grained siliceous, organic-rich component. Scanning electron microscopy on the shale samples shows a close spatial relationship between anhedral sphalerite and amoeboid Ti-V oxide, which is the dominant V-hosting phase in the shales. In some places, Ti-V oxide is also intergrown with clays but does not show a close spatial association with organic matter. Shale samples have average SiO_2 and Al_2O_3 concentrations of 80.9 ± 8.2 wt.% and 3.7 ± 3.4 wt.%, respectively, and are relative enriched in V (2565 ± 1274 ppm), organic C (6.5 ± 4.1 wt.%), graphite (3.2 ± 2.5 wt.%), and S (0.7 ± 0.5 wt.%), whereas other critical metals (e.g. Bi, Co, Cr, Mo, Sb, Te, U) are in the lower ppm level (< 100 pm to < 10 ppm) and are not elevated. However, strong positive correlations between critical metals and organic C, graphite and S are observed. One of the shale samples is relatively enriched in Al_2O_3 (10.6 wt.%) and shows strong Ba (1.2 wt.%) enrichment. The calcareous concretion sample has high CaO concentrations of 49.2 wt.% and low abundances in critical metals including V (53 ppm), organic C (0.22 wt.%), graphite (0.22 wt.%), and S (0.12 wt.%), and shows no other enrichment in critical metals. Shales have a relatively flat REE pattern with a negative Ce anomaly, and low Th/Sc ratio (< 0.6) indicating a mafic source and deposition along a passive margin. These results are in agreement with critical-metal-enriched shales at other locations in the Selwyn Basin. Although shale-hosted V is generally assumed to be hosted in clays and sulfide minerals, Ti-V oxide dominates at the Van property. The formation of Ti-V oxide may be attributed to either syngenetic deposition or epigenetic formation due to diagenesis and metamorphism.

WERE THE BYLOT BASINS INTERCONNECTED BETWEEN CA. 1090–1040 MA? INSIGHTS FROM SEDIMENTOLOGICAL AND TRACE ELEMENT STUDIES ON THE FURY AND HECLA AND THULE BASINS

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The Bylot basins are an important archive of the late Mesoproterozoic Era (1.2–1.0 Ga). Deposition is captured in four sub-basins: the Borden, Thule, Hunting-Aston and Fury and Hecla basins, which are preserved in northeastern Canada and northwestern Greenland. Stratigraphy of the Bylot basins is subdivided into three tectonostratigraphic packages (TA1–TA3) related to distinct phases of basin evolution: a lower package with presumed ca. 1270 Ma volcanic rocks interbedded with shallow-marine to terrestrial sandstone coincident with emplacement of the Mackenzie Large Igneous Province, a middle package comprising mostly shale and carbonate deposited during an extensional phase, and a third package dominated by sandstone and siltstone, possibly deposited during a final phase of compression and lithospheric flexure. Depositional age constraints only exist for strata of TA2, for which Re–Os ages from both the Borden and Fury and Hecla basins indicate deposition between ca. 1090–1040 Ma. Geochemical analyses of the lower part of TA2 (Arctic Bay and Ikpiarjuk formations) record restricted, and possibly lacustrine settings in the Borden Basin at this time. Strontium isotope data on carbonates of the overlying deep-water Nanisivik, and shallow-water Iqqittuq and Angmaat formations suggest renewed marine connectivity. Much less is known about TA2 strata of the Thule and Fury and Hecla basins, which are inferred to be tectonically linked with the Borden Basin. Here we integrate sedimentology, trace-element geochemistry, and Nd isotopic analyses to assess the fine-grained siliciclastic units of the Thule (Steensby Land Formation) and Fury and Hecla basins (Agu Bay and Autridge formations) to test and refine tectonostratigraphic models for the Bylot basins. Preliminary results hint that restricted depositional settings may have been common in the Bylot Basins ca. 1090–1040 Ma, and possibly extended several hundred kilometres west to the Amundsen Basin. Recent work is progressively shedding light on whether these basins were interconnected, as basin paleogeography has important implications for the viability of establishing chemostratigraphic correlations between these successions, linking available geochronology to undated strata and, more broadly, contributes to understanding on how intracratonic basins form and evolve.

TOWARD AN AVERAGE COMPOSITION OF VEGETATION AND ELEMENT NORMALIZATION DIAGRAMS IDENTIFYING NATURAL AND ANTHROPOGENIC PROCESSES AFFECTING WINE AND OTHER BIOSPHERE SAMPLES

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Geochemists use the average element composition of chondritic meteorites, primitive mantle, normal mid-ocean ridge basalt, continental crust, river water and seawater to identify natural and anthropogenic processes and inputs that potentially impacted samples of Earth materials (e.g. rocks, waters) over Earth's history. There is comparatively little information on biosphere averages, in particular vegetation. Vegetation samples can be used in the exploration for ore deposits but have much broader utility. Studies on plants and agrifoods (e.g. wine and maple syrup) reveal element behaviour during various processes. These include water uptake, organ and species hyperaccumulation, seasonal and geographic concentration differences related to the extent of evapotranspiration-concentration, and anthropogenic inputs from pesticides, processing equipment (e.g. stainless-steel tanks; brass gears in pumps) and processing materials (e.g. clay-fining in wine clarification). To create a modern average for vegetation, we sampled multiples of the 5 most abundant species of woody plants at 7 "ordinary" locations across Canada, and acquired concentrations for 33 elements using inductively coupled plasma mass spectrometry (ICP-MS) and ICP optical emission spectrometry (ICP-OES). Sample composition is somewhat correlated with location but does not correlate with clade (angiosperm versus gymnosperm) or species. Our preliminary average for all data opens the door to plots like primitive mantle normalized diagrams where anomalies reflect processes that affected basalts. The order of elements is critical, and for primitive mantle normalized diagrams, it reflects average mantle/magma element partitioning over Earth history. Diagrams where new biosphere/agrifood/wine samples are normalized to average vegetation to identify process-related anomalies, could have elements ordered based on partitioning estimated from either average vegetation/continental crust or vegetation/average freshwater ratios.

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GENETIC RELATIONSHIPS BETWEEN PERALUMINOUS GRANITES AND METAPELITES BASED ON GRENVILLIAN ROCKS IN THE LONG RANGE INLIER, NEWFOUNDLAND

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Rare Grenvillian (1030 ± 5 Ma; U–Pb, zircon) peraluminous granite sills in the Newfoundland Long Range Inlier are hosted by similarly uncommon pelitic gneisses with high peak metamorphic temperatures of 630–745°C at 3.4–5.0 kbar. The inlier is dominated by metaluminous megacrystic granites emplaced, during two Grenvillian magmatic events (ca. 1022–1232 and 985–993 Ma; U–Pb, zircon), into quartzofeldspathic gneisses of Pinwarian age (~1.5 Ga). The peraluminous granite age is within error of the age of the first pulse of Grenvillian magmatism. Metapelite xenoliths with prismatic sillimanite and K-feldspar occur in a pluton near Airplane Lake and show that source rocks at depth have compositions and grades suitable for generating the peraluminous granites. Feldspar Pb isotopes can potentially test that the former generated the latter; feldspars contain little U and measured Pb ratios largely reflect initial ratios, unless disturbed. Feldspar $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios in the metapelites range from 17.3–18.3 and 15.5–16.0, respectively, and between 16.7–17.4 and 15.3–15.7 in the granites. Over 40% of the ratios overlap and $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios are highly correlated ($r = 0.97–0.99+$ with $p = 0.00$). Thus, the two rock types appear genetically related and there was no net addition of new crustal material associated with Grenvillian peraluminous magmatism. Low to moderate Rb/Sr ratios (1.3–4.0) and high Ba contents (214–747 ppm) in the peraluminous granites indicate that magmatism was triggered by fluid-present melting of muscovite in the metapelite source rocks. Incomplete overlap in the Pb isotopic composition of granite and pelite feldspars, and the higher Pb isotopic ratios in the pelites, suggest disequilibrium melting. Apparently, pelite melting only partially released radiogenic lead from zircons because it occurred below the zircon closure temperature.

IMPLICATIONS OF GERMANIUM PARTITIONING INTO AMORPHOUS SILICA FOR THE CHERT RECORD

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The chemical composition of Precambrian marine sediments provides unique insights into the co-evolution of Earth's surface environment and biosphere. Banded iron formations (BIFs), shales and carbonates have been used as geochemical proxies, providing insights into the coupled evolution of Earth's surface and biosphere. Surprisingly, the most abundant lithology, marine cherts (90 wt.% silica in the form of microcrystalline quartz), have received considerably less attention. The problem, in general, has been ascertaining whether cherts are primary versus secondary in origin. This challenge, however, can be resolved by looking only at the chert layers from BIFs (approximately 50 wt.%) because those were chemically precipitated from seawater on the continental shelf. Previous geochemical investigations on cherts have largely focused on oxygen isotope composition to constrain seawater temperature (ranging from 25 to 85°C), or its silicon isotopes to investigate provenance. However, there is a gap in knowledge regarding the trace element composition of chert and its variations through time. For instance, the analysis of germanium (Ge) in the chert layers of BIF led to the recognition of past fluctuations between hydrothermal and continental inputs due to the upwelling of Fe-rich waters onto the continental shelf. Given the chemical similarities between Ge to Si, constraining the Ge composition of cherts may provide insights into the effect of increasing continental landmass on seawater chemistry during the late Archean (~2.8 Ga). Despite the importance of using Ge to track Si provenance, understanding how Ge partitions into chert remains poorly resolved. Here we study the kinetics and mechanisms of amorphous silica precipitation in oversaturated sodium metasilicate solutions using Fourier-transform infrared spectroscopy. The produced silica gel is further used in co-precipitation and adsorption experiments to define germanium's partitioning coefficient. Experimental findings are then used to infer temporal variations in Ge concentrations throughout the Precambrian based on the analysis of chert layers from BIFs. This work generates new knowledge regarding the Ge concentrations in BIF chert layers and provides additional context for Precambrian seawater, especially regarding potential temporal variations in the respective fluxes of hydrothermal versus continental inputs to seawater.

LITHOLOGICAL AND STRUCTURAL CONTEXTS OF THE SONNY ZINC SHOWING IN THE META-SEDIMENTARY BELT OF THE GRENVILLE PROVINCE IN WESTERN QUÉBEC

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The Grenville Province is known for its zinc deposits, but significant examples, such as Balmat-Edwards (NY), are rare and exploration models are nonetheless based on the characteristics of such large occurrences. This study presents a recent zinc discovery and its lithological and structural contexts, with the aim of refining favourable environments to such mineralization in the Grenville Province. Discovered in 2014, the Sonny zinc showing is located at Ile-du-Grand-Calumet in Québec, 100 km to the NW of Ottawa, within Mesoproterozoic marble units of the Grenville Metasedimentary Belt. A detailed map was completed on the southern portion of Ile-du-Grand-Calumet to characterize host rock stratigraphy, and to constrain the roles of deformation and metamorphism on zinc distribution. The stratigraphic sequence is composed of meta-volcanic mafic rocks (1.232 Ga, U–Pb on zircon), garnet-biotite-sillimanite paragneiss, quartzofelsdpathic schist and dolomitic to calcitic marbles containing minor calc-silicate units and highly recrystallized chert. The metavolcanic rocks developed hornblende-clinopyroxene assemblages, with local orthopyroxene and quartz, indicating metamorphism varying from amphibolite to granulite facies. The marble and associated mineralized layer are deformed and highly recrystallized. As such, primary structures are rarely preserved within the sequence, making a determination of polarity difficult. The mineralization is stratiform and composed of sphalerite ± pyrite in centimetric layers. It is found exclusively in the marble, with a thickness of up to five metres, at 3.8% Zn. The mineralized layer is also associated with an anhydrite-bearing layer within the marble, demonstrating an oxidizing shallow environment in arid conditions. At least three phases of ductile deformation are documented. The first one is characterized by isoclinal E-dipping folds (F1). The second phase of deformation is characterized by E-plunging isoclinal folds (F2). This D2 phase explains the variation in the orientation of the S1 foliation in the northern portion of the mapped area. A complex hook-shaped interference pattern (Type III) results from the sum of these phases and the folds show an important thickening within their hinge zones. The third phase of folding is represented by open E-W trending folds. This structural model makes it possible to target prospective Zn zones at the scale of Ile-du-Grand-Calumet. Combined with geochronological and thermobarometric studies, it will contribute to the refinement of the geological models in this portion of the Grenville. In addition, the identification of anhydrite-bearing and chert marker horizons provides metallotects that define a favourable environment for zinc mineralization.

AN OVERVIEW OF THE GEOLOGY AND MINING POTENTIAL OF SOUTHERN PROVINCES OF MOROCCO: THE REGUIBAT SHIELD (WEST AFRICAN CRATON) AND THE OULAD DLIM MASSIF

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Moroccan rocks and belts record 3 Ga of Earth geological history including various orogenic cycles (Eburnean, Pan-African, Variscan and Alpine). The different structural domains were studied and explored since the beginning of the 19th century leading to a wealth of publications and a well constrained geology, except for the remote and desert Southern Provinces, which have been the least studied until the

last 3 decades. The first step in their exploration was the geological mapping program launched by the Ministry of Energy transition and sustainable development, followed by airborne geophysical surveys (magnetic and gravimetric), strategic geochemical surveys, field studies and drilling campaigns accomplished by ONHYM (the Moroccan National Office of the Hydrocarbons and Mines). Later on, academic research followed up through field surveys and laboratory analysis to characterize for the first time the mineralogy, geochemistry and geochronology of the most important lithologies forming the Reguibat Shield and the adjacent Oulad Dlim Massif. The use of modern analytical tools unraveled the age and composition of the different rocks-forming units leading to an updated geological architecture of the Oulad Dlim massif and opening the debate about the paleogeography of this Caledonian-Variscan belt, and its Paleozoic evolution comparing with that of the other side of Atlantic Ocean. The exploration of the geology of the Southern Provinces of Morocco revealed also the presence of favourable mining targets such as syenites and synnyrites; different generations of carbonatites and granitoids; greenstone belts; gabbros; banded iron formations. These have potential for important raw strategic materials (REE, Nb, Fe, Li, etc.).

NUNAVUT, THE YOUNGEST JURISDICTION IN CANADA: YOUNG, DYNAMIC AND AMBITIOUS

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Nunavut is a vast territory – covering over 20% of Canada's landmass and more than half of its coastline – with a rich and varied geological history, and remains one of Canada's most sensitive and pristine environments. Nunavut's natural resource potential is significant; there are currently four operating mines (three gold, one iron), with at least one mine in each of the three regions. Nunavut was formed in 1999. The Canada-Nunavut Geoscience Office (CNGO), Nunavut's de-facto geological survey, was established in 1998 and is a partnered office, with partners being two federal government departments (Natural Resources Canada [NRCan] and Crown-Indigenous Relations and Northern Development Canada [CIRNAC]) and the territorial Government of Nunavut [GN]. The original and underlying idea for the CNGO is that, with devolution, the office (six professionals) would amalgamate with the other organizations (i.e. CIRNAC-Nunavut Regional Office [NRO] and GN-Economic Development and Transportation [EDT]) whose mandates also involve the management of lands and mineral resources. Devolution, slated to take effect in 2025, will improve the governance structure in Nunavut and allow Nunavut to assume control over its Crown lands and natural resources. With devolution, Nunavut's geological survey would be formed under the management of the GN. Public outreach and education efforts are varied in Nunavut, although resources and capacity are limited for the geoscience professionals in the three different organizations. The CNGO has four geologists who have expertise in bedrock mapping, surficial mapping and Paleozoic stratigraphy, and who lead appropriate outreach efforts. For any research project with fieldwork in Nunavut, the CNGO geologists conduct community engagement and information sessions before, during, and after the field, to engage with the nearest communities to the research area and inform Nunavummiut of the research goals and results. Published results are freely available on the CNGO website (www.cngo.ca). Additionally, the CNGO is working on a GeoTour of Iqaluit brochure. Self-guided and self-paced, this tour gives an overview of the geology and history at 19 stops in Iqaluit and can be done by walking (15-16 stops) or by vehicle (additional 3-4 stops). Work is undergoing to update and revamp the territory's geological databases (www.NunavutGeoscience.ca). The GN geologists have several outreach initiatives underway, including three week-long (in the evenings) prospecting courses in all of the 24 communities on a rotating basis. Numerous products (e.g. *What is Geology?* book for Grade 4's) are also available through a collaboration (www.miningnorthworks.com) with the NWT and NU Chamber of Mines.

PRECISE U–Pb ZIRCON AGES FROM ASH BEDS IN CLASSIC TERRENEUVIAN TO CAMBRIAN SERIES 2 SECTIONS IN THE SAINT JOHN AREA OF AVALONIA (SOUTHERN NEW BRUNSWICK, CANADA): NEW CONSTRAINTS ON CHRONOSTRATIGRAPHIC CORRELATIONS AND THE CAMBRIAN TIME SCALE

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Avalonian Cambrian sections in the Saint John area of southern New Brunswick have been contributing to the global understanding of Lower Paleozoic chronostratigraphy since the 1800s, and during the past 3 decades have contributed also to absolute age constraints in the Cambrian time scale through U–Pb zircon dating of ash beds. An ash bed in the Somerset Street section dated at ca. 531 Ma has been interpreted to approximate the age of the middle of the *Rusophycus avalonensis* Zone, the middle of the Placentian regional series, and the middle of the recently ratified Terreneuvian Series. The Somerset Street ash bed has traditionally been considered to postdate small shelly fossils attributed to the *Watsonella crosbyi* Zone in the classic Hanford Brook section, the oldest assemblage of diverse microfossils in Avalonia. A fine-grained grey-brown ash was collected from the Ratcliffe Brook Formation in the Somerset Street section, approximately 10 m stratigraphically below the previously dated ash layer. Youngest recognized zircon grains from this unit are tiny, sharply faceted short prisms that yielded a weighted average $^{206}Pb/^{238}U$ age of 532.3 ± 0.3 Ma. In the lower part of the Ratcliffe Brook Formation in the Hanford Brook section, U–Pb analyses of sharp, equant to short prismatic zircon grains from a coarser-grained grey ash sample yielded a weighted average $^{206}Pb/^{238}U$ age for 6 clustered, concordant single grain analyses of 531.5 ± 0.3 Ma. A third ash sample from near the top of the Ratcliffe Brook Formation in the same section in Hanford Brook yielded a weighted average $^{206}Pb/^{238}U$ age for 8 single grain fractions at 520.3 ± 0.3 Ma. A fourth ash sample was collected, also from near the top of the Ratcliffe Brook Formation but in Ratcliffe Brook. The best six analyses from that sample are all highly consistent, strongly overlap Concordia, and give a weighted average $^{206}Pb/^{238}U$ age of 519.1 ± 0.3 Ma. The new radiometric ages confirm the revised correlation between the Somerset Street and Hanford Brook sections that was proposed recently based on acritarchs. The revised correlation makes the association of small shelly fossils in the Hanford Brook section younger than 531 Ma, and hence in need of biostratigraphic revision. The radiometric ages from the upper part of the Ratcliffe Brook Formation show that it is significantly younger than previously assumed, placing it close to the Terreneuvian-Cambrian Series 2 transition and perhaps extending into Series 2.

"FIVE-ELEMENT"-TYPE (Ni-Co-As-Bi-Ag) VEIN DEPOSITS: A NON-MAGMATIC ORE STYLE GENERATED THROUGH BASEMENT INFILTRATION OF FORMATION BRINES AND METAL-ENRICHED HYDROCARBONS FROM OVERLYING INTRACRATONIC SEDIMENTARY BASINS

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"Five-element"-type (Ni-Co-As-Bi-Ag) vein deposits: a non-magmatic ore style generated through basement infiltration of formation brines and metal-enriched hydro-

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carbons from overlying intracratonic sedimentary basins. Polymetallic, uranium-bearing "five-element" type hydrothermal vein systems in the Northwest Territories of Canada show widely contrasting grade and tonnage characteristics from one deposit district to another, with historically world-class deposits at Great Bear Lake (Eldorado-Echo Bay, Contact Lake, Terra-Norex, Silverbear, Normin). Such deposits have been historically most widely attributed to granitic or bimodal magmatism based on tenuous spatial and temporal coincidence of mineralization to major igneous systems. In this study, integration of a variety of microanalytical methods (CL, SEM, fluid inclusion microthermometry, SIMS, LA-ICP-MS) focused on revising the current model for this deposit style, specifically with respect to metal and fluid sources, precipitation mechanisms, and reasons for variability in metal tenor at a regional scale. In particular, the study has focused on characterizing the onset of U and Ni-Co-As co-precipitation. Fluid salinity (~20–30 wt.% $CaCl_2$ equivalent) and entrapment conditions (^{18}O values increased by > 10‰ at the onset of U-Ni-Co-As-Bi-Ag mineralization). Fluid inclusions in mineralized quartz-carbonate veins are enriched in Ca-Sr-Ba-Mn-Pb-Zn, wholly consistent with a sedimentary origin (oilfield or basinal brine), but contain only sub-ppm concentrations of ore metals. Coeval bitumen (now solid hydrocarbon) inclusions, in contrast, are metal enriched, containing thousands of ppm of U-Ni-Co-Bi-Ag-Sb-As-Mo-Cu. Integration of all data types suggests that the precipitation of metals and bitumen was triggered by isothermal mixing of basement (metal-poor) and ^{18}O-rich basinal-type brines that were transporting metal-rich bitumen colloids or oil droplets. Oxidation of this hydrocarbon phase resulted in metal precipitation. The basinal brines and associated metal-rich bitumens were derived from the former overlying Athabasca-Hornby Bay-Thelon sedimentary basins that now only outcrop ~300–1000 km away from the study areas. U–Pb dating of vein minerals indicates arsenide-stage mineralization having formed at 1470–1400 Ma, consistent with the prerequisite occurrence of evaporite and black shales in the overlying sedimentary sequences. Co-precipitation of metals and bitumen highlight the role of hydrocarbons in transporting U and other metals in these polymetallic vein systems. Importantly, the study provides a direct confirmation from the fluid inclusion record that high-grade polymetallic vein systems of this variety are linked to the metal and fluid budgets of previously overlying sedimentary basins rather than the basement rocks in which the deposits are hosted and precludes magmatic fluid and metal sources.

BINDING AND TRANSPORTATION OF Cr(III) BY CLAY MINERALS DURING THE GREAT OXIDATION EVENT

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A spike in chromium (Cr) abundance above crustal background in iron formations post-dating the Great Oxidation Event (ca. 2.5–2.3 billion years ago) has been suggested to reflect the evolution of terrestrial aerobic pyrite and siderite oxidation and the initiation of widespread acid rock drainage which would enhance Cr transport from terrestrial weathering environments to the oceans. However, it remains unclear whether Cr was transported in a soluble form (as Cr(III) or Cr(VI)), or bound to particulate surfaces. Here, we experimentally test the complexation of Cr(III) – the typical oxidation state associated with primary igneous minerals such as chromite – to three common soil clay minerals (kaolinite, illite, and montmorillonite) and the associated bonding mechanisms using extended X-ray adsorption fine structure (EXAFS) spectroscopy. Our results demonstrate that Cr(III) precipitates on the clay surfaces over a pH range of 6 to 8 as guyanaite (β-CrOOH) due to the replacement of surface Al-octahedra by paired Cr(III) octahedra. Bidentate bonding with a Cr-Cr interatomic distance of 3.43–3.51 Å allows Cr(III) to become strongly incorporated into the clay structure. A comparison between Cr(III) adsorption/precipitation onto the three clays and the desorption of Cr(III) from Cr(III)-spiked clays shows that kaolinite has the highest retention capacity for Cr(III), a predictable result given that an entire Al-octahedral sheet is exposed for Cr(III) binding, while illite and montmorillonite only have Al-edge sites. Moreover, Cr(III) was essentially immobilized in our experiments except under very acidic conditions (pH < 2). Extending our results to the interpretation of the Cr record in iron formations, we suggest that under intense chemical weathering conditions, not only did acidity promote the solubilization of Cr(III) from primary Cr-bearing minerals, but that parent rocks were more systematically weathered to an advanced state dominated by kaolinite – creating ideal conditions for Cr adsorption. Erosion of regolith that scavenged mobilized Cr(III) could then facilitate transport of Cr(III)-bearing kaolinite to coastal environments where it contributed to the super-crustal Cr abundances above detrital background preserved in ca. 2.5–2.0 Ga iron formations.

PERCEIVED VERSUS QUANTIFIABLE PRODUCTIVITY OF EARTH SCIENTISTS DURING COVID-19 WORK-FROM-HOME INITIATIVES

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The Covid-19 pandemic has caused the implementation of widespread work-from-home initiatives to combat the spread of the virus. These restrictions have presented challenges for Earth scientists as they adapt to the "new normal". An online survey was distributed to Earth scientists globally (N=662) who were working from home during the pandemic to investigate the impact of these protocols on the productivity of different groups within the field. Responses were collected from September to December of 2020. Participants were asked whether they felt their productivity had increased, decreased, or stayed the same during the pandemic. Several factors influencing productivity were also investigated, including working environment, family obligations, financial situation, and changes to work hours. Due to a variety of circumstances, young Earth scientists, particularly female-gendered, reported the highest decrease in their productivity. Fifty-six percent of female respondents reported a decrease in productivity compared to 39% of male respondents. These results only indicate individuals' perception of their own productivity, which can vary greatly day-to-day. To compare these results to quantifiable productivity, accepted publications were analyzed as a proxy for academic productivity. Web of Science was used to find publications accepted in journals with an impact factor greater than 2 within the topics of Geology, Geoscience Multidisciplinary, and Geochemistry and Geophysics. Publications from April 1, 2019, to March 31, 2020 ("before pandemic"), were directly compared to April 1, 2020, to March 31, 2021 ("during pandemic"), for females versus males. The total number of publications increased from the 2019-2020 year to the 2020-2021 year, indicating that an individual's perception of their productivity may not match their actual, quantifiable productivity. When publications by gender are normalized to match the proportion of women in geoscience careers (24%), there are more female first authors than male first authors, most notably by 4% in the 2020-2021 year. Although the pandemic has undoubtedly created new challenges for Earth scientists, it is important to note that our perceptions may not always match the reality.

USING DETRITAL CHROMITE IN PROVENANCE STUDIES – INSIGHT FROM THE SLAVE CRATON

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Provenance determination of clastic sedimentary rocks has largely been carried out by the use of detrital zircon U–Pb dating, which has shown to be particularly powerful when combined with Lu–Hf, $\delta^{18}O$ and trace element data. However, the use of detrital zircons is restricted to felsic-intermediate provenance and does not constrain the source and flux of mafic-ultramafic magmas to the crust. To address this issue, we show with an example from the Slave craton, the value of using detrital chromites to appraise the nature and role of mafic-ultramafic provenance in the evolution of the Archean lithosphere. Ultramafic magmatism such as komatiite is a characteristic feature of Archean cratons, reflecting the addition of juvenile crust and a clue to the thermal evolution of the Earth lithosphere. The Slave craton in northwest Canada contains multiple greenstone belts but no identified komatiite. The reason for this lack of komatiite remains unresolved. The Central Slave Cover Group (ca. 2.85 Ga) includes fuchsitic quartzite with preserved detrital chromite grains as part of the heavy-mineral laminations. Major and platinum group element systematics indicate that the chromite grains were sourced from Al-undepleted

komatiitic dunites. The grains have low $^{187}Os/^{188}Os$ ratios relative to chondrite with a narrow range of rhenium depletion ages at 3.19 ± 0.12 Ga. While these ages overlap a documented crust formation event, they identify an unrecognized addition of juvenile crust that is not preserved in the bedrock exposures or the zircon isotopic data. The documentation of komatiitic magmatism via detrital chromites indicates a region of thin lithospheric mantle at ca. 3.2 Ga, either within or at the edge of the protocratonic nucleus. This study demonstrates the applicability of detrital chromites in provenance studies, complementing the record supplied by detrital zircons.

CONTROLS OF DIAMOND FORMATION AND PRESERVATION, SLAVE PROVINCE, CANADA

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Diamond-forming processes operate world-wide, but their timing is craton-specific. Yet in all cratons, the formation of lithospheric diamond deposits is intricately connected with craton-forming processes. The Slave Province is a composite Archean craton consisting of a Paleo- to Mesoarchean nucleus (ca. 4.03–2.85 Ga), the Central Slave superterrane (CSST), with remnants of a quartzite-dominated late Mesoarchean cover sequence, to which juvenile Neoarchean supracrustal terranes were accreted between about 2.738 and 2.62 Ga. The entire province was affected by a post-tectonic granite bloom between 2.605 and 2.58 Ga, and cratonization followed between 2.5 and 2.4 Ga. Diamond production from Slave Province mines is bimodal, consisting mainly of lithospheric P-type and E-type diamonds, with minor sub-lithospheric diamonds and late-stage fibrous overgrowths. P-type diamonds are concentrated in depleted parts of Mesoarchean lithosphere under the CSST that are tectonically buried under the eastern Neoarchean accreted terranes. Isotopic evidence for Mesoarchean ages of these diamonds suggests early crust-mantle coupling which is corroborated by detrital diamond occurring in 2.96 Ga metasediments of the Central Slave Cover Group. Significant Neoarchean diamond-forming events have not been recognized to date. Cratonization of the province was followed by a ca. 200 Myr magmatic hiatus, after which Paleoproterozoic mafic magmatism (beginning at 2.23 Ga) led to breakup of the Neoarchean precursor craton of the Slave Province at ca. 2.03 Ga. Deposition of passive margin sequences along the rifted craton margins was followed by collisional and transpressional orogenic activity along the margins, culminating in the incorporation of the province into Laurentia at about 1.84 Ga. Alkaline Paleoproterozoic magmatism may have caused pervasive metasomatism under the southwestern part of the CSST, but numerous pre-Laurentia mafic dyke swarms did not have widespread deleterious effects on the P-type diamond content under the rest of the CSST. E-type diamonds are mostly post-Archean and were emplaced by a Paleoproterozoic subducted slab recognized on LITHOPROBE seismic reflection sections. Underplated from the west, this slab is thought to have protected the overlying remnants of the depleted Mesoarchean lithospheric root from further thermal erosion. The Mesoproterozoic Mackenzie plume profoundly modified the lithosphere under the northern part of the Slave Province, negatively affecting diamond potential north of Contwoyto Lake. Eocambrian and Phanerozoic kimberlite events are unlikely plume-related, as plumes of that age were not recognized within and around the Slave Province.

THE PERMIAN SYSTEM: A COLLABORATIVE EFFORT DIRECTED BY THE INTERNATIONAL UNION OF GEOLOGICAL SCIENCES (IUGS), THE INTERNATIONAL COMMISSION ON STRATIGRAPHY (ICS) AND THE SUBCOMMISSION ON PERMIAN STRATIGRAPHY (SPS)

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Sir Roderick Murchison named the Permian System in 1841, but the succession he recognized is very different from today's Permian; this evolution can be attributed to the efforts of IUGS. The ICS, the largest and oldest constituent scientific body in IUGS, is charged with precisely defining global units of the Geologic Time Scale. The formation of these scientific organizations resulted in an ongoing international collaborative effort to define our language of time. Permian rocks crop out in British Columbia, western Alberta, the Yukon, and PEI, but the most remarkable successions are found in Nunavut in the Canadian Arctic Archipelago. Ellesmere and Axel Heiberg islands have some of the best outcrops of Permian rocks anywhere in the world, unobscured by a mere trace of vegetation, but their remoteness means they are not the best places to define Global Stratotype Sections and Points (GSSPS). However, the efforts of a few Canadian geoscientists working on these successions have influenced many GSSP decisions by demonstrating the potential for interregional correlation. Ray Thorsteinsson, Walter Nassichuk, John Utting and Tim Tozer collected many fossils while mapping out the Permian and Triassic successions under arduous conditions. Their remarkable framework influenced the PhD studies of two young geoscientists and set in motion long careers gathering more knowledge of the succession. In turn, Benoit Beauchamp and Charles Henderson introduced many students to the region. The Permian began with a great ice age and ended with Earth's greatest extinction. The waning stages of the late Paleozoic Ice Age are realized on SW Ellesmere as high-frequency marine cyclothems of the lower Raanes Formation transformed into longer duration sequences – at the same time, early synapsids roamed PEI red sand. The arctic succession significantly influenced SPS determinations leading to recent IUGS (2020, 2021) ratification of Sakmarian and Artinskian GSSP proposals, but these stages are defined in the southern Urals of Russia – very close to the region that inspired Murchison. The base Middle Permian can be correlated, using a few serrated conodonts recovered from the Assistance Formation, with a great reefal succession in the Guadalupe Mountains, West Texas. Finally, a ceratite and a few conodonts, including *Hindeodus parvus*, discovered in black shale of the Blind Fiord Formation, provide a link to the base-Triassic GSSP at Meishan, South China, where an IUGS Geopark and two museums were constructed to celebrate the body stratotype of the last Permian Stage and the dawn of the modern biota.

TRACE ELEMENT LOSS IN PYRITE AT DIFFERENT PRESSURE AND TEMPERATURE

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Pyrite is a common accessory mineral in orogenic gold deposits as in several deposits. Orogenic gold deposit systems are one of the most important sources of gold that is valuable for economic geology all around the world. Although ore fluid sources are debated by researchers, metamorphic fluid source is the most popular model recently. During syngenetic and/or early diagenetic formation, pyrite is enriched with gold and trace elements that are present in the water column. When the metamorphism starts, later pyrite overgrowths replace earlier pyrite, and some trace elements and gold are released to fluids that may precipitate as a free gold in cracks or as a rim around the pyrite. If the metamorphism reaches high grade (Greenschist and/or Amphibolite facies), pyrite converts into pyrrhotite, and gold and associated trace elements are released to metamorphic fluids to form ore deposits. But this model is only based on the interpretation of pyrite and pyrrhotite from optical petrography. Our research aim is to convert pyrite to pyrrhotite experimentally, and determine which trace elements are released or retained and in what quantities. To do this a piston cylinder apparatus was used to apply pressure and variety temperatures. After the conversion, reductant pyrrhotite was analyzed by scanning electron microscopy (SEM) to check amount of pyrrhotite produced, and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used to determine trace elements In this way, how trace elements are depleted and/or enriched at the reaction edge and if the pyrite converts partially into pyrrhotite, and how trace elements behave will be explained.

HAZARD MAPPING OF UNSTABLE ROCK SLOPES IN NORWAY INCLUDING SECONDARY AND CASCADING EFFECTS

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Mapping of unstable rock slopes that can cause catastrophic failures started in Norway by the Geological Survey of Norway (NGU) in 2005 and a procedure to assess the hazard and risk of failures was developed by Norwegian experts supported by selected European key scientists in 2012. This procedure focusses first on a hazard

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and second on a consequence analysis. Unstable rock slopes are identified by systematic analysis of aerial photos, high resolution LIDAR data and InSAR deformation maps (https://insar-norge.no) that are all freely available in Norway online. After recognition of the deforming rock slopes the hazard assessment combines mapping of morphological signs of rock slope deformation, structurally based stability considerations, the state of slope activity and past failure events to come up with a hazard score that is categorized in 5 hazard classes. The state of activity is defined by deformation measurements, comparison of paleo slip rates determined with cosmogenic nuclide dating with those deformation measurements and rock fall activity. Into the consequence analysis goes the analysis of the volume, the potential run-out area and, where applicable, the assessment of related displacement waves or the formation of rockslide dams. Possible future dams are assessed considering potential dam height, related inundation areas and the stability of such dams using the geomorphic blockage index. This method will be showcased with the Reinbenkan unstable slope in northernmost Norway. Cascading effects such as landslide dam failure or secondary mass flows are considered where relevant. The results are used by the Norwegian Water and Energy directorate (NVE) which is responsible for landslide hazard mapping carried out in Norway to define hazard zones. The consequences in terms of potential loss of life for possible failure scenarios are assessed by calculating the expected number of persons in the areas that are exposed by the direct failure or its secondary consequences. Hazard and risk management is a task of NVE. So far, more than 500 unstable rock slopes have been identified, of which 110 were hazard- and risk-classified. Forty-eight of the slopes have hazard zones and thus result in building restrictions. All medium and high-risk sites are followed up by NVE with continuous surveillance. This approach was built for the typical conditions of Norway characterized by fjord landscape on a passive continental margin with a low number of medium and high magnitude earthquakes and thus similar to the NE of Canada.

U–Pb VEIN XENOTIME GEOCHRONOLOGY CONSTRAINTS ON TIMING AND LONGEVITY OF OROGENIC GOLD MINERALIZATION IN THE MALARTIC-VAL-D'OR CAMP, ABITIBI SUBPROVINCE, CANADA

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Despite a well-developed structural framework for orogenic gold deposits from the Val-d'Or camp (MVC), southern Abitibi subprovince, reported mineralization ages span ~350 million years (ca. 2705–2360 Ma), significantly post-dating the tectono-metamorphic history of the ca. 2700–2580 Ma Abitibi-Wawa Orogeny. Structurally controlled gold deposit clusters in the MVC are distributed along the E-W striking Larder Lake-Cadillac fault zone and hosted in lower-order structures that cut volcanic rocks and intrusions of the greenstone belt. In these structures, gold is commonly associated with two vein sets that form pre- or syn- the regional-penetrative fabric (S2) developed during major N-S shortening and peak-metamorphism. This include: (1) highly deformed quartz-carbonate veins entrained in the S2-fabric and (2) laminated brittle-ductile quartz-tourmaline-carbonate reverse-shear and sub-horizontal tension-veins that are sub-parallel to oblique to the S2-fabric, the latter which contains the bulk of orogenic gold in the MVC. Here we present in-situ U–Pb geochronological and rare-earth-element (REE) data from 85 xenotime grains, on average 25 µm in size, hosted within pre-S2 quartz-carbonate veins (Kiena-S50) and syn-S2 quartz-tourmaline-carbonate veins (Kiena-Deep, Goldex, Triangle, Plug #4, Beaufor, Pascalis Gold Trend and Akasaba West). Xenotime in equilibrium with pyrite hosting gold inclusions, within pre-S2 quartz-carbonate veins of the Kiena-S50 orebody, shows a subtle negative Eu anomaly and yields an age of ca. 2686 Ma (n=19 analyses) consistent with the age of pre-S2 diorite (2686 Ma) at Kiena. Based on textural and chemical observations, the syn-S2 laminated quartz-tourmaline-carbonate shear veins record two separate hydrothermal events. Xenotime, in textural equilibrium with pyrite containing native Au- and Au-Te inclusions, contains elevated Nd (> 1000 ppm) and Sm (> 2490 ppm) and yields an age of ca. 2643 Ma (n=102 analyses). Based on equilibrium textures between Au-bearing pyrite and hydrothermal xenotime, we interpret this age to reflect the timing of major gold precipitation in the MVC. Xenotime in textural disequilibrium with auriferous sulphide assemblages, hosted near dissolved sulphide grain boundaries and fractures, contains lower medium-REE values and yields an age of ca. 2607 Ma (n=68 analyses). We interpret this age to reflect hydrothermal remobilization of gold in five orebodies, where xenotime was sampled. These data imply that district-scale orogenic gold endowment formed during three tightly-constrained to short-lived, individual periods of < 10 million years, with the bulk of gold introduced along the retrograde path of the orogenic cycle at ~2643 Ma and 25–30 million years post-peak metamorphism.

RELATIVE MOBILITY OF ARSENIC AND ANTINOMY IN A NEUTRAL-MILL TAILINGS IMPOUNDMENT AT THE GIANT MINE, NORTHWEST TERRITORIES

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Contamination of groundwater by toxic elements stemming from the extraction of base and precious metals is a global issue. The toxic elements arsenic (As) and antimony (Sb) are often associated with gold (Au) extraction. In this study, we examine the mobility of As and Sb within a neutral-mill tailings impoundment at the Giant Mine, NT, through a mineralogical, geochemical, and hydrological investigation. The Giant Mine is a legacy gold mine located 5 km from Yellowknife, NT, Canada. Currently the mine is undergoing one of the largest remediation projects in Canadian history. During active production between 1948 and 1999, 220 000 kg of refractory Au was extracted from arsenical pyrite and arsenopyrite. As a by-product, 16 Mt of roaster residue and flotation tailings, bearing As (3000 mg kg^{-1}) and Sb (220 mg kg^{-1}), was produced. Impoundments continue to be utilized as storage areas for underground water prior to treatment and tailings have been subjected to weathering processes over the last 20 years. Core samples were collected and analyzed for total C-S and the mineralogical composition was determined using X-ray fluorescence, optical microscopy, scanning electron microscopy-electron dispersion spectroscopy, and synchrotron-based bulk and microprobe measurements. Porewater was collected from the vadose and saturated zone and analyzed for pH, Eh, alkalinity, and major and minor dissolved ions, and interpreted using geochemical modelling. Active oxidation of sulphide minerals is present to a depth of 3 m, however, arsenopyrite persists with low alteration in weathered samples. Dissolved concentrations of As and Sb are primarily elevated in the groundwater and vadose zone respectively. Arsenic is incorporated in secondary Fe-oxides in the vadose zone and mobility in the groundwater is associated with reducing conditions and underground dewatering effluent. Antimony liberation is associated with sulphide mineral oxidation in the vadose zone with no evidence of subsequent incorporation in secondary Fe-oxides. The management of As and Sb in neutral mine drainage tailings requires consideration of the respective conditions in which these elements are mobile.

VOLCANISM ASSOCIATED WITH TRANSTENSIONAL BASIN DEVELOPMENT IN THE DEER LAKE BASIN, NEWFOUNDLAND

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Continental-scale strike-slip shear and fault zones extend from 100s to 1000s of kilometres and typically delimit zones of intense continental deformation and lithospheric plate boundaries. The initiation of these large-scale shear zones occurs during collision and lateral escape tectonics, rifting processes and differential rotation of plates. Transtensional strike-slip shear zones and rifting typically occur in localities where there are pre-existing lithosphere scale discontinuities and breaks that may mark zones of earlier plate boundary sutures. Much of the northern Appalachian Orogen, in northeastern Canada, is dissected by major strike-slip to transtensional faults. The faults have long histories and are complex, crustal- and lithospheric-scale features reactivated throughout the late Paleozoic assembly of Pangea. The continuous interplay between the lithospheric plates, their subcontinental lithospheric mantle, and surficial processes (i.e. riverine, biological, atmospheric, gravitational, erosional) controlled the development of the Carboniferous Deer Lake Basin in western Newfoundland, which formed along the sutured Laurentia and peri-Gondwana margin (Long Range-Cabot Fault System). The earliest deposits of the basin include the late Tournaisian lacustrine-deltaic succession of the Saltwater Cove For-

mation, Anguille Group that includes minor intervals of basalt flows and pyroclastic deposits. The basalt samples have E-MORB (enriched-mid ocean ridge basalt) to OIB (ocean island basalt) chemical affinities (i.e. enriched LREE to HREE), and have $\varepsilon Nd_{(t=345\ Ma)}$ values between +2.8 to +6.4. Pyroclastic deposits include mafic lapilli and intermediate tuff, and have compositions similar to CAB (continental arc basalt), with steeply inclined LREE relative to HREE patterns, negative Nb and Ti anomalies, and have $\varepsilon Nd_{(t=345\ Ma)}$ ranging from -6.1 to -1.0. Geochemical variability within the mafic rocks is explained by their common derivation from an E-MORB source but suggests that pyroclastic subsets of the magmas were subsequently variably contaminated by substantially older lithospheric material including Grenvillian basement. Field evidence, petrography, geochemical and isotopic data support emplacement of the Anguille volcanic rocks in a transtensional, intra-orogenic rift basin setting that formed during the initial assembly of Pangea. Reactivation of the fault system enabled adiabatic decompression partial melting proximal to the lithospheric edge of the Laurentian margin, asthenospheric upwelling via edge-driven convection processes aided by continental insulation that enhanced magma ascent to the surface. Slowing convergence that resulted in a reduction in the magnitude of transtensional faulting closed the conduits for mantle-derived melts and this led to the termination of volcanism.

PALEOPROTEROZOIC ARC MAGMATISM ALONG THE LAURENTIAN MARGIN: EVIDENCE OF CRUSTAL GROWTH DURING SUPERCONTINENT ASSEMBLY

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Arc magmatism in convergent plate margins has been a major contributor to continental crustal growth. Magmatism along convergent margins provides valuable insights into crust–mantle interaction during the growth of a supercontinent. Granitoids form the major component in convergent margin architecture and thus the lithogeochemistry and isotopic compositions of the granitoids can elucidate the role (if any) of mantle contribution in their genesis. This is particular true for A-type granites (sensu lato), where despite their widespread global occurrence, there is still much debate on their origin. The southern margin of the Archean North Atlantic Craton witnessed major pulse of continental arc magmatism at ca. 1800 Ma, following the arc-backarc–continent collision (onset of the Makkovikian Orogeny) during the Paleoproterozoic assembly of Nuna. Major- and trace-element lithogeochemical signatures indicate intrusive rocks having compositions typical of A-type, ferroan granites. Extended trace- and rare-earth-element patterns have strong negative Nb and Ti anomalies, signatures typically associated with crustal-derived melts related either to subduction or crustal contamination processes. Trace-element ratios (e.g. high $La/Yb_{(PM)}$ and Zr/Y) are indicative of low degrees of partial melting at high temperatures (~850-900°C), where garnet and amphibole are stable in the melt. Most of the intrusions have $\varepsilon Nd_{(0)}$ values that range from -5.1 to +2.0, with $T_{(DM)}$ model ages that range from 2750 Ma to 1880 Ma, suggesting derivation by partial melting of predominantly Neoarchean to Paleoproterozoic sialic crust. The neodymium crustal index (NCI) values indicate a crustal neodymium contribution ranging from 21% to 58% (mean = 42%), suggesting an equal volume of recycled crust relative to the addition of juvenile mantle-derived magma during the derivation of silicic magmas. Based on petrology, lithogeochemistry and isotopic compositions the ca. 1800 Ma magmatism appears to constitute a continental magmatic arc. This arc developed after collision of the Cape Harrison arc with the North Atlantic craton during Nuna assembly.

THE MILLSTREAM SUBBASIN WITHIN THE MIDLAND TO LOWER MILLSTREAM AREAS: IMPLICATIONS FOR THE REGIONAL TECTONICS OF SOUTHERN NEW BRUNSWICK DURING THE EARLY MISSISSIPPIAN

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A Recent integration of multiple datasets has confirmed the existence of an approximately 90 km^2 pull-apart basin (termed the Millstream Subbasin) within the Midland area of southern New Brunswick. From the late Tournaisian (?) to Serpukhovian ages, the Millstream Subbasin was deposited as a pull-apart basin resulting from differential rates of strike-slip movement along major faults (the Belleisle Fault to the north and the Kennebecasis Fault to the south) which were both intermittently active as major dextral systems during this time range. The age justification of the stratigraphy is through analysis and correlation of palynology samples collected from boreholes and outcrops across the subbasin. The Millstream Subbasin is bounded by a minor system of normal faults (the Lower Millstream-Parleeville faults to the north and the Dickie Mountain-Peekaboo faults to the south) contained in the area between the major strike-slip faults. An initial episode of major fault activity caused the opening of the basin by movement of the northern Lower Millstream and southern Dickie Mountain normal faults, which allowed for the deposition of Late Tournaisian (?) basal thick red bed clastic sequences and subsequent deposition of the Visean limestone and evaporite facies. After a period of quiescence, renewed dextral transtension along the major faults caused the formation of the Parleeville (north) and Peekaboo (south) normal faults which crosscut the older normal faults. This second phase of normal faulting resulted in the deposition of red clastic sequences above the evaporites and the down-dropping of the central portions of the basin until fault movement waned during the early Serpukhovian. The formation of the newer cross-cutting normal faults is most likely due to the differential rotation of the subbasin area between the Belleisle and Kennebecasis major faults and/or the transfer of dextral movement between the major faults. Subsequent field evaluations in the Smiths Creek area to the east have revised the dextral displacement kinematics of the Kennebecasis Fault during the Visean-Serpukhovian ages, but additional field studies and palynology analysis will have to be done to improve the confidence level of these initial observations at Smiths Creek.

THE DEVELOPMENT AND EMPLACEMENT OF FIELD TESTING METHODS FOR ENGINEERED BARRIERS FOR NUCLEAR WASTE MANAGEMENT: BOREHOLE MODULES

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The Nuclear Waste Management Organization is characterizing sites to implement a deep geological repository (DGR) to safely isolate and contain Canada's used nuclear fuel. As part of the site selection process, the NWMO has drilled, cored and tested several deep boreholes, including six one-kilometre long holes in the Ignace area. In parallel with site characterization activities, the NWMO has been further developing the engineered barrier system (EBS), consisting of containers that will be loaded with used nuclear fuel and a clay-based sealing system, which will surround the containers and fill the space between the containers and the host rock. Development of this system includes both manufacturing and testing activities, many of which are unique to the Canadian system, which uses copper coatings instead of separately fabricated copper parts, and uniquely large bentonite clay block materials. Analyses have been benchmarked against reference materials from both Canadian and other international programs. Much of the focus of the studies has been within controlled settings, such as laboratories or specialized engineering/manufacturing facilities, and performance assessments have tended to be based on one or very few criteria, such as corrosion in simplified solutions, or mechanical strength tests of as-manufactured materials. More recently, there has been a shift in the program to better consider components through a synergistic lens that emphasizes multiple DGR processes occurring simultaneously. The approach is not entirely new, in that radiation-corrosion experiments, for example, have been conducted for many years; however, the increased emphasis has created a desire to identify new techniques to assess the EBS materials. Coupled with a need to migrate the program toward site-specific vs. generic conditions, this has led to a need for new NWMO collaborations to create new methods. The first such method to be deployed was the borehole module, which contains copper coupons inside a granular bentonite material, but also allows in situ water to saturate the module once emplaced in borehole. In September of 2021, a series of borehole modules was inserted by a team of geologists and material scientists into a 300 m into a deep borehole. This paper will present results from that emplacement, but also provide details on the design of and materials selected for the borehole modules, and the plan for retrieval and analysis in the future.

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THE PACIFIC MUSEUM OF EARTH: A LOOK BACK, A STEP FORWARD

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The Pacific Museum of Earth (PME) is Vancouver's hidden gem. Located in the Department of Earth, Ocean and Atmospheric Sciences (EOAS) at the University of British Columbia (UBC), the museum provides an educational window into a wide range of topics including climate science, oceanography, geology, mineral resources, environmental sciences, geological engineering, and planetary science. The PME is UBC's oldest museum (established ca. 1924) and is one of the main public outreach venues at UBC. Our interdisciplinary nature places our outreach programs in a powerful position to engage, excite, and educate university students, faculty, and staff as well as local youth and their teachers about fundamental science and its linkages to topics of environmental, economic, and societal importance. In 2019, we wrote a 5-year strategic plan as a way to fine-tune the museum's goals and create a systematic approach to achieve them. One of the activities outlined in our strategic plan was to develop an annual reporting process to PME stakeholders in UBC's Faculty of Science and EOAS. As a starting point, we took a closer look at our outreach program data collected since 2013, when the museum underwent a complete transformation — new exhibits, outreach programs and new staff. We wanted to place our current and future activities into the broader context of where we started. In this presentation, we will showcase historical statistics from our outreach efforts and explain how these data allowed us to think more broadly about how we engage with local school groups, creating opportunities to shift our focus and push beyond our traditional outreach approach. We will highlight, in particular, how the COVID-19 pandemic required us to re-imagine our entire outreach program menu — specifically, how we engage with students and teachers outside of the museum space. This sudden shift resulted in a new virtual dimension to our outreach offerings and gave us a pathway to connect with K-12 students and public audiences far beyond our local schools and communities.

REEVALUATION OF THE TECTONIC HISTORY OF THE DASHWOODS TERRANE USING IN SITU AND ISOTOPE-DILUTION U–Pb GEOCHRONOLOGY, WESTERN NEWFOUNDLAND

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Synthesis of the Ordovician Taconic orogeny in the northern Appalachians has been hindered by along-strike variations in Laurentian, Gondwanan, and arc-generated tectonic elements. The Dashwoods terrane in Newfoundland has been interpreted as a peri-Laurentian arc terrane that collided with the Laurentian margin at the onset of the Taconic orogeny, whereas along strike in New England, the Moretown terrane marks the leading edge of peri-Gondwanan arcs. The peri-Laurentian affinity of the Dashwoods terrane hinges on the correlation of its oldest metasedimentary rocks with upper Ediacaran to Lower Ordovician rift-drift deposits of the Laurentian Humber margin in western Newfoundland. Here, we report U–Pb dates and trace-element geochemistry on detrital zircons from metasedimentary rocks in the southern Dashwoods terrane that challenge this correlation and provide new insights into the Taconic orogeny. Based on age and trace-element geochemistry of detrital zircons analyzed by laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) and chemical abrasion–isotope dilution–thermal ionization mass spectrometry (CA-ID-TIMS), we identified ca. 462–445 Ma sedimentary packages with a mixed provenance consisting of Laurentian, Gondwanan, and arc-derived Cambrian–Ordovician sources. These deposits overlap in age with Upper Ordovician strata of the Badger Group of the Exploits subzone, which also contain Laurentian detritus. We infer dominantly east-directed transport of Laurentian detritus from the Taconic collision zone across a postcollisional arc–back-arc complex at ca. 462–455 Ma followed by dominantly west-directed transport of detritus from the Red Indian Lake arc at ca. 455–445 Ma. Analysis of zircon inheritance from Dashwoods igneous rocks suggests that 1500–900 Ma Laurentian crystalline basement of the Humber margin is an unlikely source of Dashwoods inherited zircon. Instead, a more cosmopolitan Laurentian inheritance may be best explained as sourced from subducted Laurentian sediment. Sampled metasedimentary units from the southern Dashwoods terrane do not correlate with rift-drift strata of the Humber margin as previously proposed, nor with the basement of the Moretown terrane; yet, these Middle to Upper Ordovician successions suggest an alternative plate-tectonic model in which the Taconic orogeny was initiated by collision of Gondwanan arc terranes that closed the main tract of the Iapetus Ocean along the Baie Verte–Brompton Line.

BENTHIC ECOSYSTEM EXPOSURE TO ROAD SALT (CHLORIDE) ASSOCIATED WITH GROUNDWATER – STREAM INTERACTIONS

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Increasing salinization of surface waters due to excessive chloride inputs is a growing threat to aquatic ecosystems. An important source of chloride in temperate climates is road salt, used as a de-icing agent on roadways, sidewalks, and parking lots. Road salt can travel to freshwater streams through direct surface runoff, stormwater drainage, and via infiltration and groundwater transport. Most prior research has focused on the direct runoff pathway and resulting increased surface water concentrations, while few studies have evaluated the groundwater pathway and its potential impact on the chloride concentrations in shallow streambed sediments. The objective of this study is to evaluate the spatial and temporal variability of chloride exposure to benthic zone species found in streambed sediments as well as the controls associated with groundwater – stream interactions. This objective was addressed by conducting field work in two urban streams located adjacent to major arterial roadways in London, Ontario. The porewater streambed chloride concentrations were measured along ~100 m stream sections monthly starting November 2020. These concentrations were typically > 120 mg/L, the long-term freshwater aquatic life guideline for chloride in Canada, during all sampling events. Some locations sustained year-round concentrations > 640 mg/L, the short-term freshwater aquatic life guideline. These data also showed substantial spatial variation in chloride concentrations, with highs > 5000 mg/L generally nearest the roadways and only 20 m away from areas at ~150 mg/L. Porewater concentrations were often over 1000 mg/L greater than stream water Cl indicating long-term influence of high Cl groundwater discharge to the stream. Novel electrical resistivity tomography (ERT) surveys were also performed at one of the stream sites every month to permit time-lapse monitoring of changes in electrical resistivity (reflecting changes in chloride concentrations) in the groundwater below the streambed between sampling events. ERT surveys match the patterns in porewater sampling and show the contamination extend to a greater depth. ERT has also shown that the subsurface electrical conductivity is generally highest in the spring and early summer months and lowest in the late fall. The highest Cl zone indicated by porewater and ERT is found to be associated with a long groundwater plume extending 15 m into the riparian zone towards possible sources of snow piles form the roadway and nearby parking lot. The study findings are needed to inform road salt usage and management programs and policy across North America, as well as inform ecological management and restoration initiatives for urban streams.

CARBONATE $\delta^{13}C$ VARIATION IN CRYOGENIAN DIAMICTITES AS RECORDS OF EROSIONAL UNROOFING

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In a snowball ocean, little carbonate production is expected due to progressive CO_2 accumulation and resultant acidification of the ice-covered residual brine. Buffering by carbonate dissolution could maintain $(CaMg)CO_3$ saturation near unity, well below levels of supersaturation normally required for precipitation. Discrete beds of micritic $(CaMg)CO_3$ within Cryogenian glaciomarine sequences are mostly detrital. It was recently proposed that authigenic dolomite did form in the matrix of Sturtian diamictites and stratified synglacial deposits in South Australia. The $\delta^{13}C$ of matrix dolomite is distinctly lighter (−5 to +2‰ VPDB) than dolomite clasts in associated diamictite (+2 to +7‰), which are clearly derived from the disconformably under-

lying preglacial Burra Group (Tonian). The isotopically-light matrix dolomite has no known source and is inferred to be authigenic. However, other regions preserve carbonates with negative $\delta^{13}C$ values lying directly beneath Sturtian-age diamictites and above carbonates with heavy Burra-like values (e.g. Garvellach negative anomaly in Scotland & northern Namibia). Stratigraphic relations in Scotland and U−Pb geochronology in Ethiopia imply little to no hiatus between the Garvellach anomaly and panglacial onset. It is possible therefore that the matrix dolomite in South Australia was detrital, eroded from Garvellach-anomaly strata no longer preserved. Those strata, being as yet poorly-lithified, would yield only fine-grained detritus. Abrasion and quarrying of the older well-lithified Burra Group supplied matrix detritus and clasts. Progressive erosional unroofing is supported in South Australia by increasingly-heavy matrix values upsection (−5.3 to +1.77‰, 3-pt moving average in Frontier Blinman−2 core). Similar $\delta^{13}C$ secular trends, attributable to unroofing, are observed in regions where relict Garvellach-age strata are preserved. Their thickness is ≥ 60 m in Scotland (base covered) and ≥ 140 m in Namibia (top truncated). Unless their original thickness was far greater, their partial survival and extended detrital unroofing records support extraordinarily low rates of Sturtian glacial erosion given its 56-m.y. duration.

HOW COLD WERE SNOWBALL-EARTH OCEANS?

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Theory and modelling imply that ice-covered terrestrial oceans would be well-mixed and nearly isothermal because they were warmed only from below. Their temperatures would be close to the freezing point, since water columns were everywhere in contact with ice. The freezing point of seawater varies inversely with salinity and pressure — its values over the range of conditions relevant to snowball Earth have been computed from thermodynamic equations, supported by experimental data. We do not know the salinity of ambient (nonglacial) Cryogenian seawater, but the uncertainty would be dwarfed by the magnitude of salinity change due to sequestering of freshwater in snowball ice sheets and sea-glaciers. Phanerozoic seawater ranged between 45 and 35 ppt salinity, with slow rises from riverine input and rapid falls from output of giant evaporite deposits. If we assume a Cryogenian ambient salinity of 40 ppt, the residual brine would have been ~80 ppt assuming a km-thick sea glacier and an ice-sheet thickness of 2 km averaged over all continents. Since pressure increase with water depth is 1.0 MPa/10 m, the pressure at the base of a km-thick sea-glacier would be ~90 MPa. The freezing point of 80-ppt brine at 90 MPa is computed to be −13°C (260K), which would pertain to the early-stage glacial-maximum conditions. In a snowball Earth scenario, numerical simulations indicate that ice-sheets shrink and the sea-glacier thins as atmospheric CO_2 accumulation warms the surface. Near the end of a snowball stage, salinity and pressure would be ~60 ppt and ~36 MPa, corresponding to a computed freezing temperature of −6°C (267K). Such cold brine temperatures, combined with anoxia, would be favourable for burial of juvenile organic matter, flushed from surface cryoconite pans. This would translate as a source of oxygen for the snowball atmosphere.

TRANSITION METAL MOBILITY AND RECOVERABILITY FROM WEATHERED SERPENTINITE AND SERPENTINITE SKARN TAILINGS FROM LORD BRASSEY MINE, AUSTRALIA AND RECORD RIDGE, BRITISH COLUMBIA, CANADA

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Ultramafic and mafic mine tailings host transition metal resources, such as nickel (Ni), cobalt (Co), and platinum group elements (PGE), whose high value could serve as a motivator for existing mines to reprocess their tailings. Many of these target metals are initially hosted by olivine, repartitioned during serpentinization to form sulphides, oxides and alloys, and then remobilized during weathering to form authigenic carbonates, sulphates and oxyhydroxides. Reprocessing tailings may further provide environmental benefits, including a reduction in waste output and the ability to offset greenhouse gas emissions by enhanced silicate-weathering and carbonation reactions. Here we use powder X-ray diffraction (XRD), scanning electron microscopy, electron probe micro-analysis and synchrotron X-ray fluorescence (XRF) mapping to demonstrate how Ni and Co are mobilized to their final sinks. Samples of serpentinite, skarn and weathered tailings from the historical Lord Brassey nickel mine in Tasmania, Australia and weathered outcrops of serpentinite ore from the proposed magnesium mine in Record Ridge, BC, Canada are analyzed and compared. Our results show that nickel is preferentially sequestered in weathering products, primarily Fe-oxyhydroxides. We demonstrate that it is possible to calculate an accurate elemental bulk composition comparable to that obtained using bulk XRF analysis by integrating electron probe micro-analysis and quantitative XRD results. This approach accounts for the compositions and quantities of the minerals in each sample to provide geometallurgical context that cannot be obtained using bulk XRF alone. An improved understanding of the deportment of Ni and Co in ore and tailings will aid in making an economically viable framework for tailings reprocessing.

EVOLVING PERMIAN ARC MAGMATISM ASSOCIATED WITH SLAB ROLLBACK IN THE SOUTHERN BEISHAN OROGEN COLLAGE, CENTRAL ASIAN OROGENIC BELT, NW CHINA

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The southern Beishan Orogen Collage contains the youngest suture zones in the Central Asian Orogenic Belt and is a key area to understand the contentious terminal accretion and collision history of this orogen. Based on a multidisciplinary study combining structure with new geochronological, geochemical, and isotopic data, we established a temporal and spatial linkage between the back-arc ophiolite of the Liuyuan Complex, and the Ganquan Complex. The latter mainly comprises felsic volcanic and volcaniclastic sedimentary rocks and is divided into a lower and upper sequence separated by an unconformity and/or intervening thrust. U–Pb ages and εHf values of detrital zircons confirm a genetic relationship between the two sequences. The lower and upper sequences have U–Pb zircon ages ranging between 295–285 Ma and 283–281 Ma whereas the εHf values vary from -4.2 to +1.9 and +1.3 to +7.6, respectively, indicating the magma source attained a more juvenile signature over time. Geochemistry of the two sequences is similar, and both have an arc signature, characterized by LREE enrichment, flat HREE patterns, and negative Eu anomalies. Their trace element signatures display high LILEs/HFSEs characteristics and negative anomalies in Nb, Ta, Sr and Eu normalized to NMORB, suggesting a high degree of fractionation and subduction-related origin. The correspondence in age between spatially closely associated 290–286 Ma Liuyuan Complex and the Ganquan Complex suggest they likely represent part of a related arc-backarc system, which initiated between 292 Ma and 290 Ma with opening of the backarc due to slab rollback. The progressive increase of juvenile isotopic signatures over time in the Ganquan arc suggests that arc-trench migration progressively removed the arc from the influence of a continental contaminant.

SETTING AND PROCESS EVOLUTION OF THE CENTRAL NEWFOUNDLAND GOLD BELT

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The eastern Dunnage Zone of the central Newfoundland Appalachians hosts Early Devonian (ca. 410 Ma) orogenic gold mineralization along a major northeast trending fault corridor that is delineated by latest Silurian syntectonic magmatic and clastic sedimentary rocks. The orogenic gold system is characterized by structurally controlled, polyphase, quartz vein sets that form offshoots within a triangle zone-like structural domain that is defined by southeast- and northwest-dipping thrust faults.

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The southeast-dipping fault system includes the Victoria Lake Shear Zone, which uplifts metamorphic rocks of Ganderia and buries gold-mineralized, latest Silurian syntectonic magmatic and sedimentary rocks. The northwest-dipping fault system includes the Valentine Lake Shear Zone, which hosts an approximately five million ounce (5 Moz) orogenic gold deposit within generally shallow dipping quartz-tourmaline-pyrite ± gold veins that cut uplifted Neoproterozoic granitoid rocks. High-precision CA-ID-TIMS U–Pb zircon geochronology defines a ca. 422–420 Ma syntectonic magmatic pulse along the length of the orogenic gold-mineralized fault corridor throughout central Newfoundland. These magmatic rocks are slightly older than the associated syntectonic, basal, clastic sedimentary rock sequence (Rogerson Lake Conglomerate); however, they structurally overlie the Rogerson Lake Conglomerate in some areas. Latest Silurian syntectonic bimodal magmatism and immature clastic sedimentation along the central Newfoundland gold belt are attributed to a transient phase of lithospheric extension or transtension resulting from asthenospheric and crustal melting related to slab break-off that marked the end of the Salinic orogenic cycle. In north-central Newfoundland, extension began earlier in the Silurian (ca. 429 Ma) than along the Rogerson Lake Conglomerate belt because the normal fault system did not propagate across- and along-strike until ca. 424–418 Ma. A latest Silurian (Ludlow to Pridoli), southeast-dipping, listric normal fault system in central Newfoundland may have provided structural surfaces for subsequent northwest-directed thrust reactivation and, as well, increased heat and fluid flow in the crust leading to orogenic gold mineralization. Hydrothermal rutile from structurally controlled, gold-mineralized quartz veins of the Leprechaun Pond deposit (Valentine Lake) and Wilding Lake prospect yielded ID-TIMS ages of ca. 410 Ma. These are consistent with Early Devonian quartz vein emplacement and orogenic gold mineralization in central Newfoundland during thick-skinned thrusting, backthrusting, and hydrothermal fluid-pressure cycling along the Acadian deformation front of Ganderia. Ultimately, the setting and process evolution of the central Newfoundland gold district are strikingly similar to world-class Archean orogenic gold systems of the Canadian Shield.

SETTING AND STRUCTURE OF MEGUMA GOLD DEPOSITS: EVIDENCE FOR VEIN DEVELOPMENT DURING LATE, PROGRESSIVE, FLEXURAL-SLIP FOLDING

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Over sixty past producing gold districts are scattered throughout the Meguma Supergroup metasedimentary rocks of southern Nova Scotia. That these gold districts all share many similarities in terms of vein types and related mineralogy suggests a common origin for all deposits. Although several models have been proposed for the formation of the auriferous veins, including both pre- and syn-folding origins, their regional and local setting and the character of the vein arrays point to a saddle-reef (flexural slip) model late in the evolution of gold development. All Meguma gold deposits (MGD) occur in hinge areas and adjacent steep limbs of regional anticlines that are attributed to the Neoacadian orogeny. The regional folds are characterized by chevron and box folds that develop by flexural folding and, importantly, involve hinge migration throughout their development; thus, auriferous veins concentrated in fold hinges developed late in the fold history. MGD are dominated by bedding-concordant veins, including both laminated- and massive veins, en echelon vein arrays, and saddle reef veins; importantly all record flexural-shear on fold limbs and related dilation in fold hinges. Discordant veins show mutual cross-cutting relationships with bedding-concordant veins, have increased concentrations in deposits compared to regional occurrence, and reflect hinge-parallel extension during vein emplacement. All veins of the "vein array" consist of similar mineralogy and include gold, thus consistent with synchronous emplacement. Documented flexural-shear strain from displaced discordant veins and rotated en-echelon veins records significant shear strain localized within minor mudstone layers that reflects only minor changes in limb dip of steep limbs. MGD deposits occur throughout the entire stratigraphic sequence; however, regional, and local stratigraphy may influence the charter of individual deposits. Documented gold distribution in many deposits is controlled by minor overprinting structures, including minor folds, vein intersections, and fault intersections with veins, and therefore suggests remobilization of gold or introduction of late gold. A flexural-shear model for vein formation late in fold development provides an explanation for the distribution of MGD in fold hinges and steep limbs of regional anticlines and provides a model for exploration for new deposits and extensions of existing deposits.

WHY IS THERE STILL A DIVERSITY GAP IN THE STEM SECTOR IN CANADA?

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Why is there still a diversity gap in the STEM sector in Canada? How can organizations create the conditions to ensure an inclusive and accepting environment for everyone? In this session Deputy April Howe will discuss the systemic barriers that prevent equity-seeking people from pursuing a STEM career in Canada. She'll share her perspective on the impact of unconscious bias, discrimination, and the importance of creating "inclusive space".

NON-CONVENTIONAL ISOTOPES AS PALEOREDOX PROXIES FOR BANDED IRON FORMATIONS FROM THE BATHURST MINING CAMP, NEW BRUNSWICK, CANADA

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The Bathurst Mining Camp (BMC) located in northeastern New Brunswick, Canada, hosts mid-Ordovician Algoma-type banded iron formations (BIFs) that are associated with economically significant volcanogenic massive sulphide (VMS) deposits. These BIFs are chemical sedimentary rocks that contain alternating thin laminations of magnetite, chert, chlorite, and/or siderite, and are important archives for Earth's paleoceanographic evolution. This study presents data for multiple non-conventional stable isotope systems (e.g. δ^{57}Fe, ε^{205}Tl, δ^{98}Mo, and δ^{65}Cu) to identify basin redox conditions and hydrothermal inputs. The goal of this study is to constrain the scale of anoxia required in the model for Algoma-type BIF deposition and to establish a spatial-isotope relationship with VMS deposits. The BMC has also undergone greenschist facies metamorphism and intense deformation, so a salient question is whether any of the isotope systems have been disturbed or if depositional fractionation is preserved. Powders from 30 geographically dispersed samples were digested using a sequential extraction protocol where silicate and Fe-oxide phases were chemically separated, avoiding the mixing of isotopic signatures observed in bulk isotopic analysis. A series of ion exchange chromatography methods were used to isolate elements of interest such as Fe, Tl, Mo, and Cu. Isotopic compositions were measured using a Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS). The distinctive fractionations of the redox-sensitive metal isotopes are related to varying depositional conditions. Iron isotope geochemistry can highlight potential contributing sources of iron input such as hydrogenous, terrestrial, hydrothermal, and biological origins. The fractionation of Tl, Mo, and Cu isotopes can record alternating periods of oxic or anoxic settings, driven by redox transformations and geochemical adsorption mechanisms. Thallium isotopes can also be used to trace ore-forming processes in mineralized lithologies. Petrographic studies show the presence of finely laminated magnetite and lack of primary hematite, suggesting that redox conditions for the formation of these secondary phases were most likely anoxic as opposed to suboxic. Our multi-isotope, mineral-specific, paleoredox proxy approach allows for the reconstruction of the paleoenvironment for BIF formation, pinpoints isotopic differences between proximal and distal BIF localities relative to VMS deposits and resolves the scale of anoxic conditions. This multi-isotope approach has rarely been applied to hydrothermal systems, and not previously in this important mining camp.

INTEGRATION OF CHRONOSTRATIGRAPHIC METHODS AND IMPLICATIONS FOR CONVERGENT-MARGIN BASIN CHRONOLOGY

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Studies of sedimentary strata in convergent-margin basins, including forearc basins, are used to infer the evolution of the associated continental margin, including uplift

and sedimentation from the adjacent arc and development of the accretionary prism. These basin-scale interpretations depend on the accuracy of the stratigraphic framework developed for the basin, as stratal ages are used to define the chronology of events therein. Detrital zircon (DZ) maximum depositional ages (MDA) are a relatively new method for approximating true depositional ages (TDA). In convergent-margin basins, DZ MDAs are inferred to closely approximate TDAs based on the proximity of the basin to the active arc. The youngest DZ within the sedimentary fill of the basin should possess ages similar to the TDA. However, DZ MDAs represent only the upper limit of TDA rather than the TDA itself, and in the absence of other age controls, it is impossible to verify the accuracy of the MDA. The lower Nanaimo Group is a forearc succession that comprises part of the fill of the Georgia Basin, Vancouver Island, Canada. We evaluate the accuracy of DZ MDAs to approximate TDAs within the lower Nanaimo Group by integrating all available age data, including macrofossils, an absolute age from an ash bed, and high-n detrital zircon datasets. Using the DZ dataset, we generate MDAs, a multi-dimensional scaling plot, and a map of DZ age spectra. We plot DZ MDAs and macrofossil ages with a recently developed genetic stratigraphic framework for the lower Nanaimo Group, which allows for direct comparison of results between the two methodologies. The most accurate MDA estimations of TDA are derived from the weighted average of the youngest grain cluster which overlap in 2σ uncertainty. Our data also reveal that the strata above the basal unconformity and away from the basin margins yield the most abundant near-depositional age DZ, and that DZ age spectra can be used to detect important stratigraphic surfaces.

VERTEBRATE COPROLITES FROM THE LATE DEVONIAN TO LATE CARBONIFEROUS OF EASTERN CANADA AND THEIR SIGNIFICANCE

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The Late Devonian to Pennsylvanian represents a significant period in the evolution of vertebrates, notably with the diversification of tetrapods and chondricthyans. Coprolites can both act as proxies for biotaxa distributions and as direct evidence of predation and digestion. Eastern Canada yields several significant coprofaunas from this time interval. Middle Devonian vertebrate coprolites are well known from Scotland, notably the Achanarras Quarry and other localities in Moray and Orkney. However, Late Devonian coprolites are scarce and the best ichnofauna is from the Upper Devonian Escuminac Formation of the Miguasha Lagerstätte, Quebec, that yields over 100 specimens. These coprolites are typical of Devonian assemblages in that spiral forms are relatively uncommon (only 3–4 in the Escuminac) as are specimens over 4–5 cm in length, and larger forms are very rare. There are early Mississippian coprolites from Scotland (e.g. Foulden) but the most significant described coprolites from this interval are from the Tournaisian Horton Bluff Formation of Nova Scotia. Six morphotypes are recognized including ovoid, elongate and twisted pellets and irregular masses. Several individual coprolites and coprolitic masses are over 5 cm in length but spiral morphologies are absent. Younger Mississippian (Visean and Serpukhovian) coprolites are locally common in the United States and Scotland. The fossil record of vertebrate coprolites first becomes abundant in the Pennsylvanian and several different facies associations can be discerned. The Muscovian Minto Formation of New Brunswick preserves an early example of the *Crassocoprus* Ichnofacies which is characterized by a prevalence of spiral coprolites mirroring the corresponding body fossil record of this stratigraphic unit that is dominated by chondrichthyans. The *Crassocoprus* Ichnofacies is common in many younger Pennsylvanian coprofaunas in the United States and Europe. Kasimovian localities in New Mexico document an ecological transect from lacustrine to shallow marine environments, all with spiral coprolites. Buckland first noted coprolites from Carboniferous coal-bearing facies from England in 1835 and soon thereafter they were recorded in 1854 and 1862 in the late Bashkirian Joggins Formation of Nova Scotia. The Joggins coprofauna includes a variety of ichnotaxa and morphotypes including *Crassocoprus, Crustacoprus, Dakyroc*opros and *Hyronocopros*. Coprolites range up to 10 cm in length and thus are some of the earliest large vertebrate coprolites in the fossil record.

UPPER HAZELTON VMS SYSTEMS: NEW INSIGHTS FROM THE KITSAULT AREA, NORTHWEST BRITISH COLUMBIA

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The Kitsault River area hosts significant Ag-rich volcanogenic massive sulphide (VMS) deposits in late Early to Middle Jurassic volcano-sedimentary rocks of the upper Hazelton Group. We have studied the lithostratigraphic and structural setting of the mineralization systems through combined field, geochemical and geochronological studies. Unlike VMS systems within the Eskay rift (e.g. Eskay Creek, Anyox), the Kitsault River area does not host extensive rift-related tholeiitic mafic to bimodal volcanic rocks of the upper Hazelton Group. In contrast, stratabound- to vein-style Ag-Pb-Zn mineralization at Dolly Varden, Torbrit and North Star is hosted within andesitic-dacitic volcaniclastic to epiclastic rocks that are overlain by calc-alkaline basaltic tuff to tuffaceous epiclastic sandstones of the upper Hazelton Group. The Pb-Zn-Ag-Sr mineralization at the Sault showing resides in a similar overall stratigraphy but is hosted within a locally graphitic and calcareous sedimentary to volcaniclastic rock package. New geochronological results show that the epiclastic sandstones at Sault are ca. < 188 Ma (detrital zircon age), which may indicate that the Sault showing is slightly older than the Eskay Creek VMS deposit. At the Wolf deposit, a felsic tuffaceous sandstone to argillaceous tuff yielded a crystallization age of ca. 178 Ma, similar to ages for the upper Hazelton Group within the Eskay rift. The presence of slightly older to contemporaneous VMS-type systems outside the main Eskay rift reveals that calc-alkaline upper Hazelton Group strata are prospective for VMS- or hybrid VMS-epithermal-style Ag-Pb-Zn mineralization. Such systems represent potentially overlooked exploration target within the Golden Triangle.

CRITICAL METAL TRANSPORT AND SPECIATION IN HIGH-TEMPERATURE MAGMATIC-HYDROTHERMAL FLUIDS: ORE DEPOSITS, EXPERIMENTS, AND NUMERICAL SIMULATIONS

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Critical minerals are classified as essential elements for society and are subject to potential supply disruptions. With advancing technologies, the list of critical elements changes over time and comprises a list of 50 mineral commodities compiled by the U.S. Geological Survey as of 2021. We have a significant knowledge gap when it comes to understanding the formation conditions of economic resources of critical elements that are essential to modern technology such as for example rare earth elements, Te, Li, Ni and Co. Previous studies of natural occurrences of critical minerals show that for economic enrichment a combination of magmatic and hydrothermal processes are necessary, with the latter representing the last step controlling zoning and grades at the deposit scale. Our capability to predict critical element mobility in magmatic-hydrothermal fluids is commonly limited by the availability of thermodynamic data for individual aqueous and/or gaseous species in particular at elevated temperature and pressure relevant to ore genesis. The new Department of Energy (DOE) funded U.S. geoscience critical minerals experimental – thermodynamic research hub between NMT, LANL and IUB addresses this knowledge gap for rare earth elements (REE) by combining various high-temperature experimental techniques, molecular dynamic simulations, and methods in thermodynamic theory. Experimental techniques applied comprise various hydrothermal batch-type reactors (Hastelloy, Inconel and Ti) with and without pressure transducers and gold capsule experiments in cold-seal pressure vessels for investigating the solubility of REE. A series of spectroscopic techniques such as hydrothermal UV-vis cells (Hastelloy and Ti) and hydrothermal diamond anvil cells combined with confocal Raman spectroscopy and EXAFS are coupled with standard density functional theory (DFT) computational techniques for characterization of the speciation and hydration/solvation of REE. Finally, our collective efforts will be compiled into a thermodynamic database, which will become available to the larger scientific com-

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munity and greatly expand our capability in predicting critical element mobility in geologic fluids. Here we will present results from our recent works on natural deposits in New Mexico and Colorado, discuss thermodynamic data compilations providing an accurate review of existing data and show some new insights from thermodynamic modeling focusing on REE and Te. We will further present preliminary results of REE-phosphate solubility experiments at 400 to 700°C and 500 to 2000 bar in NaCl-bearing solutions and spectroscopic UV-vis and Raman experiments investigating REE speciation.

GEOCHEMISTRY AND Sm–Nd ISOTOPES OF THE VOLCANIC ROCKS OF TACHDAMT AND BLEÏDA FORMATIONS (BOU AZZER EL GRAARA, CENTRAL ANTI-ATLAS, MOROCCO)

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On the basis of recent radiometric data, the Tachdamt-Bleïda series, thought to be unique, has been divided into two distinct formations: the Bleïda formation and Tachdamt formation. The volcaniclastic rocks of the Tachdamt formation yield an age of ca. 883 Ma while the detrital zircon ages from the Bleïda formation argue for a maximum depositional age at ca. 700 Ma. It becomes necessary to consider these two formations independently and to revise their geodynamic significance. The Bleïda and Tachdamt formations consist mainly of mafic rocks (basalts and dolerites) associated with rare keratophyres. Indistinctly, in the Bleïda as well in the Tachdamt formation, the rocks display geochemical features of passive margin tholeiites with flat to slightly LREE-enriched patterns and are consistent with an E-MORB type source. Exceptionally, some rocks (keratophyres or dolerites) are more enriched in HREE and LILE. They could correspond to a different magmatic episode or could come from a previously enriched source. Except for one sample, positive εNd values argue for a juvenile source of magmas. TDM ages fall into three age groups for Bleïda at 2080, 1600, and 1244 Ma, and range from 1990 to 1710 Ma for the Tachdamt formation. This magmatism started during the earliest stages of the rifting of Rodinia that was responsible for the development of a passive margin in the NW edge of the West African Craton.

RECENT INSIGHTS INTO THE LINKED DEPOSITION, DEFORMATION, AND DISSOLUTION OF APTIAN (LOWER CRETACEOUS) EVAPORITES ON THE SAO PAULO PLATEAU, SANTOS BASIN, OFFSHORE BRAZIL

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In this talk we outline new insights into the deposition, deformation, and dissolution of Aptian evaporites in the Santos Basin, with specific focus on the São Paulo Plateau. These new insights were gained by integrating: (i) 3-D seismic and borehole data - to characterize the salt structure, composition, and kinematics; (ii) physical modelling – to test the mechanical plausibility and basis of intrasalt kinematic models; (iii) structural restorations and flexural backstripping (reverse basin modelling) - to constrain the timing and patterns of salt-related deformation and impact on crustal structure. We show that the pre-rift geometry of the São Paulo Plateau influences spatial variations in evaporite composition, with anhydrite being relatively common on relict, rift-related highs, and halite and Mg-rich salt being volumetrically more significant in flanking lows. Subsequent flow resulted in a range of complex intrasalt structures, including reverse shear zones, feeders, flaps, and sheets. Borehole data suggest that these structures locally formed due to compositionally-driven, Rayleigh–Taylor (R-T) overturn within growing diapirs, especially in parts of the basins characterized by pronounced vertical (stratigraphic) changes in intrasalt composition and density structure. Sometime in the Paleogene after the main phase of diapirism, the crests of mature diapirs were dissolved over much of the São Paulo Plateau, the pattern and style of which was related to the primary intrasalt lithology. Flat, halite-dominated diapirs crests are mainly characterized by sub-circular mounds, up to 100 m tall, likely comprising insoluble evaporite. In contrast, rugose, evaporite-interbedded diapir crests are mainly characterized by oval-to-circular sinkholes, up to 100 m deep, formed above more soluble evaporite units (e.g. Mg-rich salts). Breccia pipes, up to 60 m tall, capped by collapse-related sinkholes, formed within the overburden above both flat and rugose diapir crests. Reverse-basin modelling suggests salt dissolution occurred in a fully submarine environment in water depths of 1900 m (± 100 m). In summary, this talk demonstrates a direct link between the primary intrasalt stratigraphic heterogeneity, and the style and sequence of subsequent deformation and dissolution.

THE POTENTIAL FOR CARBON SEQUESTRATION IN SOUTHWESTERN ONTARIO

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In April 2021, Prime Minister Trudeau pledged that Canada will reduce CO_2 emissions 40–45% by 2030, compared to 2005. Funding for this was incorporated in the 2021 federal budget, some of which is being applied to carbon capture and sequestration (CCS) in Alberta. To meet the 2030 deadline, CCS in the industrial heartland of southwestern (SW) Ontario must begin within 8 years! Our biggest challenge is to match sequestration sites to the CO_2 sources that exist between Hamilton and Sarnia. A critical need for CCS implementation is detailed characterization of prospective storage resources. In SW Ontario, these include (a) the saline Cambrian aquifer where sufficiently deep (> 800 m) to sequester supercritical CO_2 and (b) depleted Cambrian oil and gas fields. The former has much larger storage volumes available but requires ~5 years of characterization and testing before beginning industrial scale sequestration. Because CO_2 is buoyant in brine-saturated reservoirs, confining "caprock" integrity is fundamental to the suitability of the host formation for CO_2 injection. Furthermore, the integrity of legacy wellbores must form part of the assessment, as virtually all large-volume sequestration sites 800 to 2500 m deep are in sedimentary basins that have experienced oil and gas exploration and development. Potential faults must be identified and evaluated by geophysical surveys both in the proposed reservoir, where they may cause CO_2 leakage, and in the basement below, where they may slip causing felt earthquakes. The storage capacity of a sequestration reservoir depends in part on the available pore volume, but because of porous medium multi-phase flow instabilities, in practice only a fraction of the accessible pore space may be available to accommodate CO_2. As CO_2 is injected into a deep saline aquifer, brine will be displaced to accommodate the CO_2 volumes injected and this will lead to regional pressure changes. Once a suitably detailed "static" geomodel is available, injection strategies can be evaluated by numerical simulation to optimize sequestration outcomes, i.e. to maximize capacity and minimize pressurization. Detailed "static" geomodels are being developed to evaluate injection strategies from core- and wireline-log analysis. These can then be evaluated by numerical simulation to maximize storage capacity and minimize regional pressurization during CO_2 sequestration.

CONTRASTS IN CRUSTAL CHARACTER BETWEEN MEGUMA TERRANE AND AVALONIA BASED ON WIDE-ANGLE SEISMIC REFLECTION/REFRACTION PROFILES ALONG THE SCOTIAN MARGIN AND ACROSS NOVA SCOTIA, CANADA

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Two wide-angle seismic reflection/refraction profiles provide new information about the velocity characteristics of the Meguma terrane of southern Nova Scotia in comparison to adjacent Avalonia. Line 99-1 extends ENE along the Scotian shelf parallel to the coastline from southwest Nova Scotia to offshore Avalonian southeastern Cape Breton Island; line 99-2 extends NNE across the Scotian shelf, mainland Nova Scotia, and the Avalonian Antigonish Highlands, and into the Gulf of St. Lawrence. Velocity models for both lines derived by forward modelling of seismograms show a P-wave velocity of 5.5–6.0 km/s in the uppermost crust under the Meguma terrane, interpreted to characterize metasedimentary rocks mainly of the

Cambrian Goldenville Group. P-wave velocity gradually increases through the underlying upper Meguma terrane crust. Offsets in travel time curves on seismic sections indicate a low velocity zone at 7–15 km depth in the offshore southwest of Halifax. A P-wave velocity of 6.6–6.7 km/s in the lower crust overlies the Mohorovičić Discontinuity (Moho) at a depth of about 37–38 km underlain by upper mantle with a velocity of 8.0 km/s. The crust thins to ~30 km under the onshore segment of the Meguma terrane where the upper mantle velocity is as low as 7.7 km/s. In contrast, the onshore segment of the Avalonian crust displays a different velocity profile, with a thick high-velocity (6.8–7.1 km/s) lower crust and a deeper Moho (~40 km). Line 99-2 shows that the boundary (Chedabucto Fault at surface) between Meguma and Avalonia crust is steep and appears to offset the Moho. On offshore line 99-1, the velocity model confirms that thinner Meguma crust underlies the Orpheus graben and that the fault between Meguma and Avalonian crust is at the northern margin of the graben. The bounding fault dips to the south beneath the graben, and the crust of Avalonia extends only ~50 km under the Meguma terrane south of the graben. Poisson's ratios calculated from velocities of P- and S-waves in the crust under the Meguma terrane are 0.19 to 0.22, lower than average for continental crust. In contrast, a Poisson's ratio of 0.25 for the crust under Avalonia shows that it differs from the crust under the Meguma terrane.

CONSIDERATION OF MULTICOMPONENT MASS TRANSFER FOLLOWING GAS MIGRATION FROM ENERGY WELLS

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The release of natural gas to shallow groundwater systems from energy wells suffering integrity issues (termed gas migration) can lead to the reduction of groundwater quality, safety concerns associated with explosion risks, and the release of greenhouse gases. A key environmental monitoring approach at impacted sites is to collect groundwater samples and measure dissolved gas concentrations. Dissolved gas signals can be difficult to interpret because of interactions of multiple gas components present in the subsurface: natural gas is comprised of multiple hydrocarbons (methane, ethane, and propane) and dissolved background gases (N_2 and Ar) are naturally present in groundwater. Additionally, the oxidation of released hydrocarbons can lead to the production of biogenic gases such as CO_2 and H_2S, further affecting dissolved gas concentrations measured at these sites. Therefore, to better understand the impact of gas migration and develop better monitoring techniques, consideration of these multicomponent effects is needed. In this study, hypothetical natural gas released in a two-dimensional shallow confined aquifer were simulated. Free-phase gas movement was modeled using macroscopic invasion percolation. The resulting free-phase gas distribution was then inputted to the multicomponent reactive transport model, MIN3P. A variety of scenarios were tested to understand the impact on dissolved gas concentrations downgradient of the release. The scenarios included varied composition of released free-phase gas (pure methane and natural gas), the presence of multiple sources of free-phase gas, and anaerobic oxidation in the presence of sulphate and iron. Simulations show that exsolution of dissolved background gases during simultaneous dissolution of free-phase hydrocarbons cause delayed and variable breakthrough of dissolved gas concentrations at monitoring points across the domain. The results also suggest that monitoring of background dissolved gases may provide a means of quantifying the longevity of natural gas leaks in aquifer systems. It is clear from the modeling results that multicomponent mass transfer and transport need to be considered when interpreting dissolved gas concentrations at sites impacted by gas migration. Further development of coupled multiphase and multicomponent reactive transport models is required to aid in the design of monitoring networks and quantification of environmental risk to the shallow subsurface from gas migration.

HYDRATION CAVES IN THE ABANDONED GYPSUM QUARRY AT DINGWALL (NOVA SCOTIA, CANADA)

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Hydration caves are a rare type of caves, formed within the weathering zone of the gypsum-anhydrite rock due to hydration of anhydrite associated with a large volume increase. They form under the detached and uplifted rock layer and usually take the shape of domes and tepee structures. At Dingwall (north of Cape Breton), the hydration caves are forming today in the abandoned gypsum quarry that operated from 1935 to 1955. Since then, the anhydrite was exposed and has been subjected to significant weathering. This weathering has the greatest impact on the relief of the quarry. Due to contact with water the mineral anhydrite ($CaSO_4$) is transformed into another mineral – gypsum ($CaSO_4.2H_2O$), in the process of hydration, i.e. gypsification of anhydrite. The process takes place in two stages: 1) dissolution of anhydrite, and 2) the crystallization of gypsum from a Ca-sulphate saturated solution. Gypsum is crystallizing by both replacing and displacing the anhydrite and this latter growth (connected with gypsum crystallization pressure) leads to volume increase and formation of hydration caves. The local volume increase leads to deformation of the rock and creation of convex hydration forms of relief (domes, tepee structures, pressure ridges) which together represent a unique hydration landscape. Many listed individual hydration forms contain the mentioned hydration caves in their interior. During field work in September 2018 and August 2019, 77 most distinguished hydration forms were measured, identified and numbered, about half of them having a cave accessible to people. The largest one is the ridge having a tepee shape (length: 23.05 m, height: 2.08 m). The largest hydration cave is located inside the dome-shaped form called the Ramesh Cave (length: 8.87 m, width: 2.97 m, height: 1.35 m). The development of hydration forms is influenced by the joint system present in the quarry, affecting their shape, determining the development of an entrance to a cavity, and the number of fractures cutting the form. Hydration forms are generally larger and more durable over time if the thickness of the uplifted rock layer is greater and the joint system within the bedrock negligible or absent. Hydration landscapes with hydration caves are rare and yet not a satisfactorily recognized phenomena, which together with other geological features present in the Dingwall quarry, such as karst relief, textural and structural petrographic features, joint system, and evidence of ice sheet action, create a unique geosite of geological heritage worthy of special protection.

THERMAL AND HYDROLOGIC FUNCTION OF GROUNDWATER SPRINGS DISCHARGING TO A THREATENED COASTAL ECOSYSTEM

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Groundwater discharge to freshwater streams and rivers is known to modulate diel and seasonal temperature signals and create thermal refuges, but the thermal role of groundwater discharge to coastal zones is not well studied. We conducted a field and modelling study of a warm lagoon ecosystem in eastern Prince Edward Island using a combination of hydrologic measurements, in-situ thermal monitoring, drone-based thermal infrared mapping, and radon to quantify groundwater inflow rates at springs and their thermal impact. Estimates of total spring inflows from radon measurements and from analysis of their thermal plumes, revealed by drone imagery, were in general agreement (~0.050 $m^3 s^{-1}$). Based on our analysis of thermal advection, the thermal effects of groundwater inflows were small compared to atmospheric forcing at a lagoon scale; however, spring flows dominated heat transfer

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locally and generated pronounced cold-water plumes along the shore. We also used a numerical model (SHAW) to simulate seasonal groundwater temperature dynamics and long-term groundwater warming in response to climate change. The modelled seasonal groundwater temperatures revealed the source depths of the different springs based on their measured seasonal temperature amplitudes. Also, the modelled 5-year averaged subsurface temperatures increased up to 2.23°C from 2020 to 2100 in shallow groundwater and up to 1.42°C in the deeper portion of the aquifer. To our knowledge, this is the first study of coastal groundwater warming and highlights the potential impacts of climate change on groundwater-dependent ecosystems in coastal zones.

NOVA SCOTIA BASALT FOR CO_2 CAPTURE AND ENHANCED CROP YIELD

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The chemical storage of carbon dioxide by injection into buried basalt deposits has been recently proven, using the crystallization of carbonate mineral species in basaltic pore spaces to permanently sequester injected CO_2 mixed in water. Recent work on enhanced rock weathering (ERW) shows that pulverized basalt, spread over croplands is a stand alone CO_2 sink and an effective crop fertilizer and soil conditioner. Airborne carbon dioxide with water, upon contact with the various mafic minerals in basalt dust rapidly forms new carbonate mineral compounds. The basalt dust also acts to raise soil pH, which is an agricultural benefit when acidic soils are present. Compared to subsurface CO_2 injection, this method of capture is relatively inexpensive with the added benefit that the eventual basalt fertilizer runoff is chemically basic and can contribute to the amelioration of coastal ocean acidification. Nova Scotia has an abundance of basalt deposits, both exposed and buried. The Jurassic age North Mountain Basalt of Nova Scotia is an immense tholeiitic volcanic flow that appears to be a strong candidate for this ERW application. The deposit lies mostly beneath the Bay of Fundy where it has potential for subsurface CO_2 sequestration, but is prominently exposed along the southern Fundy shore and on Grand Manan Island. Mapped estimates give the accessible onshore volume of North Mountain Basalt as over 2300 km^3, spread over some 9400 km^2 with the potential for relatively easy extraction and bulk transport shipping. This formation is also known to host zeolites that act as cation intensive agents making an excellent supplement for enhanced plant growth. Testing of similar basalts has given good results in the field and one estimate shows that if applied nationally, this method of ERW could contribute as much as 15% of Canada's planned CO_2 emission targets. Studying the North Mountain Basalt and similar basalt formations in the Maritimes, with respect to their suitability for ERW development is a necessary first step, which can be done with archival data sets. An initial laboratory proof-of-concept test for ERW is needed to add credibility in a Canadian soils context toward the application of this new method of carbon sequestration and possible "green mining" product. The work described here is being carried out under the carbon capture utilization and storage project within the Marine Geoscience for Marine Spatial Planning program of the Geological Survey of Canada.

LASER ABLATION (U-Th-Sm)/He DATING: ADVANCING DETRITAL THERMOCHRONOLOGY AND GEOCHRONOLOGY

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Detrital thermochronology and geochronology are valuable tools for resolving the evolution of mountainous regions. Low-temperature thermochronology (e.g. fission-track and (U-Th-Sm)/He dating) and geochronology (e.g. U–Pb) applied to detrital apatite and zircon are widely used to resolve the tectonic histories, provenance and exhumation of river catchments. However, the application of apatite (U-Th-Sm)/He (AHe) in detrital studies, the lowest temperature thermochronometer (70–40°C), remains hindered by issues surrounding the conventional 'whole-grain' analytical approach. These issues include grain selection bias and the high cost of analysis, limiting the number of measurements that can be made. Laser ablation AHe dating (LA-AHe) is a new innovative dating technique that can measure a much larger number of grains quickly (n > 100) and at lower analytical costs. The technique essentially removes grain selection bias and allows for the simultaneous collection of U–Pb ages and chemical composition to create more comprehensive and detailed detrital datasets. We present new LA-AHe, apatite U–Pb and zircon U–Pb dates from 6 river catchments along the Appalachian Mountains, between New Hampshire and North Carolina. Using our new approach, a total of 493 single grain LA-AHe ages and 450 apatite U–Pb ages were obtained, while an additional 1906 zircon U–Pb dates were measured to contextualize apatite dating results. The majority of LA-AHe ages are Cretaceous, consistent with previous AHe bedrock studies from the Appalachians. Catchments underlain by crystalline bedrock show little age dispersion while those underlain by sedimentary strata exhibit much higher levels, highlighting previously discussed limitations in the AHe method. Both apatite and zircon U–Pb dates are consistent with each catchment's metamorphic or stratigraphic histories and assist with the interpretation of our LA-AHe results. Finally, catchment-wide thermal histories derived using Pecube-D modeling show that LA-AHe ages may be explained through an absence of tectonic uplift across the region and the protracted erosion and exhumation (20–30 m/Myr) of a post-orogenic elevated landscape. Our work highlights how LA-AHe analysis can greatly advance thermochronology and geochronology producing vast datasets in shorter analytical times and at less cost.

TOWARDS AUTOMATED MINE TAILINGS DETECTION: A MULTISPECTRAL REMOTE SENSING TOOL IN GOOGLE EARTH ENGINE

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Waste from historical gold mines continue to be a source of contaminants such as arsenic and heavy metals at locations around the world. Remote sensing analysis has been used at many of these locations to create classification models which can provide an initial indication of potentially contaminated sediments and help direct fieldwork efforts. Several gold rushes took place in Nova Scotia between the late 19th and mid 20th centuries. Gold was extracted from veins throughout the shales and quartzites of Meguma supergroup rocks and crushed into a fine, sandy material from which gold was extracted using mercury or, later, cyanide. This rock contained more than gold. Commonly occurring in these same deposits were sulphur-bearing minerals – particularly arsenopyrite. Milling the ore rock crushed sulphides, increasing their surface area, and expediting oxidative processes. Like other mines of this pre-regulation era, little attention was paid to quantities of waste or where that waste was placed. Leftover material, called tailings, was deposited in rivers, wetlands, the ocean, or other nearby depressions. Much of these tailings are still present where they were left sometimes a century or more later. The government of Nova Scotia has estimated the cleanup cost of the 2 highest-risk sites at $60 million. Over 60 sites still require more research before estimates can be made. Testing each of these sites for contaminants on the ground would be a monumental and expensive task. Many sites are in rural areas and may even be inaccessible except by a long or difficult hike. A site may have multiple tailings areas that are hidden by trees or terrain and so are missed in surveys. Many of the tailings maps that the province and researchers rely on were created while these mines were still active. Using multispectral satellite imagery from the European Space Agency's Sentinel-2, we have created a tool in Google Earth Engine to classify bare land at historical mine sites and identify pixels that are spectrally similar to known tailings. This tool uses the Nova Scotia Tailings Database to create a training data set, then generates a map that could be used as a first-look at mine sites that can highlight priority areas for on-the-ground efforts.

IMPACTS OF COVER CROPPING ON NITRATE LEACHING FROM AN INDUSTRY STANDARD POTATO ROTATION

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Excessive nitrate leaching from the industry standard potato rotation (forages-potatoes-grain) in Prince Edward Island (PEI) has been linked to nitrate contamination in groundwater. Elevated nitrate leaching was observed to occur during the periods of postharvest of potato and fall forage plowing. This study was conducted to assess

nitrate leaching reduction by planting a cover crop following potato harvest and terminating the forages and planting a cover crop in the midseason. The experiment was performed at the tile-drain site on the Agriculture and Agri-Food Canada (AAFC) Harrington Farms from 2018 to 2021. It included three treatments: T1 red clover/fall plowing (2018)−potatoes (2019)−barley underseeded red clover (2020)−red clover/fall plowing (2021), T2 red clover/terminated midseason and followed by planting buckwheat as a cover crop (2018)−potatoes (2019)−barley underseeded red clover (2020)−red clover (2021) and T3 red clover/fall plowing (2018)−potatoes (2019)/planted winter rye as a cover crop−winter rye (2020)−red clover (2021). The treatments were arranged on 0.5-ha plots clustering on a large field with three replicates. This field has sandy loam soil with a pH of 6.3. Tile drains spaced at about 16 m and looped to a main discharging line were installed at a depth of about 85 cm in each plot. Each discharging main line was equipped with a ISCO sampler for collecting drainage samples for testing nitrate and a tipping bucket system for monitoring tile drainage. During the fall of 2018, tile-drain nitrate concentrations (30−50 mg N/L) in T2 were higher than those (20−30 mg N/L) in T1 and T3, suggesting that the buckwheat cover crops increased nitrate leaching. During the period of postharvest of potato, nitrate concentrations in the three treatments were similar (20−145 mg N/L) even though the cover crops (winter rye) were well established in T3. T2 created the least nitrate leaching during the spring of 2020. Another rotation cycle is being conducted to further assess the effects of cover cropping on nitrate leaching from the system.

PALEOGEOGRAPHIC RECONSTRUCTION OF THE NUNA SUPERCONTINENT AND THE ASSUMPTION OF 'OROGENIC RIGIDITY'

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A common assumption in making paleogeographic reconstructions is that orogens maintain a fixed shape during and after their formation. Hence map-view bends are interpreted as primary features (promontories and re-entrants) despite studies of well-preserved and little overprinted Phanerozoic orogens in which it has been demonstrated that some bends are products of deformation and oroclinal buckling. The assumption of 'orogenic rigidity' has, for example, informed attempts to reconstruct the Paleoproterozoic supercontinent, NUNA. The case for NUNA is strong. The 2.1 to 1.8 Ga orogens and juvenile crustal provinces characterize and are consistent with there having been links between most of the major continental blocks at that time. However, attempts to reconstruct NUNA have met with limited success, perhaps due in part to the assumption of orogenic rigidity. Our focus has been on the NUNA-forming Trans-Hudson orogen of northeastern Laurentia and the Svecofennian orogen of Baltica. Both orogens are characterized by significant bends and complicated geometry. In Baltica, oroclinal buckling affects only hot, juvenile arc-crust and appears to have overlapped with the final stages of ocean closure. Coeval deformation in adjacent cold, thick Archean lithosphere mainly consisted of reactivation of older fault zones. In Greenland and Baffin Island the involvement of mainly Archean crust suggests that dramatic changes in orientation and vergence direction of Trans-Hudson orogenic belts likely, but not necessarily, reflect tectonic inheritance. Determining which bends are primary and which are secondary remains a major and commonly unrecognized challenge in the reconstruction of supercontinents, including NUNA.

PETROGENESIS, RARE METAL MINERALIZATION AND TECTONIC SETTING OF ALKALINE INTRUSIONS IN THE ALEXANDER TERRANE, SOUTHEAST ALASKA

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Alkaline intrusive rocks ranging from early Paleozoic to Mesozoic in age are widely distributed in the Alexander terrane in southeast Alaska. Some of these intrusions form a metallogenic province of rare metals in southeastern Alaska. Two examples are the Late Devonian (~367 Ma) Corner Bay pluton, part of the Sitkoh alkaline plutonic suite on Chichagof Island, and the Bokan Mountain intrusive complex on Prince of Wales Island. The Corner Bay pluton is a shallow-seated intrusion composed predominantly of syenitic/monzonitic rocks with minor alkaline gabbros. Their Upper Devonian shallow marine sedimentary and felsic and mafic volcanic host rocks, and trace element compositions of the volcanic rocks and alkaline intrusive rocks are consistent with their emplacement in a rift. The rocks have high contents of alkalis, are rich in U, and rich in large ion lithophile elements, including Rb, Sr, and Ba. Their isotopic composition is characterized by relatively high $\varepsilon Nd_{(t)}$ values (+3.4 to + 3.6), Neoproterozoic Nd model ages (700–650 Ma) and initial $^{87}Sr/^{86}Sr$ ratios (~0.704). These rocks were generated by fractional crystallization of alkali basaltic magma formed by partial melting of lithospheric mantle. The mantle source underwent a Neoproterozoic metasomatic enrichment. Some syenitic rocks were enriched in incompatible trace elements (ITE) by fluids from an undetermined source. Such fluid enrichment is common in alkaline rocks of the province and is known to generate rare metal (including rare earth element (REE) and ITE) mineralization. On Prince of Wales Island, the Early Jurassic (~177 Ma) Bokan Mountain complex is composed of peralkaline A-type granitic rocks generated through extensive fractional crystallization of an enriched mantle-derived parent. The Bokan complex hosts significant rare metal (U, Th, REE, Y, Nb) mineralization formed by a two-stage process. The first stage involved concentration of incompatible elements during late-stage crystallization of peralkaline granite, pegmatite, and felsic dykes, while the second involved ingress of hydrothermal fluids that both remobilized and enriched the initial magmatic mineralization. Structures that controlled emplacement of the Bokan complex and the nearby (~176 Ma) Dora Bay alkaline intrusion indicate emplacement in an extensional tectonic setting. The character, distribution, association with rare metal mineralization, and long age range of repeated alkaline magmatism in southeastern Alaska supports the existence of an old, incompatible element enriched, strongly metasomatized lithospheric mantle in this part of the Alexander terrane. Extensional tectonic settings through time enabled emplacement of lithospheric mantle-derived magmas that in places contain significant rare metal deposits.

RESEARCH AND COLLABORATION FOR MINE SITE TRANSITIONS

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Increasingly, researchers, policy makers, and industry actors recognize the need to integrate social objectives and community engagement into mine closure and reclamation processes. Historically, closure and remediation were lightly regulated activities dominated by technical experts aimed principally at winding down operations and rehabilitating post-mining lands at minimal cost. While reclamation planning aims to ensure post-closure human and environmental safety, it tends to emphasize technical fixes over longer-term socio-economic, cultural, and ecological considerations in mine site transitions. For mines operating on Indigenous territories, where communities have complex and nuanced connections to land and varying levels of jurisdiction, these issues are further exacerbated by the exclusion of Indigenous voices from planning and decision-making. Local and Indigenous community engagement in closure and reclamation is haphazard and often confined to end-stage planning, if at all. This presentation reviews recent research undertaken through the TERRE-NET Network exploring the key challenges related to the social dimensions of mine closure and mine site transitions at both active and abandoned mines. Through community-engaged research and dialogue, we explore the role of environmental assessment in closure planning; the inclusion of local/Indigenous knowledge and community engagement in regulatory guidelines and closure plans themselves; and the place of socio-economic considerations and local values in mine site transitions. Integrating social objectives and community engagement into mine site transitions is an emerging industry and regulatory practice, and we also offer examples from our research of innovative approaches to community and stakeholder engagement.

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WHITEHORSE TROUGH RECORDS LATE TRIASSIC–EOCENE ACCRETIONARY OROGENIC CYCLE IN THE NORTHERN CANADIAN CORDILLERA VIA DETRITAL MINERAL THERMOCHRONOMETRY

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In the northern Canadian Cordillera, latest Triassic to Early Jurassic Intermontane terrane assembly and accretion to Laurentia was accompanied by the deposition of siliciclastic sediments into the > 600 km long Whitehorse Trough. The sources, deposition, and thermal and structural evolution of these sedimentary strata can be used to track the evolution of the Intermontane accretionary orogenic cycle. We use low temperature thermochronological methods, including (U–Th)/He dating applied to detrital zircon and apatite (ZHe, AHe) and detrital apatite fission track dating (AFT), along with detrital geochronology, and stratigraphic and structural constraints, to develop plausible temperature-time histories of these sedimentary rocks to constrain the context of terrane accretion and orogenesis. The 172 single crystal ZHe data from 35 samples, 164 single crystal AHe data from 33 samples and 12 AFT central ages document the thermal history of the Whitehorse Trough. ZHe ages across the basin fall into four age groups: detrital; Late Jurassic (155–145 Ma); Cretaceous (120–70 Ma) and Paleogene (65–50 Ma). AFT and AHe ages form unimodal age populations with dominant age peaks at 52 and 47 Ma, respectively. Inverse thermal modeling of these data show they are consistent with a polyphase heating and cooling history of basin rocks during the Mesozoic and early Cenozoic that also satisfies the known geological constraints. Igneous and metamorphic source rocks rapidly cooled as they were exhumed, then eroded and deposited as sediments into the Whitehorse Trough during latest Triassic and Early Jurassic. Early Jurassic deposition of Laberge Group siliciclastic sediments was followed by a Jurassic cycle of heating and cooling interpreted to be caused by sedimentary burial, shortening into a thrust belt, and subsequent erosion in response to orogeny, resulting in an angular unconformity by Late Jurassic. This was followed by a second, longer cycle of heating and cooling that initiated with Late Jurassic deposition of successor Bowser Lake Group and Tantalus Formation units on the Laberge Group unconformity and ended with rapid cooling during the latest Cretaceous to Eocene.

NOT YOUR SUPERVISOR'S GEOCHRONOLOGY

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A lot has changed in the field of geochronology and thermochronology over the last decade. High spatial resolution geochronology and thermochronology have played an increasingly important role in studies about the tectonic evolution of the Earth, offering new and previously inaccessible information about the timing, rate, and duration of a wide range of Earth processes. Both incremental improvements in laser and mass spectrometry technologies and breakthrough advances like applying tandem mass spectrometry to beta decay geochronometers (e.g. Rb–Sr, Lu–Hf, Re–Os), have allowed for a diversification of high spatial resolution approaches beyond the well-known in situ U(-Th)-Pb dating of zircon and monazite. This is not your supervisor's geochronology. In the theme of this session on "using nano- and micro-scale observations to better understand Earth processes", we will review some of the exciting new high-spatial resolution additions to the current geochronology/thermochronology toolbox. Potential applications and geological insights to be gained from these new approaches will be explored through case studies involving novel mineral-decay system geochronometers, multi-dating of minerals, and pairing of novel geochronometers with isotopic tracers.

ASSESSING THE PROCESS AND TIMESCALE OF MEGAGRAVEL EMPLACEMENT IN A COASTAL BOULDER DEPOSIT, ANNAGH HEAD, WESTERN IRELAND

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We measure in-situ produced ^{10}Be from a wave-emplaced coastal boulder deposit (CBD) located on Annagh Head in County Mayo, on the west coast of Ireland. CBD often contain megagravel weighing 10s to 100s of tonnes and are an indicator of high energy wave events. They are generally found along coastlines exposed to the open ocean where deep water is close to shore, facilitating the efficient onshore transfer of wave energy. Recent work has demonstrated that these deposits are dynamic, with documented displacement of megagravel by storm waves at other sites in western Ireland. The Annagh Head CBD forms a ridge that is 8 m high (14 m a.s.l.), ~180 metres wide (from the seaward edge to the farthest inland boulders), and ~160 m in shore-parallel length. It is comprised of gneissic boulders which can be in excess of 50 t mass. Repeat photographs have documented the movement of boulders up to ~5 t mass, attributed to wave action during winter storms, but little is known about the long-term history of the deposit. To date, geochronologic studies of CBD emplacement have had limited success. Radiocarbon dating of attached organisms provides maximum limiting chronologic constraints on megagravel emplacement, but this approach is limited to boulders eroded from the inter-tidal or sub-tidal zones, which represents a relatively small fraction of the clasts in supratidal CBD, as most are sourced from subaerial coastal platforms. In-situ produced cosmogenic isotopes present a promising avenue for assessing the timing of CBD emplacement. Here we make the first attempt to quantify CBD emplacement history using in-situ produced cosmogenic ^{10}Be from 20 quartz-bearing boulders. Our sampling focused on the largest boulders in the deposit, ranging from just over 1 to ~59 t mass, with samples collected along a shore-normal transect across the full width of the deposit. Initial results yield a range of ages encompassing much of the Holocene, with a cluster of ages falling within the mid-Holocene. Our interpretation is ongoing, but we hypothesize that the apparent cosmogenic exposure ages reflect a combination of pre-erosion bedrock inheritance, in addition to a protracted history of deposition and re-mobilization in response to wave action and rising post-glacial sea level. In total, this dataset provides a quantitative view on a dynamic feature of coastal landscapes, allowing for investigation into the geomorphic processes at work, as well as exploration of possible linkages to climate and landscape evolution.

TIDAL RHYTHMITE DEPOSITS PROVIDE SUPPORT FOR A LATE CARBONIFEROUS MID-EURAMERICAN SEAWAY

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Support for the presence of a mid-Euramerican seaway during the Late Carboniferous is minimal. Current research performed on a sedimentary succession endorses the notion of a seaway linking with the Paleo-Tethys Ocean. In the Cumberland Basin of Nova Scotia, the Joggins Formation preserves an unrivalled record of terrestrial life in their environmental framework throughout the Late Carboniferous 'Coal Age'. Regardless of the research conducted over the past two centuries, questions persist concerning the paleoenvironment, including the extent and form of marine impact. The analysis of tidal rhythmite deposits allows for paleomarine conditions, including tidal regimes, to be inferred. This rhythmicity is primarily associated with tides in marine environments. In the Joggins Formation, we find spring-neap-spring cycles within parallel, thinly laminated, vertically accreted tidal rhythmites. The examples include: 1) sand and mud couplets deposited during flow and slack water phases, respectively, which correlate to ebb and flood tidal sequences; 2) variation in sand and mud lamination thickness from variations in sand and mud

availability during neap-spring tidal cycles; 3) spring couplet thickness variations indicating lunar cycles of low and high spring tides; and 4) rhythmite thickness variations suggesting tidal variations with longer cycles or sediment concentration fluctuations. Here, we employ quantitative and visual frequency analysis procedures to investigate and interpret the laminae-scale cyclicity of tidal rhythmite intervals. Visual core assessment identified three ideal intervals for tidal rhythmite thickness data collection. Visual cyclicity analysis uncovered the cycles in the intervals. Fast Fourier transform and continuous wavelet transform analyses revealed the primary periods and substantiated the visually uncovered tidal regime with that established geomathematically. Our findings suggest tidal rhythmite deposition followed the semi-diurnal tidal pattern with a lunar monthly tidal cycle. This research offers support for the existence of a mid-Euramerican seaway, which may help with clarifying the irregularity in paleoecological trends between the northern and southern Paleo-Tethys Ocean.

DO ARCHEAN GREY GNEISS DOMAINS REPRESENT MID-CRUSTAL-SCALE CRYSTAL MUSH COMPLEXES?

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Exposures of Archean middle crust are dominated by grey gneiss domains and although various metaigneous and metasedimentary components may be present, grey gneiss is commonly composed mainly of tonalite-trondhjemite-granodiorite (TTG) suites. The trace element compositions of TTGs have been conventionally used to infer the geodynamic settings of their sources. Whole-rock Sr/Y and La/Yb ratios in particular have been linked to the depth of source melting, which in turn may indicate a subducted slab (high-pressure) versus crustal (low-pressure) origin for TTGs. However, this approach assumes that TTGs represent primary magmas with source-controlled compositions. This contrasts with recent work showing that fractional crystallization may have strongly influenced TTG geochemical compositions. Here, we present a petrological–geochemical model for the evolution of coexisting TTGs with high- and low-pressure geochemical signatures in a mid-crustal grey gneiss domain in the southern Superior Province. We propose that this domain represents a former crystal mush complex of TTG magma. Field relationships, petrographic observations, and phase equilibrium modelling indicate that TTGs in this region may represent variable accumulation of plagioclase crystals and fractionated melt derived from a common parental magma. The models show that plagioclase-rich TTGs exhibit "high-pressure" geochemical signatures whereas fractionated melt-rich TTGs have "low-pressure" signatures. Results of zircon U–Pb geochronology and Hf isotopic analysis from several TTG samples support our interpretation that TTGs with different chemical compositions share a single origin. This work demonstrates the importance of plagioclase fractionation in the chemical evolution of TTG magmas, as this mineral can influence not only Sr/Y but also fractionation of light rare earth elements from heavy rare earth elements. In addition, the existence of a mid-crustal crystal mush has implications for the rheology of Archean continents. Finally, our results indicate that interpreting source characteristics based on TTG compositions should be done with caution.

ON A PATH TO UNDERSTANDING AND ADDRESSING THE HUMAN HEALTH RISKS OF GEOGENIC CONTAMINANTS IN NOVA SCOTIA DOMESTIC WATER WELLS

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Over 40% of Nova Scotians rely on private wells for their domestic water supply. Various geogenic contaminants are commonly found in our groundwater, including arsenic, uranium, and manganese. Testing and treatment of private well water is the responsibility of the well owner and is voluntary, but there are significant barriers to testing and treatment. As a result, few well owners regularly test their well water quality, and it is estimated more than half of the province's private well owners have never tested the chemical quality of their well water. Therefore, many private well users are drinking unsafe water, which can lead to illness and disease, and incur costs to our health care system. The Province of Nova Scotia has been working intermittently on the safety of private wells impacted by geogenic sources of contamination since arsenic was discovered in a private well in 1976. Over the past 45 years, various task forces and interdepartmental working groups have acted to better understand and manage the human health risks associated with geogenic contaminants, especially arsenic and uranium. The province's *Environmental Goals and Climate Change Reduction Act* sets out a goal to address and mitigate barriers Nova Scotians face to testing and treatment of rural wells by 2026. The province has developed a framework for improving private well water safety in Nova Scotia involving (a) improving our understanding of the issue (e.g. linkages between disease and private well exposures to geogenic contaminants, baseline testing and mitigation behaviours (e.g. water treatment), barriers to testing and treatment, and distribution of geogenic contaminants in private well water), (b) promoting water testing and treatment through various channels, (c) developing interventions based on behavioural analyses of barriers to testing and treatment, and (d) evaluating the impact of these interventions and outreach activities on private well safety. Considerable progress has been made to date by the Province of Nova Scotia's interdepartmental committee implementing the framework, although further work is needed to achieve the province's goals.

A NULL HYPOTHESIS FOR THE STUDY OF CONTINENTAL MARGIN MOUNTAIN BELTS

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Overall mass balance in continental margin mountain belts can be reconciled in terms of vertical thickening and belt-perpendicular shortening with zero belt-parallel deformation. This simple view of mass balance appears to predate mechanical theories of crustal evolution. This simple view of mass balance is also consistent with the theory of geosynclines, where belt-perpendicular shortening is linked to the radial contraction of a cooling mantle, and the theory of plate tectonics, where belt-perpendicular shortening is linked to the radial convection of a cooling mantle. Plate tectonic theory accommodates alternative types of mass balance in mountain belts because varied movements of local blocks correspond to the evolution of plate boundary networks. Alternative types of mass balance include, for example, crustal bending (i.e. oroclines), sideways collapse or escape (i.e. lateral extrusion), and oblique-to-strike slip transport or rotation of marginal blocks (e.g. Baja California) along the length of specific mountain belts. Belt-parallel deformation can be linked to out-of-sequence deformation patterns and the repetition or absence of specific geological components along strike generally. I propose to formalize the above observations as follows. The mass balance condition: $D_{xx} = -D_{zz}$ with $D_{yy} = 0$ (labelled MBC_0 here) can be identified as a null hypothesis for the study of continental margin mountain belts, where D is finite deformation, x is tangential and belt-perpendicular, y is tangential and belt-parallel, and z is radial to the surface of earth. The MBC_0 is then both: (1) *a default hypothesis*, which can be assumed to reconcile continental margin mountain-building everywhere prior to testing for contrary evidence, and (2) *a null hypothesis*, in which key studies will be studies which test for evidence sufficient to nullify or reject the default hypothesis following standard scientific method. In the context of plate tectonics and in the absence of testing against the above null hypothesis, evidence for localized and episodic mountain-building in specific mountain belts can only lead to interpretations of multiple intervening oceans that have since closed. Multi-ocean interpretations are too profound to accept as self-evident when plate tectonics accommodates alternative possibilities. The use of the proposed null hypothesis could change debate between proponents of competing models for specific mountain belts by targeting a shared research goal to test against the null hypothesis in each case. Testing against a null hypothesis can strengthen studies of continental margin mountain belts everywhere regardless of outcome. Examples from the Appalachians, the Cordillera, the Himalayas and elsewhere can be instructive.

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A GOOD POPULAR EDITOR: BRENDAN MURPHY'S SIGNIFICANT CONTRIBUTIONS TO THE EFFORTS OF OTHERS TO PLACE RESEARCH AND THOUGHT IN THE SCIENTIFIC LITERATURE

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This session honours our colleague's scientific contributions, but we should not forget his role in encouraging and assisting many other geoscientists to publish papers. I am bereft of coherent thought on Appalachian tectonics, so will instead offer some thoughts about Brendan's many contributions as an editor. Scientific editors walk a fine line, and we undoubtedly are graced with quiet curses from some authors, but our role is important. It starts with the solicitation of papers, or ideas for papers, but later we may reluctantly have to be cruel to be kind. We have to adopt the perspective of careful critical readers, to help authors deliver messages clearly and concisely. 'Geoscience Canada' will turn 50 in 2023. Over 10 years ago, Brendan became its editor, with a vision of our future that diverged from our past. We became a standalone journal, available beyond society membership, to showcase geoscience within and beyond Canada, and to diversify content. We soon became a fully digital journal and found even more flexibility beyond the tyranny of printed pages. Brendan expanded the idea of 'thematic series' papers, and fiercely solicited reviews from GAC medallists. His skills in extracting papers from the well- known and well-funded were matched only by his work with many younger scientists still building their careers. He saw the journal as an important tool in developing geoscience skills in Canada. I became 'editor-in-training' in 2015, and I am grateful that Brendan helped to keep my head above water as I learned this new trade. If you think that Brendan quit with a sigh of relief when I showed up, you are mistaken. He went on to serve with GSA as editor for their flagship journal 'Geology', and then to CJES, but he still handles papers for us. I do my best to keep the ship on the course that he charted, but only wish that I could steer it with such precision and skill. When I first took on this role, a colleague remarked that 'there are good editors, and there are popular editors, but there are no good popular editors'. There may be a grain of truth to that clever line, but I would say that Brendan is as good and as popular as any editor could ever be, and we should celebrate that contribution just as much as we celebrate the many papers and books that bear his name.

THE CABOX ASPIRING GEOPARK ON THE SCENIC WEST COAST OF NEWFOUNDLAND: WHERE THE EARTH SCIENCES REVOLUTION FIRST RESOLVED THE TECTONIC REVOLUTIONS OF THE DISTANT PAST

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On an island renowned for spectacular scenery and distinctive cultures, the west coast of Newfoundland has captivated visitors since the days of Captain Cook with mountains, fiords and majestic rivers. It also has a very special place in the history of geology. From latest Precambrian (> 542 Ma) to Late Ordovician (~450 Ma) times, western Newfoundland was a dynamic region, experiencing events akin to those of the more recent interaction between the Australian craton and multiple volcanic arcs of Papua New Guinea and Indonesia. The ancient continental margin of North America, then a tropical region not unlike the modern Bahamas, collided with approaching volcanic arcs of the long-vanished Iapetus Ocean, and attempted (unsuccessfully) to descend into a subduction zone. This slow but inexorable process led to the vertical juxtaposition of ancient Precambrian basement from the Canadian Shield, its doomed carbonate platform, and several deeper-water environments of the continental shelf and continental slope. The disrupted and amalgamated architecture of this ancient continental margin was then overridden by igneous rocks representing oceanic crust, subjacent mantle and associated volcanic arc(s) from the Iapetus Ocean. The Bay of Islands igneous complex was among the first ophiolite sequences to be recognized, and is one of the most influential examples. More importantly from our perspective, it is also one of the best places on Earth to walk from the ancient intertidal zone right into the mantle, and perhaps even eat lunch on the MOHO. From north of Gros Morne National Park to south of Stephenville, rock sequences that were moved hundreds of kilometres by tectonic forces sit close to those that have hardly moved since their deposition, and the sequence of ancient events is revealed by spectacular folds, faults and dramatic stratigraphic changes. Western Newfoundland was affected by the later events that built the Appalachians as we now see them, but these did little more than rearrange a few pages in its fascinating story. The modern landscape of western Newfoundland was carved by Pleistocene glaciations hundreds of thousands of years ago, and then modified again by the formation and catastrophic drainage of large Holocene glacial lakes. Work continues to define geosites that will encapsulate chapters in this story for non-geologists and other visitors and advance the region within the UNESCO GeoPark concept. This talk reviews the ongoing and planned activities in a remarkable region that influenced geological thinking on a global scale.

FACIES DISTRIBUTIONS AND PALEOENVIRONMENT OF THE NEOPROTEROZOIC MISTAKEN POINT FORMATION ON THE NORTHERN AVALON PENINSULA

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The Mistaken Point Formation (MPF) is a late Neoproterozoic siliciclastic-volcaniclastic unit that crops out in the Avalon Zone of Newfoundland, particularly on the Avalon Peninsula. The ca. 575–565 Ma MPF is recognized as one of the world's leading Ediacaran fossil-bearing deep-water successions. During MPF sedimentation, bottom currents are believed to have provided oxygen and nutrients critical to Ediacaran fauna on the deep-sea floor. Tectonostratigraphically, the MPF sits as the uppermost part of a thick succession of the volcaniclastic submarine fan strata of the Conception Group, deposited at or near the transition of a fore-arc basin to pull-apart basin. Thus, MPF strata provide context of this basin transformation in the Avalon Zone and can provide insight into whether basin configuration affected bottom currents or other key elements of the local environment that affected Ediacaran fossil abundance. The MPF is subdivided into two members: the lower Middle Cove Member, defined by medium-bedded, fossiliferous sandstone, volcanic ash, and chert; and the upper Hibbs Cove member, defined by medium-to-thick beds of red-green siltstone interbedded with fine-grained sandstone with parallel laminations. The thickness of this upper member increases from the southern to the northern Avalon Peninsula. The boundary between these two members is sharp and conformable with a change from highly silicified strata to more argillaceous rocks. To bring out more details about depositional environment and processes, four stratigraphic sections of the MPF in the St. John's area were measured. Seven facies were recognized, including: massive sandstone (F1); graded sandstone (F2); graded cross-laminated sandstone (F3); siltstone (F4); volcanic ash/ tuff (F5); matrix-supported conglomerate (F6); and red-purple mudstone (F7). Preliminary stratigraphic evidence suggests MPF strata in the study area were deposited by concentrated density flows to low-energy turbidity currents. In the lower part of the succession, F1, F2, F6 dominate, whereas in the upper part, F3, F4, F7 dominate, suggesting an overall upward reduction in grain size and flow energy. The abundance of volcanic ash layers (F5) throughout suggests proximity to an island arc, and deposition by hemipelagic fall out of volcanic ash from discrete eruptions. The absence of wave-generated structures, erosional features, and debris flow deposits suggest that deposition occurred in a deep-water setting, on a generally flat submarine fan, lacking prominent distributary channels. Ongoing investigations of the facies, paleoflow, and provenance will be used to better constrain the details and conditions of basin reconfiguration, and provide environmental context for Ediacaran fossils, or the lack thereof.

MARINE VERTEBRATES FROM THE UPPER CRETACEOUS (LATE CENOMANIAN TO MID-TURONIAN) FAVEL FORMATION IN MANITOBA, CANADA

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The Manitoba Favel Formation is composed of calcareous mudstones and limestones deposited during the Greenhorn marine cycle of the Western Interior Seaway, hosts excellently preserved marine vertebrate fossils, and represents an interval of peak greenhouse temperatures during Late Cretaceous time. Vertebrate microfossil

assemblages were analyzed and reported for the first time from two regionally extensive, stratigraphic marker beds within the Favel Formation of southwestern Manitoba; the early Turonian Laurier Limestone beds at the top of the lower Keld Member and the mid-Turonian Marco Calcarenite near the top of the upper Assiniboine Member. Favel Formation faunal assemblages are dominated by actinopterygian and chondrichthyan taxa, including (from most to least abundant): *Enchodus petrosus*(?), *Palaeoanacorax pawpawensis, Squalicorax curvatus, S. falcatus, Xiphactinus audax, Cretoxyrhina denticulata, Ptychodus rhombodus, Ptychodus rugosus, Ichthyodectes ctenodon,* and *E. shumardi*. New occurrences for the Marco Calcarenite include: *Apsopelix* cf. *A. anglicus, Roulletia canadensis, Rhinobatos incertus, Cretomanta canadensis*, and the avian *Ichthyornis* cf. *Ichthyornis* sp.; all representing local stratigraphic range extensions from the mid- to late Cenomanian of Saskatchewan to the mid-Turonian of Manitoba and taken together indicate a diverse small-bodied vertebrate community in the central, mid-Turonian Western Interior Seaway. Notable occurrences identified from vertebrate macrofossil material include the reptiles *Polycotylus latipinnis* and Elasmosauridae indet. from the Assiniboine Member and *Terminonaris robusta*, Mosasauridae undet., Polycotylidae undet., and Pliosauridae undet. from the Keld Member. New occurrences for the Late Cretaceous of Manitoba include *Ptychodus polygyrus* and *Thryptodus loomisi,* which occur in the Keld Member and Marco Calcarenite, respectively, and significantly extend their northernmost ranges from Texas to Manitoba for their respective time intervals. Recently discovered, new vertebrate occurrences from the Manitoba Favel Formation highlight the important biostratigraphic and biogeographic potential of their formation by increasing representation of historically underrepresented microvertebrate species, as well as the compositional similarity of Manitoba escarpment late Cenomanian to mid-Turonian faunal assemblages with coeval assemblages known from southern localities, such as those in South Dakota, Kansas, and Texas.

THREE PRIMARY TARGET DEPOSIT TYPES FOR NORTH AMERICAN LITHIUM BRINES: EXPLORATION TO SUPPORT VEHICLE ELECTRIFICATION

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Demand for lithium has increased dramatically over the past decade, primarily due to battery applications. The last four years have seen an even sharper jump in demand, as many countries introduced incentives for electric vehicle (EV) adaptation. Currently, the two main sources for industrial lithium are pegmatite deposits in Australia and brine deposits in South American salars (dry salt lakes). Ramped up lithium demand has fueled interest in alternative exploration targets around the world. In North America, three primary deposit types are being rigorously explored for lithium: 1) playas (similar to South American salars), 2) deep geothermal waters, and 3) oil field brines. These three deposit types tend to have lower lithium grades than those that occur in many South American salars. However, the North American deposits have the potential for economic feasibility at lower grades, due to their proximity to infrastructure and existing or future production facilities. In addition, an emerging range of brine processing technologies may open new production options for lower grade brines. In this presentation, we will review the attributes and accumulation processes of the three primary North American lithium brine deposit types. We highlight the unique aspects of each and discuss some differences in exploration and recovery methods.

RECONSTRUCTING DEFORMABLE CONTINENTAL BLOCKS AND CRUSTAL THICKNESSES BACK THROUGH TIME WITHIN THE SOUTHERN NORTH ATLANTIC OCEAN

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The offshore rifted margins of the southern North Atlantic Ocean have been extensively investigated using a variety of geophysical, geological, and plate kinematic approaches. Despite being well studied compared to rifted margins elsewhere, the complex present day architecture of the North Atlantic has made it challenging to assess its tectonic evolution. For the Newfoundland, Irish, and West Iberian margins, examples of such complexity include architectural variations caused by contrasting crustal morphologies, continental blocks, and inherited structures. Recently, deformable plate tectonic models, built using the GPlates software, have provided an approach for investigating the interplay of plate kinematics and deformation experienced within tectonic regimes. Within the southern North Atlantic, previously published deformable plate models have provided a clearer link between the kinematics of continental blocks (e.g. Flemish Cap and Galicia Bank) and temporal variations in strain partitioning and crustal thickness along its offshore rifted margins. In spite of these advancements, previous deformable plate modelling approaches have involved limitations that can be geologically inadequate. Some examples include, but are not limited to, uniform crustal thickness assumptions at model start times and the rigid nature of continental blocks and boundaries that define the limits of where deformation takes place. As a potential solution, we present a new deformable plate modelling approach and application within the southern North Atlantic using the interplay of GPlates and its python programming module, pyGPlates. In particular, this approach involves the reconstruction of present day gravity inversion crustal thickness estimates back through time and allows for internal deformation to be experienced within continental blocks. In addition, we also demonstrate the mitigated edge-effect impact of rigid landward model boundaries using this approach and the resultant ability to reconstruct rift domain boundaries a priori. The results of this study provide insight into the pre-rift (200 Ma) crustal thickness template of the southern North Atlantic and the evolution of relevant continental blocks during rift-related deformation. Furthermore, this work also highlights the potential impact of Appalachian and Caledonian terrane boundaries on the distribution and extent of rifting experienced along the Newfoundland, Ireland, and West Iberian offshore rifted margins.

PALYNOLOGY OF THE HORTON BLUFF FORMATION OF NOVA SCOTIA

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The Late Devonian to Tournaisian Horton Bluff Formation is part of the widespread Horton Group in the Maritimes Basin of Atlantic Canada. It is exposed at several sites in the Blue Beach-Horton Bluff type area in Nova Scotia. These formations and locations have been known for their early, terrestrial tetrapod fauna since the pioneering work of Logan and Dawson. Ages of the Horton Bluff Formation are constrained by macrofloras and palynology (miospores). Questions about the existing palynological biostratigraphic zonation in this area arose when evaluating historical work. While a small number of samples have been analyzed from high in the section, a systematic palynological study of the entire tetrapod-bearing interval has not been published. New samples were taken from Horton Bluff coastline in Nova Scotia, commonly referred to as Blue Beach. Sample coverage extends from the southernmost and stratigraphically deepest coastal exposure up to the axis of a syncline along the shore. It thus encompases all of the tetrapod-bearing strata in the section. These strata should preserve subdivisions within the *Vallatisporites vallatus* miospore Biozone: the *Claytonispora distincta* and *Spelaeotriletes cabotii* subzones (informally "spore zones 2 and 3"), but the exact position of the subzonal boundary cannot be identified from exisiting data. Preliminary results and taxonomy of these samples across the *Claytonispora distincta* and *Speleaotriletes cabotii* subzones will be discussed. This locality and stratigraphical interval are important because some of the oldest know tetrapod materials from within Romer's Gap come from this coastal section. Understanding the detailed biostratigraphy will allow correlation with tetrapod records from within Romer's Gap in the Horton Group in nearby New Brunswick. The study will also allow correlation with other euramerican tetrapod sites.

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PALYNOLOGY OF THE ALBERT FORMATION OF NEW BRUNSWICK

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A palynological (plant spores) biostratigraphic study of the Tournaisian (Early Carboniferous) sites between the townships of Bloomfield and Norton, New Brunswick (NB), is being conducted. Newly collected and historical samples are being used to study the subdivisions within the Vallatisporites vallatus zone: *Claytonispora distincta* (formerly *Dibolisporites distinctus*) and *Speleaotriletes cabotii* subzones (informally NB spore zones 2 and 3). The Tournaisian and Visean stages of the Mississippian Period are considered part of 'Romer's Gap', an interval of time when tetrapods diversified and made the transition from aquatic into terrestrial environments. Three fossil locations are known to yield fossil evidence of tetrapods from Romer's Gap: Scotland; Horton Bluff, Nova Scotia; and the newly discovered tetrapod tracks preserved in sites around Norton, New Brunswick. Interest in the relative age of these fossil-bearing strata arose due to the discovery of these important tetrapod ichnofossils as they could represent some of the earliest evidence of terrestrial tetrapods within this hiatus. Refining the age of the fossil bearing strata is important to better understand how the new NB sites compare to the broader evolutionary story of vertebrate life on land. A lack of marine biota, datable macrofossils or radiometrically-dateable volcanic rocks leaves palynology as the sole tool to assess the relative timing of the New Brunswick stratigraphy. The historical palynological framework (biozonations) applied to the Tournaisian in the region is based on sites along the Horton Bluff, NS shoreline and surrounding area. This biozonation framework has been widely accepted and applied across Atlantic Canada. Upon further inspection of the original literature and sampled sites, questions have been raised about the *Claytonispora distincta* (formerly *Dibolisporites distinctus*) and *Speleaotriletes cabotii* biozones (informal NB spore zones 2 and 3) at the Blue Beach tetrapod locality. Once fully unravelled, this new information may affect how we determine the relative age of similar sites in Atlantic Canada. Better understanding of this original palynological framework will allow for better correlation of sites within Romer's Gap, both locally and globally.

REDISTRIBUTION OF HEAT-PRODUCING ELEMENTS DURING MELTING OF ARCHEAN CRUST

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The invisible phenomenon of heat production and transfer has played a fundamental role in creating the landscape and geology of Earth. Radiogenic decay is responsible for the majority of new heat produced within the Earth, with > 99% being produced through the decay of K, U, and Th (i.e. heat-producing elements). As these heat-producing elements are broadly incompatible and partition into a few phases (melt, accessory minerals, and amphibole) during anatexis, it is thought that heat-producing elements are concentrated in the middle and lower crust with a complementary depletion in the lower crust. This belief of heat-producing element stratification in the crust is a crucial assumption in geodynamic models, paleothermobarometry, and mantle temperature estimates. However, this assumption relies on few natural data points and the minerals (along with their P-T stability) that sequester most heat-producing elements remains unknown. Further, the effects of heat-producing element redistribution during anatexis on metamorphic timescales are abstract. We integrate field observations, whole-rock compositions, thermodynamic equilibria, and accessory mineral modelling with heat-production and heating-time modelling to provide insights into the partitioning of heat-producing elements between residue and melt during anatexis of metabasites as well as the effects this has on metamorphic timescales and production of tonalite–trondhjemite–granodiorite suites. We model six metabasite compositions ranging from relatively fertile greenschist-facies metabasites to melt-depleted residual mafic (upper-)amphibolites to granulites. Heat-producing elements are modelled to be partitioned between melt and residue; the dominant minerals in the residue that host these elements are apatite, hornblende, K-feldspar, and epidote. At 800–850°C, the melt fraction is predicted to contain roughly half of the heat producing elements in the system. The partitioning of heat-producing elements into relatively low-density melt decreases the heat production of the system during anatexis, however dense and heat-producing element amenable minerals (e.g. apatite, epidote), can buffer the decrease in heat-production during metabasite melting. Nonetheless, a protolith with a relative enrichment in heat-producing elements is expected to heat up in half the time (100–150 Myr) as a depleted protolith without considering external heat sources. Our results provide a heat-producing element and heating time argument for the dominance of enriched basaltic compositions as the protolith for tonalite–trondhjemite–granodiorite magmas as well as important insights into the sequestration and liberation of heat-producing elements during anatexis and crustal-building.

DEFORMATION BANDS AND THEIR RELATIONSHIP TO FAULTS ASSOCIATED WITH UNCONFORMITY-RELATED URANIUM DEPOSITS: A CASE STUDY OF THE C1 FAULT CORRIDOR AND WS SHEAR ZONE (GRYPHON AND PHOENIX DEPOSITS) IN THE EASTERN ATHABASCA BASIN

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Saskatchewan has world-class uranium (U) deposits associated with the unconformity between the Proterozoic Athabasca Basin and underlying Archean-Paleoproterozoic basement rocks. Many deposits exhibit a strong spatial association with post-Athabasca faults formed by the reactivation of basement-rooted structures. Deformation bands are products of localized strain in porous sedimentary rocks and are commonly associated with fault damage zones. They can significantly modify porosity due to grain rotation and granular flow. This study investigated deformation bands in sandstones of the basal Manitou Falls Group in eight drillhole fences that transect two major fault corridors in the eastern Athabasca Basin; the NNE-trending C1 fault corridor that hosts the Gryphon deposit, and the WS shear zone, a splay of the former that hosts the Phoenix deposit. The deformation bands in sandstone correspond to mainly shear-enhanced compaction bands that increase in abundance toward post-Athabasca faults. The proportion of bands with visible signs of cataclasis increases with depth. Petrographic study places band formation relatively early in the host-rock paragenetic sequence, before introduction of drusy quartz veins and tourmaline associated with U mineralization. Paleo-stress analysis performed using basement- and sandstone-hosted structural orientation data identified two major stress regimes associated with each fault corridor. The first regime (A) groups strike-slip (cover) and thrust (cover and basement) solutions at both localities wherein the principal stress ($\sigma1$) lies in the horizontal plane roughly perpendicular to the fault; while the second regime (B) groups additional data, with the derived $\sigma1$ (~E-W) lying near-parallel to faults. Based on collective macroscopic to microscopic observations, we infer that deformation bands formed after Manitou Falls deposition in successive homogeneous stress regimes. It is contended that the bands initially formed in a strike-slip regime (A), characterized by subhorizontal NW-SE-trending $\sigma1$ that promoted reverse reactivation of moderately ESE-dipping basement-rooted faults. A younger set of thrust-sense bands may have facilitated fault propagation through the sandstone cover, and potentially records the evolution of A to a fully contractional i.e. thrust regime. Most deformation bands thus appear to have formed early, under regional compression that preceded and accompanied basement fault reactivation, related unconformity offset and associated influx of uraniferous fluids. The second regime (B, $\sigma1$ E-W) may mark younger sinistral strike-slip motion (basement and cover) and influenced development of NW-SE transverse faults. The nature and timing of the bands in this study is compatible with the shallow basin model of uranium ore genesis.

APPLICATION OF HYPERSPECTRAL IMAGING AS AN EXPLORATION VECTOR TOWARDS MINERALIZATION AT THE SOUTH WOOD LAKE (STAGHORN) GOLD PROSPECT, WESTERN NEWFOUNDLAND

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The Staghorn Gold Prospect occurs in the Victoria Lake shear zone, near the junction of three lithotectonic domains; the Exploits, Meelpaeg and Notre Dame sub-

zones. This region contains multiple structurally controlled gold deposits, associated with major fault systems within the Dunnage Zone. Previous studies and reports indicate that the mineralization in the South Wood Lake deposit is hosted by variably brecciated and mylonitic orange-pink monzogranitic rocks, of the Peter Strides granite suite. The monzogranite is crosscut by veins and fractures with adjacent wall-rock sericitization and silicification. This unit has upper and lower contacts with deformed biotite paragneiss, shale, mudstones and chlorite schist of the Storm Brook Formation; there are lower gold grades in the host rocks. Drill holes, from the main zone of the deposit, were analyzed with the high-resolution CNA - hyperspectral scanning unit imaging spectrometer system (photon etc.), covering - VNIR (400–1000 nm), SWIR (1000–2500 nm), MWIR (2500–5000 nm), and LWIR (8000–12000 nm) spectral ranges. Analysis of the main absorption features in the VNIR-SWIR range identified white mica in the mineralized granitic rocks; previous petrographic studies had indicated its presence in the matrix and fractures of the brecciated monzogranite. The occurrence of white mica is mainly restricted to this unit, allowing for a clear and fast visualization and definition of potentially economic areas of interest. Variation in the 2190–2200 nm wavelength was also mapped, however, no direct correlation between the gold grades and a given composition was confirmed. Low white mica crystallinity was observed through the deposit, based on the ratio of the depth of the 1900 and 2000 nm features, with no association between the crystallinity and mineralization. Additionally, the hyperspectral system identified other minerals, such as chlorite, biotite, amphibole, tourmaline and kaolinite. Chlorite, biotite and amphibole more commonly occur in the chlorite schist of the Storm Brook Formation, emphasizing contrasts between the mineralized unit and its surroundings. In the MWIR range, minor carbonates were also identified. Although it was not possible to obtain a direct link between spectral parameters (composition, crystallinity) and the mineralization, the hyperspectral imaging provided for a better visualization and insight into the prospective lithology for this prospect. Considering the short scanning and processing times, this technique can quickly identify zones of interest in the exploration process.

ACID WEATHERING, CLAY TRANSPORT AND ENHANCED NUTRIENT SUPPLY TO EARLY PALEOPROTEROZOIC OCEANS FOLLOWING THE GREAT OXIDATION EVENT

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It was previously hypothesized that following the Great Oxidation Event (GEO) at ca. 2.5 billion years ago, oxygenation of the atmosphere led to unprecedented acid production from biological oxidation of crustal pyrite and siderite, leading to enhanced levels of nutrient transport to the oceans. For instance, higher levels of terrestrial phosphate supply would then have facilitated marine primary production, the burial of more organic carbon than any previous time in Earth's history, a rise in atmospheric oxygen, and a large increase in the $\delta^{13}C$ value of marine carbonates; these events are collectively known as the Lomagundi Event (LE) between ca. 2.22 and 2.06 Ga. Although phosphate was initially sourced from apatite dissolution via acidic soil pore- and ground-waters, the mechanisms by which the phosphate was transported to the oceans and then concentrated into P-rich deposits is unclear. Here we show that phosphate is readily adsorbed onto kaolinite particles under freshwater conditions (pH 6, ionic strength=0.01 M) but that phosphate is released in marine aquatic environments (pH 8, ionic strength=0.56 M). Phosphate sorption is significantly increased when the pH is further dropped to pH 4, conditions mimicking waters impacted by acid rock drainage. We suggest that during post-GOE terrestrial weathering, P was carried by suspended clay particles to estuarine and coastal environments, where P was desorbed, released into seawater as ionic phosphate species, and then utilized by photosynthetic plankton. Interestingly, clay sorption experiments with molybdenum – an important metal in biological nitrogen fixation – show similar results to phosphate. Our research provides new perspectives on the mechanisms that link the rise in atmospheric O_2 with the evolution of aerobic chemoautotrophy on land to the LE. It also introduces the potential for nonlinearity in the fluxes of phosphorous (and molybdenum) to the oceans with increases in chemical weathering intensity.

LOTS OF SMOKE BUT NO FIRE YET!: IOCG MINERALIZATION ALONG THE COBEQUID-CHEDABUCTO FAULT ZONE OF NOVA SCOTIA (CANADA)

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The Cobequid-Chedabucto Fault Zone (CCFZ) of Nova Scotia is an important tectonic feature in the northern Appalachians as it marks the dextral docking of Avalonia against Meguma during the Neoacadian orogeny. Following terrane collision, this zone was often reactivated and the locus of A-type magmatism, deformation, and fluid flux. It has long been known for the occurrence of spatially related but genetically enigmatic zones of Cu, Co, Ni, and Au mineralization, localized Fe-oxide and Fe-carbonate development (e.g. extensive former Londonderry Fe-carbonate veins and oxidized zones). Since the advent of the IOCG deposit nomenclature, the CCFZ has appeared as a metallotect on many global compilations. Although the regional setting and general features of this IOCG-type metallotect will be reviewed, the Copper Lake (CL) and Mt. Thom (MT) areas will be discussed in detail. At CL, a former small Cu mine, Devonian siltstones and shales are bleached against quartz-Fe carbonate veins ± Cpy, Py, Hmt with elevated Co, Ni, and Au. Intense wall-rock alteration includes its dissolution with porosity lined by pyrite, albite, chlorite, muscovite, clays, Fe-carbonate, apatite, monazite, thorite, xenotime, and zircon. Fluid ingress is constrained to ca. 320 Ma from muscovite (Ar–Ar) and pyrite (Re–Os) dating. At MT, Cu mineralization (wt.% over multi-metre sections) associated with abundant pyrite and elevated Ni, Co, Au in quartz-carbonate-hematite veins and disseminations is centred on a high-level (granophyric and spherulitic textured) multiphase leucogranite intruding mid-Carboniferous clastic rocks. Alteration is variable (silica, Fe-carbonate, hematite with chlorite, sericite, arsenian pyrite ± monazite, xenotime, zircon, and rutile) and intense; locally dissolution cavities are lined by scapolite-phologopite-muscovite-carbonate ± sulphides-Cl-rich apatite-monazite. Timing of alteration is constrained to ca. 325 Ma from Ar–Ar dating of sericite-altered granite and sedimentary rocks. Fluid-chemistry at CP, MT and regionally (e.g. Londonderry) is inferred from isotopes (S, O, C, Sr), carbonate REE, and fluid inclusions: 1) $\delta^{34}S$ (Cpy, Py, Po; n= 28) is bimodal at -2 to 3‰ and 7 to 14‰; 2) $\delta^{18}O$ (Qtz, n = 19) and $\delta^{18}O$ (Carb, n = 54) indicate $\delta^{18}O_{H2O}$ of 4.2–10‰ and 6.4–11.5‰, respectively at 300–200°C; 3) $\delta^{13}C_{PDB}$ (Carb, n = 54) is -5 to -9‰; 4) Sr_i (Carb, n = 10) = 0.7106 to 0.7613; 5) carbonate REE normalized to NASC is LREE depleted with $(Lu/La)_N$ = 10–100; and 6) fluid inclusions include L-V, V, and L-V-multi-solid types in all cases. These data suggest mineralization along the CCFZ at ca. 325–320 Ma involved circulation of heated basinal brines with likely contributions from evaporite rocks.

GEOCHEMICAL AND GEOCHRONOLOGICAL ATTRIBUTES OF MEGUMA GOLD DEPOSITS ARGUE FOR A SINGULAR MODEL OF FORMATION DURING LATE-STAGE REGIONAL OROGENESIS AND MAGMATISM

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The Meguma terrane of southern Nova Scotia is well-known for hosting slate-belt type orogenic quartz-vein gold deposits, i.e. Meguma gold deposits (MGD). With over 60 past producing districts, it is apparent the terrane experienced widespread influx of mineralizing fluids. Here we review an extensive database for these deposits and argue for that their commonality reflects a similar genesis. The MGD are hosted in a thick sequence of folded metaturbidites deformed during the Neoacadian orogeny (<410–380 Ma) that was accompanied dominantly by greenschist facies metamorphism. Emplacement of vein arrays localized to high zones of anticlines is related to late-stage fold tightening that overlaps with emplacement of widespread meta- to peraluminous granitoids at ca. 380–370 Ma. Dating of several MGD using Ar-Ar (Amph, Biot, Musc) and Re-Os (Aspy) yielded ages that mostly overlap with magmatism and thus support field relationships. Historically most MGD are

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vein type, but the economy of Au now also favours mining of low-grade (1 g/t Au) disseminated-type mineralization. Vein settings are simple, being dominated (> 90%) by quartz with minor carbonate (Ca-Fe-Mg) and sulphide (Fe-As-S) phases, although enrichment of other sulphides (Cu-Zn-Pb-Bi-Ag) and silicates (plagioclase, tourmaline, muscovite, biotite, hornblende, garnet) occurs locally with a general correlation with proximity to intrusions. Although most Au recovered is non-refractory, LA-ICP-MS analysis indicates it is locally abundant in arsenopyrite. Fluid inclusions from all vein types across many deposits indicate a similar low-salinity, dominantly single-phase aqueous-carbonic (X_{CO2} < 0.2) fluid, but variable fluid density reflects transient cycling of P_{fluid}, as does the abundance of decrepitated fluid inclusions. Whereas $\delta^{18}O$ for both quartz and carbonates are generally uniform and indicate $\delta^{18}O_{H2O}$ = 7 to 12‰ for 350°C, the $\delta^{13}C$ (-18 to -25‰) and $\delta^{34}S$ (9 to 25‰) values for carbonates and sulphides, respectively, suggest a strong influence of the wall rock. The latter therefore raises issues in regards to the origin of the CO_2 component of the fluid and how Au was precipitated if S was scavenged from the wall rock; these aspects will be expanded on. Interpreting all the observations collectively, we suggest MGD represent a singular, widespread fluid focusing event that overlapped with the termination of regional deformation and metamorphism of the area with emplacement of intermediate to felsic magmas into the upper crust; the latter likely contributed to the vein fluids, possibly even some metal endowment (e.g. Au, Sb?), but further work is needed to constrain this.

DEUTERIC VS METEORIC FLUIDS IN KIMBERLEY-TYPE PYROCLASTIC KIMBERLITES: CONSTRAINTS FROM THERMODYNAMIC MODELLING

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The extent to which the post-emplacement hydrothermal processes modify the kimberlite mineralogy and textures remains a controversial issue. Magmatic fluids exsolved from the erupting kimberlite magma are involved in the emplacement processes, but it is debated to what degree the meteoric fluids recrystallize and reset the observed kimberlite mineralogy. Some models suggest that kimberlites can be fresh and contain only primary minerals formed from deuteric magmatic fluids, while others view all kimberlites as pervasively altered by the hydrothermal meteoric fluids. This study constrains the fluid origin for Kimberley-type pyroclastic kimberlite (KPK) using petrography, bulk composition, thermodynamic modelling and conserved element ratio analysis. KPK is distinguished from other kimberlites by texture, mineralogy and the presence of 15–90 vol% of crustal basement xenoliths. To explain the KPK mineralogy deviating from the mineralogy of crystallized kimberlite melt, we study reactions between hypabyssal kimberlite transitional to KPK and felsic xenoliths and model thermodynamically the common zonal patterns pectolite–diopside–phlogopite–serpentine–olivine on contacts between xenoliths and kimberlite. Reacted xenoliths are replaced by pectolite, prehnite, diopside, serpentine and phlogopite, with minor garnet and wollastonite. To replicate the observed mineral assemblages, we extended the thermodynamic database to include pectolite, using calculated density functional theory methods. PERPLE_X equilibrium phase modelling was carried out at near surface conditions, T= 250–1400°C for moderately altered granitoid and gneiss xenoliths. Observed and modelled mineralogy was compared for (i) CO_2 and H_2O treated as fixed components, as reported in the bulk chemical analysis, and (ii) fluid-saturated conditions, where the fluid composition was set as 10% CO_2 and 90% H_2O to simulate meteoric fluid. The low-temperature (< 350°C) phases predicted by fluid-saturated models have not been observed in the actual samples. Formation of pectolite and prehnite cannot be simulated in excess of hydrous volatiles. Modelling of the sub-solidus mineralogy for kimberlites rich in felsic xenoliths calls for a limit in the amount of volatiles in the kimberlite-xenolith system. Our findings imply the deuteric origin of the fluids in KPK pipes where the mineralogy resembles clinopyroxene- and serpentine-rich mineralogy of the kimberlite contaminated by felsic xenoliths.

LATE DEVONIAN–EARLY CARBONIFEROUS PERI-LAURENTIAN OROGENIES AND THE POSITION OF MEXICAN TERRANES

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Late Devonian–Early Carboniferous orogenies affected the various margins of Laurentia differently. Whereas ongoing convergence of Gondwana with Laurussia is manifested in the northern Appalachians, other margins of Laurentia experienced coeval, short-lived orogenic processes, namely the Ellesmerian, Svalbard and Antler orogenies. In the Canadian Arctic, the formation of the Ellesmerian fold and thrust belt, which is coeval with inversion tectonics on Svalbard, displays frontal convergence of the Laurentian edge with the Arctic sector of remaining Laurussia. In contrast, the Antler orogeny at the Panthalassan side of Laurentia was associated with sinistral transpressional tectonics. In northeast Greenland, i.e. on the opposite side of the craton, an Early Carboniferous UHP event in the Greenland-Scandinavian Caledonides was accompanied by dextral intra-continental strike slip tectonics. Because this enigmatic intracontinental subduction-exhumation event is significantly younger than the formation of late to post Caledonian sedimentary basins, this UHP event is causally unrelated to the Caledonian orogeny. We propose a cogenetic origin of the Peri-Laurentian orogens, and explain the above tectonic patterns with the existence of a northward moving Late Devonian–Early Carboniferous lithospheric Laurentian subplate. Convergence in the north is balanced by sinistral and dextral strike slip tectonics at the western and eastern margins of the craton, respectively. The existence of a Laurentian subplate can be explained with plate reorganization processes during the Gondwana–Laurussia collision. Such a scenario requires the existence of a vast continental orogenic domain with the northern Appalachians being its external Peri-Laurentian part. The tectono-metamorphic record of the Mexican Acatlan complex of the Mixteca terrane corresponds to that of the northern Appalachians. Therefore, the "Mexican terranes", i.e. crustal fragments of Peri-Laurentian and Peri-Gondwana origin crust now located in Central America, are a possible candidate for such an orogenic domain. Thus, in our Late Devonian–Early Carboniferous plate-tectonic reconstruction of the Gondwana-Laurussia plate boundary zone, we propose the "Mexican terranes" to be adjacent to the northern Appalachians representing remnants of a voluminous crustal pile. Carboniferous–Permian zipper-style closure of the western part of the Rheic Ocean resulted in the lateral escape of the Mexican terranes and eventually in their emplacement at the Panthalassan side of Pangea.

ADVANCING CROSS-SECTOR, TRANSBOUNDARY FRESHWATER KNOWLEDGE – DATASTREAM'S OPEN ACCESS WATER QUALITY DATA PLATFORM

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Groundwater provides baseflow for all of Canada's major river systems, sustains wetland ecosystems such as fens in the boreal forest, contributes to lake water balance, and is an often overlooked pathway for potential contaminant transport in freshwater systems. The interaction between groundwater and surface water can be better understood through the compilation and access of data collected from both ecosystems. Across Canada diverse monitoring programs led by governments, researchers, communities and watershed organizations are generating valuable information to track conditions in these systems. When these data are brought together it can generate powerful insights into environmental impacts and change at spatial and temporal scales beyond the scope of any one monitoring initiative alone. However, finding ways to effectively connect this information from multiple sources in a consistent, re-useable format is a persistent challenge. Open-access tools like DataStream are transforming how water data can be shared to fuel environmental

research and inform water management decisions. Designed with communities, researchers, and decision-makers in mind, DataStream is an open data platform that brings water quality and sediment quality data together at regional-scales using consistent data and metadata formats that promote data access and reuse. DataStream was developed by the Gordon Foundation and is delivered in collaboration with regional monitoring networks across the Mackenzie Basin, the Lake Winnipeg Basin, the Great Lakes-St. Lawrence region, and Atlantic Canada. The platform provides access to over 17 million unique, standardized water quality observations at the time of writing, published by nearly 200 organizations across Canada. Though the DataStream platform has been focused on ambient surface water conditions to date, there is a recognition of the interconnection of surface water and groundwater systems and the need to access both data types easily for a more holistic understanding of freshwater systems. Hosting groundwater quality data on DataStream will enable not only regional-scale assessment of ambient groundwater conditions, but also will support investigations of surface water-groundwater interaction and the health of groundwater dependent ecosystems. This presentation provides an update on developments to the DataStream schema that will soon allow for sharing of groundwater quality data and its necessary and unique metadata. It will also highlight how DataStream's robust data standards and open data sharing is facilitating cross-sectoral and transboundary research and connecting water quality data in more meaningful ways.

THE INTERNATIONAL GEOSCIENCE PROGRAMME (IGCP): AN EXAMPLE AND A FIFTIETH ANNIVERSARY PERSPECTIVE

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The International Geoscience Programme (IGCP), the flagship program of UNESCO, facilitates international scientific collaboration in the geosciences, and particularly between more industrialized and developing countries. It promotes sustainable use of natural resources, new initiatives related to geo-diversity and geo-heritage, and geohazards risk mitigation. IGCP supports projects by providing seed grants to build international collaborations within its five themes of Earth Resources, Global Change, Geohazards, Hydrogeology, and Geodynamics. These < 5-year projects are centred around field trips, workshops and meetings. IGCP strongly supports the United Nations Sustainable Development Goals, including quality education and gender equality, in particular by inclusion of underrepresented groups in IGCP projects and activities. An example is our current IGCP project 683 "Pre-Atlantic geological connections among northwest Africa, Iberia and eastern North America: Implications for continental configurations and economic resources", which brings together > 130 participants, 30% are female geoscientists from 17 countries and 6 continents, who are working on crustal fragments of "NW African origin" that are now found in North America and Iberia. This project forms a platform for collaboration among all participants, but particularly among those from developing (mostly NW African) countries, and experts at globally leading universities. Because of Covid-19, we have had monthly virtual meetings prior to this first in-person meeting associated with the Halifax 2022 meeting. The virtual meetings include science webinars, but also sessions focused on analytical techniques, which have been particularly beneficial to our early career members in developing countries. Language, visa and financial issues normally inhibit participants to various extents from participating in IGCP projects. Virtual meetings are accessible to most, and participants can ask questions in their own language, with translation by one of the leaders. In the future we aim to more proactively involve our early-career participants, not only by providing support to attend our in-person meetings, but also by having them give brief presentations at our virtual meeting. These presentations can be pre-recorded to facilitate participation by those inhibited by language challenges. These efforts all provide more effective opportunities to build an international network and work towards future collaboration, which are a centrepiece of the IGCP program in general. More generally, with the increasing awareness of the role of global geoscience in dealing with climate change and more sustainable use of natural resources, the international cooperation, exemplified by our IGCP project and the IGCP program in general, provides a model for the future.

OROGENIC EVENTS IN THE SOUTHEASTERN NEW ENGLAND APPALACHIANS TRACKED BY THE DETRITAL ZIRCON RECORD

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The southeastern New England Appalachians consist primarily of Gondwana-derived terranes, with possible Baltican components, that accreted during the mid-Paleozoic. An additional northwest African crustal block may have arrived as recently as the late Paleozoic formation of Pangea. These basement rocks are overlain by latest Silurian to Upper Pennsylvanian sedimentary rocks that were deposited during the mid-Paleozoic Acadian and late Paleozoic Alleghanian orogenies. Detrital zircon in sedimentary basement rocks aid in distinguishing terranes and revealing their origins. The detrital zircon signatures of the overlying sedimentary rocks reflect terrane arrival and associated orogenic events. Prior to the arrival of the Gondwanan terranes, Laurentian margin sedimentary rocks show a small ~2.7 Ga detrital zircon population, a major ~1.9–0.9 Ga population that peaks at ~1.2–1.0 Ga and a Mid Ordovician population. Gondwana-derived Ganderia and Avalonia both show scattered Archean zircon grains with a small peak at ~2.7 Ga, and ~2200–540 Ma populations. Ganderia is characterized by a large ~540 Ma detrital zircon (DZ) and a smaller ~640 Ma population, whereas Avalonia shows a large ~640 Ma population and a smaller ~540 Ma population. The Mesoproterozoic DZ populations of Avalonia in southeastern New England are larger than those of Avalonia in Canada and those of Ganderia. Northwest African rocks in southeastern New England are characterized by large ~2.2–2.0 Ga and/or ~740 Ma DZ populations. Detrital zircon U–Pb data from the previously interpreted Avalonian part of Massachusetts show primarily Avalonian (Amazonian/Baltican) signatures, but two samples from the Neoproterozoic Newport Group in southern Rhode Island and two pieces of Paleoproterozoic metawacke from drill core from the Georges Bank, offshore Massachusetts, suggest northwest African affinity. The Nashoba terrane, northwest of Avalonia in eastern Massachusetts, is interpreted as the trailing edge of Ganderia. Its main ~560 and ~540 Ma zircon populations are probably derived from the Ediacaran–Cambrian Penobscot orogenic cycle and its basement, and detrital zircon ages are as young as Early to Middle Ordovician. Six formations from the Ganderian cover in the Merrimack belt to the northwest were deposited between ~435 and 420 Ma based on youngest zircon age populations and crosscutting plutons, and yielded large ~470–443 Ma populations. Three show only Gondwanan provenance while three have a mixed Gondwanan-Laurentian signal, which is typical for younger and/or more westerly sedimentary rocks that were deposited as Avalonia accreted below the recently expanded composite Laurentian margin.

POSSIBLE CRUSTAL BLOCKS OF THE SOUTHEASTERN PART OF THE NEW ENGLAND AVALON TERRANE IN THE US APPALACHIANS

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This virtual field trip provides an introduction to possible crustal blocks of the southeastern part of the New England Avalon terrane. It builds on recent U–Pb detrital zircon geochronology results that identified the Neoproterozoic Newport Group around Newport, Rhode Island, as a possible non-Avalonian block. The potential exotic nature and history of the Newport Group, as well as structural and petrologic intricacies of the southeastern part of the New England Avalon terrane is discussed. We first visit rocks of the northern and western parts of the southeastern New England Avalon terrane that correlate well with Avalonian terranes in Newfoundland, Nova Scotia and New Brunswick, Canada, based on rock types and ages, U–Pb detrital zircon signatures of metasedimentary rocks, and Sm–Nd isotope geochemistry data. Stops include: (1) quartzite of the Neoproterozoic Blackstone Group (2) quartzite of the Cambrian North Attleboro Formation, and (3) the Conanicut Group of Beavertail State Park, RI, all of which show or hint at correlations with the Avalon terrane based on U–Pb detrital zircon analysis. An enigmatic pillow basalt is exposed in the Blackstone Group, but may be as young as its youngest, latest Devonian zircon. It may correlate with the basal Wamsutta Formation of the latest Devonian to Permian Narragansett Basin that overlies parts of the

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southeastern New England Avalon terrane. The Wamsutta Formation contains the only known other undeformed basalt in the area. We then visit the Price Neck and Newport Neck formations of the Neoproterozoic Newport Group in southern Rhode Island, which, based on U–Pb detrital zircon analyses, have a likely northwest African affinity. The Newport Group may thus represent a subterrane, terrane or other crustal block with a different origin and history than the southeastern New England Avalon terrane to the northwest. The boundary of this Newport Block may be restricted to the boundaries of the Newport Group, or it may extend farther to the north, east and west. We finish our trip with the area to the east around New Bedford, Massachusetts, where, unlike the areas described above, the metamorphic grade is high and structures trend west, as in the southwestern part of the Southeastern New England Avalon terrane. This is in contrast with the greenschist and lower metamorphic grades, and northerly-trending structures of the domains described above. Preliminary detrital zircon analysis, however, suggests an Avalonian affinity for this area.

MONITORING MECHANISMS THAT CONTROL GOLD PRECIPITATION FROM AURIFEROUS FLUIDS

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During orogenic gold mineralization, the mechanism by which a hydrothermal fluid precipitates gold in sulphide-bearing quartz-carbonate shear veins remain elusive. However, due to their small geochemical footprint, understanding the specific mechanism responsible for gold precipitation is critical for targeting concealed high-grade veins, especially as exploration moves undercover. Reduced near-neutral auriferous fluids commonly ascend along deep structural corridors located in the middle crust (~7–15 km), and transport gold as reduced sulphide species such as $Au(HS)_2^-$. As a result, the precipitation of gold from hydrothermal fluids is best interpreted as the product of the evolving fluid SO_4/H_2S ratio (fO_2) and/or H_2S concentration (fS_2), each a function of multiple competing processes that destabilize gold sulphide complexes, such as fluid mixing, fluid-wall rock reaction, and/or phase separation. Recent developments in analytical techniques allow for multiple sulphur isotopes to be measured through a sulphide-paragenetic sequence, thereby lending insight into the evolving fluid physico-chemistry that lead to the destabilization of $Au(HS)_2^-$. In this talk, we demonstrate new applications of in-situ multiple sulphur isotopes ($\delta^{34}S$-$\Delta^{33}S$) combined with trace element composition through gold-bearing sulphide parageneses, with examples from orogenic gold deposits hosted in the Neoarchean greenstone belts of the Abitibi subprovince, Canada, and the Eastern Goldfields, Australia. Gold-bearing sulphides in quartz-carbonate-tourmaline veins of the Triangle deposit (Abitibi) demonstrate limited within-grain zonation in $\delta^{34}S$ and trace element contents. We interpret this signature to indicate that gold precipitated by a reduction in fluid fS_2 induced by wall-rock sulphidation of Fe-enriched host rocks. Conversely, gold-bearing pyrite in quartz veins of the Kanowna Belle deposit (Eastern Goldfields) show significant within-grain zonation, whereby gold is associated to wt.%-concentrations of As and a significant shift in $\delta^{34}S$ from 0 to -8‰, while retaining a constant $+\Delta^{33}S$ value. We interpret this signature to indicate that gold precipitated during H_2 vapourization from the fluid, thereby increasing the SO_4/H_2S ratio and destabilizing gold complexes. By understanding differences in gold precipitation mechanisms, we can better explore in the near-mine space. For instance, at the Kanowna Belle deposit, the fault structures not only act as conduits for auriferous fluids, but also as drivers for gold precipitation, regardless of the host-rock chemical composition. This understanding opens up the search space to the upper Fe-poor lithologies of the host greenstone sequence.

SUBDIVIDING THE EDIACARAN

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Bracketed between the last of the major global Snowball Glaciations and the emergence of complex animal life as signaled by the appearance of the probing trace *Treptichnus pedum*, the Ediacaran Period marks an interval of fundamental change in both biological and geological systems. Within the Ediacaran, we see the emergence of the first large and structurally complex multicellular organisms (the Ediacara biota), the evolution and diversification of skeleton-forming animals (such as *Cloudina* and *Namacalathus*), and the advent of motility (captured as trace fossils). Despite these fundamental and presumably stepwise events, the subdivision of the Ediacaran period into meaningful Series and Stages remains elusive. The current difficulties in identifying temporal subdivisions are underpinned by taphonomic overprints on the first appearances of biological and geochemical signals typically used for finer-scale subdivisions within the Phanerozoic. Previous attempts have identified three potential subdivisions for the Ediacaran System—a "First Ediacaran Stage" (FES), which would represent the time from the recovery of the ~635 Ma Marinoan glaciation to the base of the "Second Ediacaran Stage" (SES), while the subsequent "Terminal Ediacaran Stage" (TES) would lead up to the base of the Cambrian Period. Here we present a review of the biological, geological, and chemical markers that have been proposed to subdivide the Ediacaran into these stages and propose the establishment of lower and upper Ediacaran Series.

PALEOPROTEROZOIC OCEANIC LITHOSPHERE: REVISITING THE WATTS GROUP (PURTUNIQ OPHIOLITE) OF THE CAPE SMITH BELT, UNGAVA OROGEN, NUNAVIK, CANADA

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The present study focuses on the field relationships and geochemistry of an exotic terrane at the heart of the Ungava Orogen: The Watts Group, dated at 1998 Ma. These Paleoproterozoic rocks, also known as the "Purtuniq Ophiolite", are interpreted as one of the oldest remnants of obducted oceanic lithosphere on Earth. Previous studies have described the Watts Group as a thrust stack of pillowed mafic volcanic rock, mafic sheeted dykes and large cumulative mafic to ultramafic plutonic suites. These igneous rocks are metamorphosed to greenschist and amphibolite facies and imbricated as out-of-sequence thrusts sheets during the Ungava Orogeny. The presence of a sheeted dyke complex genetically related to the overlying pillowed basalts is interpreted as a proof that the Purtuniq ophiolite formed at a spreading ridge, implying that sea-floor spreading and convergent margin processes were active as far back as 2.0 Ga, thus providing a Paleoproterozoic minimum age for the onset of modern plate tectonics as our planet's convection regime. However, a competing hypothesis for the formation of the Watts Group rather points towards an oceanic plateau origin as part of the Minto-Povungnituk Large Igneous Province, thus negating the relationship between the Watts Group and modern plate tectonics. The Bureau de la Connaissance Géoscientifique du Québec, who is funding this study, has recently undertaken a decadal mapping campaign to revisit the Ungava Orogen. The present contribution provides an overview of the progress made in geological mapping and geochemical analysis. In order to characterize the Watts Group and discriminate its geodynamic setting of formation, we apply an integrated analytical approach, including regional mapping, whole-rock major and trace element geochemistry and geochronology. Geochemical discrimination of the geodynamic environment of formation of the Watts Group's rocks was undertaken via immobile trace element ratios and petrological modeling. Preliminary result indicates that mafic volcanic rocks are tholeiitic, with N-MORB to P-MORB affinity for the Watts mafic rocks, whereas the mafic dyke complex are of arc-related or crustal-contaminated affinity. These new data do not support that the dyke complex is cogenetic with the volcanics. Upcoming petrological modeling, geochronological and isotopic analysis will help better constrain the origin of the Watts Group, which may end up not being exotic at all.

A2-TYPE FELSIC AND CALC-ALKALINE MAFIC VOLCANIC ROCKS OF THE ALJUSTREL'S MASSIVE SULPHIDE DEPOSIT, IBERIAN PYRITE BELT: GEODYNAMIC SIGNIFICANCE

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The Aljustrel volcanic-hosted massive sulpide (VHMS) deposit in the Iberian Pyrite Belt comprises a thick, hydrothermally altered volcanic succession erupted at 359–

353 Ma overlaid by massive sulphides and jaspers. This volcanic succession includes both felsic volcanic rocks, which are dominant, and sparse mafic volcanic rocks. The Iberian Pyrite Belt might be a remnant of West Meguma with an Avalonian-type basement. The mafic rocks are sub-alkaline (Nb/Y ~0.13–0.32), andesite-basalts with calc-alkaline affinities (e.g. Th ~1.10–2.41 ppm; Th/Yb ~0.34–1.13; Nb/La ~0.38–0.59; Ti/Y ~229–371). Primitive mantle-normalized spidergrams show Nb-Ta-P-Ti negative anomalies (Ta_N/La_N ~0.18–0.50), Th positive anomalies (Th_N/Nb_N ~5.34–8.51), moderate LREE/HREE (La_N/Yb_N ~3.50–8.58) and slightly MREE/HREE (Gd_N/Yb_N ~1.16–1.75) fractionation, typical of orogenic settings. $\varepsilon Nd_{(355\ Ma)}$ mostly range from +1.54 to+ 2.87, except for one sample that presents a value of +5.48. Thus, the geochemical characteristics of the mafic volcanic rocks can be attributed to the melting of an enriched, garnet-free mantle source. The felsic rocks are sub-alkaline (Zr ~121–671 ppm) rhyodacite-rhyolites with A-type affinities. They present greater P, Ti and Th anomalies (Th_N/Nb_N ~6.30–18.69) and more variable REE fractionation (La_N/Yb_N ~1.66–12.05, Gd_N/Yb_N ~0.75–2.56) than the mafic rocks. $\varepsilon Nd_{(355\ Ma)}$ ranges from -5.07 to +0.54, except a high-Zr felsic chemotype with systematically positive values (+0.98 to +1.79). Aljustrel's felsic volcanic rocks are characterized by moderate to high Ga/Al and Yb/Nb ratios, typical of A2-types, suggesting a post-subduction setting. A-type felsic magmatism in the Avalonia and Meguma has been attributed to anhydrous melting of Avalonian felsic granulitic residues at lower-middle crust. However, the crustal source could have been similar to the northwest Maine crust composed of I- and S-type plutons, which by dehydration-melting of hornblende and biotite could generate A2-type felsic magmatism. This type of crustal source should have provided the abundant Devonian inherited zircons found in the Aljustrel felsic volcanic rocks. Interestingly, the 1.6–1.1 Ga model ages obtained for the Aljustrel's A2-type magmatism point to an Eastern Avalonian crust (TDM ~1.7–1.3 Ga) rather than a West Avalonian crust (TDM ~1.2–0.8 Ga). The Aljustrel's felsic and mafic volcanic rocks suggest the involvement of a subduction-related metasomatized source in a post-subduction setting. Occurrence of alkaline basalts in the other areas of the belt points to the involvement of more depleted sources. Overall, this suggests an extensional setting related to post-subduction and post-collisional processes, within a high geothermal flux setting in response to asthenospheric upwelling that might have generated abundant mafic magmatism (with contrasting mantle sources) that sustained a long-term crustal melting.

A LOOK AT THE 2.2–1.8 GA ZIRCON DISTRIBUTION AS A PALEOGEOGRAPHIC AND PROVENANCE INDICATOR FOR PERI-GONDWANAN TERRANES

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The Paleoproterozoic orogenies are among the most significant crustal growth events recorded in Western Gondwana, as depicted by their strong detrital zircon signature into the Gondwanan and peri-Gondwanan sediments. Indeed, the Neoproterozoic–Cambrian sediments of peri-Gondwanan terranes, particularly those in Iberia, Meguma, Avalonia, and Ganderia, display distinctive 2.2–1.8 Ga zircon distributions. In the Iberian Massif, the Galicia-Trás-os-Montes (upper allochthonous) and Ossa-Morena zones present distinctive 1.95–1.9 and 2.1–2.05 Ga peaks, whereas West Asturian-Leonese and Cantabrian zones show a prominent ~2.0 Ga peak. The Centro-Iberian Zone also has a curve centred at 2.0 Ga but of greater wavelength. In contrast, the Avalonian and Ganderia sediments show multiple peaks between ~1.6 and ~2.1 Ga, whereas Meguma has a distinctive ~2.05 Ga peak. These unique distributions are most likely paleogeographic indicators of the diachronic Paleoproterozoic orogenic events from the western blocks (Amazonian Craton) to the eastern blocks (Sahara Metacraton) of Gondwana. Indeed, in the Amazonian and the North African Precambrian regions, the magmatic-metamorphic Paleoproterozoic events are mainly constrained to: (1) ~2.0–1.6 Ga in the western Amazonian provinces, (2) ~2.2–2.0 Ga in the Transamazonian province, (3) ~2.2–2.0 Ga in the West African Craton, (4) ~2.1–1.9 Ga in the Trans-Sahara Belt, and (5) ~2.0 Ga in the Sahara Metacraton. Furthermore, North African sedimentary rocks show peaks within 2.1–2.05 Ga in the western block, while eastern blocks show peaks within 2.1–1.9 Ga, which are generally congruent with adjacent cratonic orogenic events. Indeed: (1) Anti-Atlas Tonian-middle Cambrian sedimentary rocks show prominent 2.1–2.05 peaks, coincident with the 2.1–2.05 Ga event in West African Craton, (2) Trans-Sahara Belt Ordovician sedimentary rocks display ~1.75, ~1.9 and ~2.1 Ga peaks congruent with the ~1.9 Ga event present in the basement inlier of this belt, and (3) Sahara Metacraton Tonian sedimentary rocks present a ~2.0 Ga peak consistent with the main 2.0 Ga event in this metacraton. However, Sahara Metacraton Cambrian rocks show 1.85 and 2.05 Ga peaks, most likely suggesting provenance from Trans-Sahara Belt or that these orogenic events have not yet been adequately identified in this metacraton. The 2.2–1.8 Ga zircon distribution is, in some cases, a distinctive feature throughout the Palaeozoic. For example, the middle-upper Devonian sediments of the Iberian Pyrite Belt display a prominent ~2.1 Ga peak, similar to the West African Craton, Anti-Atlas and Meguma, which do not occur in any of the other Iberian zones.

APLITES AND GREISENS: RARE METALS FERTILITY INDICATORS IN PEGMATITES OF THE YELLOWKNIFE DISTRICT, NORTHWEST TERRITORIES, CANADA

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Important resources of lithium, tantalum, niobium, tin, rare earth elements, beryllium, and cesium occur in granitic pegmatites in the Yellowknife area, particularly within the Yellowknife Supergroup metasediments in the southeastern edge of the Slave structural province. The region contains an astounding number of pegmatites, which range from thin stringers and lenses to pods and steeply dipping dykes several metres wide and kilometres long. The dykes commonly occur in swarms, around large granitic plutons. The characteristics of the dykes, including the presence and type of mineralization, vary significantly within and between swarms. The factors controlling these variations remain largely unconstrained and this is an impediment to exploration and development. Individual pegmatites vary from simple, with uniform mineralogical composition and texture, to complex, with distinct compositional and/or textural zones. Many of the pegmatites have spatially associated internal or marginal aplite phases. Aplites not associated with pegmatite are by no means absent in the district. Some of the pegmatites have greisens, characterized by fine secondary muscovite. The greisenization varies from incipient, characterized by marginal selvages, to pervasive, affecting a large volume of the pegmatite. One example of such pegmatites is the Moose II dyke located 115 km southeast of Yellowknife, along the northern shores of Great Slave Lake's Hearne Channel, Northwest Territories. It is a zoned pegmatite dyke, enriched in rare metals and was mined intermittently between 1943 and 1954 for Ta, Nb, and Li. It contains at least two distinct aplite units (a salmon pink and a grey) along its core. The aplites are comprised of fine-grained saccharoidal albite with disseminated fine equant ferrocolumbite and cassiterite grains. The grey aplite also contains fine-grained orange spessartine. The aplites are spatially associated with extensive pervasive greisenization, which is characterized by secondary golden-yellow muscovite with common fine K-feldspar relics. The greisen may also contain fine-grained blue to greenish apatite. Enrichment of rare metals in pegmatites is generally correlated with the presence of evolved residual magmatic fluids. The aplites in Moose II have significant affinities with the host pegmatite including endowment in columbite-tantalite minerals and likely derive from the same extremely fractionated granitic magma. The aplites are younger and were likely precipitated from more fertile fluids exsolved from the host pegmatite. The fine-grained nature of the aplite probably results from quenching, which generated the low-pH fluids responsible for the pervasive greisenization of primary muscovite and feldspars to secondary muscovite.

CORES, MID-ZONES, RIMS, AND RINDS IN OLIVINE: INSIGHTS FROM THE LESLIE KIMBERLITE, NORTHWEST TERRITORIES, CANADA

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Olivine crystals are ubiquitous in kimberlites and record petrologic events through all stages of ascent and eruption. Well-preserved olivine from the Leslie kimberlite, Northwest Territories, Canada elucidates the sequence of events attending kimber-

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lite emplacement. The Leslie kimberlite mainly hosts a single phase of extrusive coherent kimberlite. We used spatially distributed samples (n = 76) from drill core to develop a 3-D representation of the Leslie kimberlite. Petrographic investigation defined four distinct olivine populations (commonly reported in the literature): macrocrysts, phenocrysts, dunite "nodules", and mantle xenolith-hosted olivine. SEM imagery, and major and trace element geochemistry were used to characterize and quantify chemical zonation within olivine including xenocrystic cores, mid-zones, magmatically crystallized rims, high-Mg rinds, and/or monticellite coronas. Olivine core compositions ($Fo_{85.7}$ to $Fo_{93.8}$, NiO ~0.36 wt.%) and other textural evidence show that olivine cores are mantle-derived olivine xenocrysts. Mid-zones developed on olivine cores show a sharp decrease in Fo content (~$Fo_{90.9}$) across irregular, convoluted, and embayed contacts indicating disequilibrium and partial dissolution of the olivine xenocrysts combined with diffusion-driven replacement. Magmatically crystallized olivine rims can form subhedral to euhedral grains by jacketing xenocrystic cores and mid-zones. Olivine rims have uniform and distinctive chemical compositions of ~$Fo_{91.8}$ ± 0.7 (2σ) and NiO concentrations that decrease (~0.4 wt.% to ~0.1 wt.%) toward the rim margin. Rinds, thin outer fringes, often have a convoluted inner contact and a sawtooth pattern contact with the groundmass. Rind compositions have anomalously high ~$Fo_{97.1}$, low NiO, and elevated Mn and Ca. Rind textural relationships and compositions suggest a non-magmatic, post-emplacement origin. The four olivine populations and olivine chemical zonation (only cores, mid-zones, and rims) are uniformly and consistently distributed throughout the Leslie kimberlite. Thus, olivine within a single phase of kimberlite predominantly records pre-emplacement processes and illustrates that magma batches become well mixed during ascent and emplacement. In contrast, both late-stage high-Mg rinds and monticellite coronas are non-uniformly distributed throughout the pipe. Utilizing olivine geochemistry, coupled with petrographic observations, we reconstruct a sequence of events of the Leslie kimberlite ascent and eruption. Our results indicate olivine entrainment and ascent (within a single kimberlite phase) may be sufficiently characterized by a few samples. Conversely, syn- and post-emplacement processes recorded by olivine require systematic sampling to capture all potential heterogeneities within a given kimberlite phase.

OLIVINE POPULATIONS, PROPERTIES, AND DISTRIBUTIONS IN THE LESLIE KIMBERLITE, NORTHWEST TERRITORIES, CANADA

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Olivine crystals are ubiquitous in kimberlites and record petrologic events during all stages of ascent and eruption. However, olivine petrologic records are typically overprinted by olivine replacement and/or alteration during and after kimberlite emplacement. Investigation of well-preserved, non-altered olivine from the Leslie kimberlite, Northwest Territories, Canada provides an unobstructed investigation of the sequence of events attending kimberlite ascent and emplacement. A total of 76 samples were collected from spatially distributed drill core (n = 6) that captures a three-dimensional representation of the Leslie kimberlite. Here we present evidence from drill core, hand samples, and thin sections that indicate the coherent kimberlite (CK) from the Leslie kimberlite is a single phase of kimberlite (i.e. a pulse of mantle-derived magma) and was effusively emplaced as a pipe-filling lava lake. The extrusive coherent kimberlite overlies a pipe-filling volcaniclastic kimberlite (VK), interpreted to be the product of a pipe-excavating volcanic eruption. Petrographic analysis defines four olivine populations in the Leslie kimberlite: macrocrysts, phenocrysts, dunite "nodules", and mantle xenolith-hosted olivine. SEM imagery shows all populations display chemical zonation defining xenocrystic cores, mid-zones, magmatically crystallized rims, and/or late-stage high-Mg rinds. In some samples, olivine grains have monticellite coronas. Textural relationships and characteristics of olivine zones in backscatter electron images inform on processes occurring during ascent, eruption, and post-emplacement. Macrocrysts are (> 1mm) round to subhedral and are dominated by xenocrystic cores that can be jacketed by relatively thin rims of magmatic olivine. Phenocrysts (< 1mm) are euhedral to subhedral and often contain xenocrystic cores overgrown by magmatic crystallization. Dunite nodules are polycrystalline dunite grains that display mosaic textures and deformation features, considered to be mantle-derived micro-xenoliths. Olivine is also a major mineral constituent in coarse-grained peridotite xenoliths. Both dunite nodules and mantle xenolith olivine can have magmatic overgrowths. All four olivine populations are susceptible to fragmentation during extrusive emplacement and the broken faces of olivine provide an important interface to characterize the cross-cutting relationship between pre-emplacement zones (cores, mid-zones, rims) and post-emplacement zones (high-Mg rinds and monticellite coronas). The pipe-scale uniform nature of olivine populations and commonality in chemical zonation (e.g. cores, mid-zones, and rims) show that prior to emplacement, olivine records a similar sequence of events. This implies that the Leslie kimberlite extrusive CK (a single phase of kimberlite) was well-mixed during ascent and/or eruption. Non-uniformly distributed features (high-Mg rinds and monticellite coronas) form post-emplacement indicating olivine was variably affected by late-stage fluids, magmas, and/or gasses.

EVIDENCE FOR THE OLDEST URANIUM MINERALIZATION IN THE RAE CRATON: A STUDY OF THE HOPE OCCURRENCE, NONACHO BASIN, NORTHWEST TERRITORIES, CANADA

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The Rae craton hosts a prolific variety of uranium occurrences and deposit types, with the most well-known unconformity-type uranium deposits of the Athabasca Basin, the Thelon Basin, and multi-phase mineralization in the Beaverlodge uranium district. The fault-bound Paleoproterozoic Nonacho Basin, located on the western margin of the Rae craton, is less known for uranium deposits than the Athabasca or the Thelon Basins; however, it contains a suite of historic polymetallic (i.e. U, Cu, Fe, Pb, Zn, Ag) occurrences near its unconformable contact with crystalline basement rocks. Exploration began in the 1950s following the detection of anomalous radioactivity, leading to preliminary investigations of numerous uranium occurrences. Petrography, mineral chemistry, and the implementation of multiple geochronometers (e.g. U–Pb, $^{40}Ar/^{39}Ar$, Re–Os) of the Hope uranium occurrence (northern basin) reveal the oldest known uranium mineralization in the Rae craton that records subsequent alteration and isotopic resetting by magmatic and hydrothermal activity in the area. At the Hope occurrence, uraninite is disseminated within hydrothermally altered quartz-biotite-albite-rich deformation zones in the Archean basement paragneiss. Coarse-grained (~500 μm), Th- and REE-rich uraninite occurs as overgrowths on, and as intergrowths with, metamict zircon. Uraninite U–Pb ages record primary magmatic crystallization at 2790 ± 20 Ma and 2784 ± 21.7 Ma. The uraninite is highly fractured and records geochemical variations with elevated concentrations of remobilized LREE, Ca, and Pb along fractures and grain boundaries. Geochronological data of uraninite reveal three isotopic resetting and alteration events: (i) isotopic resetting by magmatic heating by the Snow Island Suite at 2614 ± 10.5 Ma, (ii) isotopic reworking at 2531 ± 17.4 Ma coincident with granitic magmatism at Hope, and (iii) alteration by hydrothermal fluids at 1778 ± 14.4 Ma, which also precipitated molybdenite (1794 ± 28 Ma; Re–Os). Molybdenite and chlorite locally overprint biotite (1834 ± 1.2 Ma; $^{40}Ar/^{39}Ar$) and are coeval with the hydrothermal resetting of uraninite. Primary magmatic crystallization of uraninite occurred between ~2780 to 2790 Ma, nearly 500 Myr earlier than previously recorded in the Rae craton (i.e. 2.3 Ga uraninite in the Beaverlodge domain). This research provides evidence for early uranium enrichment of the Rae craton, one of the most uraniferous geological provinces in Canada and demonstrates that alteration and isotopic resetting of uraninite may be recorded in their crystal structure.

CORRELATING MED-CT DENSITY AND THERMAL CONDUCTIVITY OF SEDIMENTARY ROCKS: A NEW INSIGHT INTO THERMOFACIES

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Geothermal energy produces low greenhouse gases emissions and thus represents an interesting alternative source of renewable energy, even in regions located in "cold" sedimentary basins (i.e. with a low thermal gradient). The study of porosity

and thermofacies (i.e. the dependence of geothermal parameters on sedimentary facies) is considered as one of the key elements to characterize sedimentary reservoirs. Thermofacies allow the identification of the sedimentary units that have the optimal parameters for geothermal energy production. Yet, the accurate definition of thermofacies at the submetre-scale is lacking in most geothermal studies. Medical CT scanning (Med-CT) analysis on rock cores was used to provide a 3-D high-resolution imaging along core profiles. Data obtained from Med-CT are 3-D cell volumes (voxels) where a relative grey scale illustrates the CT density expressed in Hounsfield units (HU). The output results are the physical response of X-rays attenuation and depend on rock density and mineralogical contents (hence atomic number). In turn, rock density varies with porosity. In previous works, a two-state (dry and wet) saturation protocol under medical CT-scan was tested to generate quantitative 3-D representations of the distribution and connection of meso-scale porosity of drilled cores. This provides the fundamental data that controls the capacity of rocks to store fluid and/or heat and eventually allow the efficient modelling of fluid flow in the subsurface. Thermal conductivity (TC) can additionally be measured on core samples using an infrared scanner. TC is determined at the surface using re-emitted infrared after heating the sample locally. Our ongoing work aims correlate med-CT and infrared TC measurements. To do so, samples from conventional reservoir limestone and sandstone (such as Berea sandstone) were selected and demarcated with a reference lead marker. Four equally spaced TC profiles (0, 90, 180, and 270 degrees) were measured at the core sample surface. A custom user interface was then developed to load and perform registration manually, using the reference marker position on both med-CT and TC data trying to compare TC with CT density and porosity. Coupling of med-CT and infrared techniques has never been done before and represent a potential major breakthrough. By combining the 3-D CT density and porosity data with high-resolution 2-D thermal conductivity, we believe it will become possible to define accurate thermofacies and evaluate their efficiency for heat transfer at the sample scale (centimetre), but also at the drilled well scale (decimetre to metre) and hence support upscaling.

DATING OF SLICKEN-FIBRES IN THE LIVINGSTONE THRUST SHEET, SW ALBERTA, CANADA

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Slickensided carbonates of the Wileman Member of the Mississippian Mount Head Formation in a section along Highway 3 near Blairmore were sampled. This section is in the Livingstone Thrust sheet of the Blaimore West map sheet of the Crowsnest Pass area. Sample WL-1 was collected 9 m up from the base of this section and shows calcite slicken-fibres on the bedding plane with top to the east movement indications. Calcite U–Pb geochronological analyses of those slicken-fibres were carried out via laser ablation inductively coupled plasma mass spectrometry in the Fipke Laboratory for Trace Element Research (FiLTER) at the University of British Columbia, Kelowna. Pieces of the rock specimen with slicken-fibres were cut, mounted in epoxy pucks, and polished prior to analysis. Twenty-five of thirty-one spot-analyses of slicken-fibres average ~11 ppm U and define a slightly over-dispersed population (MSWD = 1.65) with a lower intercept date of 32.37 ± 0.63 Ma. These slicken-fibres record contractional movement with top to the east movements at 32 Ma. A 52 Ma $^{40}Ar/^{39}Ar$ age has been derived for thrusting along the Lewis Thrust about 15 km west of the present sample. This early Eocene age has been interpreted to record the last phase of regional contraction. The calcite U–Pb date from the Livingstone Thrust sheet, however, indicates that it formed after movement along the Lewis Thrust. Moreover, thermal histories derived from (U-Th-Sm)/He data in the Mackenzie Mountains of the NWT indicate reactivated deformation and the formation of an eastern deformation front beginning ~30 Ma. Based on the present U–Pb age dating, it appears likely that these contractual Oligocene movements were also active in southern Alberta. Relationships to movements of the Oligocene extensional Flathead normal fault, located 30 km southwest of the study area, are not clear.

DETRITAL ZIRCON PROVENANCE OF THE FLINTON GROUP WITHIN THE COMPOSITE ARC BELT, GRENVILLE PROVINCE

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U–Pb detrital zircon ages from the Mesoproterozoic Flinton Group of southern Ontario constrain the depositional setting, provenance, and tectonic history of the region within a hinterland rift (backarc) system during the intervening time between the Shawinigan and Ottawan Phases of the Grenville Orogeny (~1090 Ma). Previous estimates of metamorphism of the Flinton Group spanned from 1150–1080 Ma; however, these new data require this metamorphism to be post-1090 Ma giving a relatively narrow range of time from deposition to metamorphism. These data provide unique tectonic constraints requiring large-scale basin formation occurring within the hinterland of the Grenville Orogeny in between two major collisional events. The presence of early pre-Flinton Group arc-related basalts and near-unimodal zircon age population support the interpretation of a backarc depositional setting for the Flinton Group.

AN EXPLICIT AGE FOR GOLD MINERALIZATION IN THE VALENTINE LAKE GOLD CAMP, CENTRAL NEWFOUNDLAND, CANADA

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The gold deposits of the Valentine Lake Gold Camp (VLGC) lie within the Exploits Subzone of the Dunnage Zone terrane in Central Newfoundland, Canada. They are hosted within the Valentine Lake Intrusive Complex (VLIC), which is dominated by felsic plutonism of Neoproterozoic age. A quartz monzonite (QM) group and a trondhjemite-tonalite-granodiorite (TTG) group are recognized within the VLIC. The VLIC also contains subsidiary volumes of gabbro as well as two generations of mafic dyke. The VLIC abuts the Silurian Rogerson Lake Conglomerate (RLC) along the Valentine Lake Shear Zone (VLSZ), part of a larger regionally extensive structure initiated during the Salinic orogeny. The VLGC comprises multiple occurrences of orogenic type gold veining, predominantly localized in VLIC host rocks in close proximity to the VLSZ. Multiple gold deposits (Marathon, Leprechaun, Sprite, Victory and Berry) and additional gold occurrences along a strike length of 20 km are related to quartz-tourmaline-pyrite (QTP) veins that comprise fracture-controlled sets, largely within the granitoid components of the VLIC. New work, involving U–Pb ID-TIMS dating of hydrothermal monazite from QTP veins, has returned concordant ages of 376.4 ± 2.0 Ma and 377.66 ± 0.88 Ma in samples from the Marathon deposit (QM hosted) and Frank Zone occurrence (TTG hosted), respectively. The close textural association of monazite with quartz-tourmaline-pyrite-native gold mineralization within the sampled veins indicates that monazite formation was contemporaneous with gold deposition. In contrast to the monazite ages, a U–Pb rutile age of 409.7 ± 8.3 Ma was obtained from a QTP vein in the Leprechaun deposit. A comparable rutile age of 407.0 ± 4.0 Ma from a gold-bearing quartz vein cutting the RLC at the Wilding Lake prospect to the northeast of the VLGC has been recently published by other workers. The new monazite dates are important in the interpretation of the VLGC deposits, and numerous other gold occurrences along the approximately 500 km length of the Central Newfoundland Gold Belt. They tie the age of gold mineralization in the VLGC, and a phase of renewed crustal shortening that fostered the fractures occupied by QTP veining (D3, as described in recent structural studies of the VLGC), to the Neoacadian orogeny at ca. 390–350 Ma, rather than to the preceding Acadian orogeny, as implied by the less robust, > 400 Ma, rutile ages.

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OCCURRENCE OF LITHIUM IN DEVONIAN EVAPORITES NEAR THE PEACE RIVER ARCH, CANADA

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In recent years, a global increase in the adoption of electric vehicles and consumer electronics has driven lithium demand to new highs, with growth expected to continue through the next several decades. To meet this demand, a push for the discovery and characterization of new lithium resources has established that deposits primarily occur within pegmatites, brines, and clays; the latter of which tend to be in relatively young and near-surface basins that have been influenced by igneous and/or hydrothermal activity. Here we examine the geologic conditions deemed necessary for the formation of modern Li-brine and clay deposits and apply them to more ancient, Devonian strata of the Fort Vermilion and Slave Point formations within the Western Canadian Sedimentary Basin (WCSB). The Fort Vermilion Formation consists of carbonate and evaporite strata that onlap the Peace River Arch and are overlain by shallow-marine carbonates of the Slave Point Formation. Core analyses from this interval indicate elevated lithium concentrations within evaporitic successions of the Fort Vermillion Formation followed by a steep decrease up section into the Slave Point Formation. In addition to bulk chemistry, we characterize the sedimentological and mineralogical features of these high-lithium intervals to reconstruct the local depositional environment. Our findings suggest that lithium within the Fort Vermilion Formation is sourced as a product of weathering from the Peace River Arch and transported into the basin through adsorption on clays. We follow up our findings by conducting lithium adsorption isotherms on three clay minerals that represent common weathering products: montmorillonite, kaolinite and illite. Our results demonstrate the high affinity for clay minerals to sorb lithium in both freshwater and seawater conditions, furthering our hypothesis that lithium within the WCSB is sourced from the continental weathering of granitic basement rocks.

CANADIAN CONTRIBUTIONS TO GLOBAL GEOSCIENCES: A FEW KEY HIGHLIGHTS AND FUTURE OUTLOOK

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Canadian geoscientists have played an integral role in the development, delivery and success of global geosciences on many fronts for centuries. This is especially evident for the past 60 years in the inception, management and impact of the International Union of Geological Sciences (IUGS) via numerous elected executive positions (Presidents, Secretary General Vice Presidents, Councilors), volunteer roles (Webmaster, Episodes Editor, and transient committees), as well as active input into scientific Commissions, Initiatives, Task Groups and other activities. In parallel, for the past 50 years, Canadians continue to add prominently as scientific Project Leaders and members in dozens of projects, as well as Board leadership and panel members, to the International Geoscience Programme (IGCP) the joint science venture between IUGS and UNESCO. Equally important has been the notable embracement of the UNESCO Global Geoparks program by a wide cross section of Canadian geoscientists. More recently, Canada has led the development of the World Community of Geological Surveys, a community of best practices that aims to share knowledge and build relationships to support global sustainable development. Herein we review these relevant successes historically and into the future by identifying opportunities Canadians may pursue in the global arena of earth sciences.

PALAEOREDOX CONTEXT OF PROTEROZOIC MICROFOSSILS FROM THE MCARTHUR BASIN (NORTHERN TERRITORY, AUSTRALIA)

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The fossil record indicates that stem-group eukaryotes had emerged by the late Palaeoproterozoic, and that the characteristics of crown-group eukaryotes (such as complex multicellularity and the capacity for aerobic respiration) are generally considered to have been acquired by the late Mesoproterozoic. However, the nature of the relationship between redox conditions and early eukaryotic evolution remains obscure during this roughly billion-year-long interval. Here we present an integrated geochemical–palaeontological dataset from the middle Proterozoic McArthur and Birrindudu basins of Northern Territory (Australia). This study focused on eight drill-core stratigraphic successions which collectively record deposition from ca. 1.75–1.3 Ga in a range of marine environments, and host microfossils of probable eukaryotic affinity. We use a multi-proxy approach by analysing iron speciation, redox-sensitive trace metal abundance, Rare Earth Element systematics and iron isotope composition of these sedimentary rocks to interpret the redox and geochemical conditions of their depositional environment. By directly analysing both fossiliferous and non-fossiliferous samples from these stratigraphic successions, we can gain insights into the redox conditions of middle-Proterozoic basins and test hypotheses about the life modes and habitats of early eukaryotes.

GEOCHEMICAL VECTORS AND GRADE INDICATORS OF MINERALIZATION IN OROGENIC GOLD DEPOSITS

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Greenstone-hosted quartz-carbonate vein deposits, also known as orogenic or mesothermal deposits, are the second most important gold deposit type worldwide in terms of production and reserves. Most gold in Canada is hosted in orogenic districts including the Yellowknife greenstone belt. One of the major challenges for exploration in orogenic gold deposits is the abundance and diversity of structures, which are not always mineralized and in which mineralization is not always identifiable in the field. In this presentation I will discuss the use of whole rock chemistry, mineralogy, and fluid inclusions within the Yellowknife greenstone belt to (1) identify vectors that can act as geochemical indicators for orogenic gold and (2) interpret how those vectors may relate with geochemical processes that can cause gold deposition.

HYDROTHERMAL FLUID EVOLUTION OF TUNGSTEN-MINERALIZED SYSTEMS

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Tungsten is a critical metal, with wide applications to the carbide and steel industries, no current substitutes, and a highly localized production worldwide. The precipitation mechanisms proposed for tungsten vary significantly between mineral deposits, to the extent that it remains unclear whether different mechanisms dominate in different deposits. In this presentation, we will discuss the geochemical parameters that control tungstate solubility, how they may manifest in different deposits, and which geochemical changes seem to dominate tungsten precipitation mechanisms broadly. Although proposed precipitation mechanisms are diverse, most tungsten deposits present three common paragenetic stages: an oxide stage, a sulphide stage, and a late carbonate stage. These paragenetic stages are not particularly relevant for tungsten mineralization, but provide information on the hydrothermal evolution during the lifetime of the system. In this study, we will discuss the evolution in compositions of fluids at two major tungsten deposits, how they relate with paragenesis, and the implication for the hydrothermal evolution of tungsten-vein deposits.

GROUNDWATER HEAT PUMP SYSTEMS TO FIGHT URBAN HEAT ISLANDS: MODELING OF A CASE STUDY IN QUÉBEC CITY, QUEBEC, CANADA

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Urban heat islands can have detrimental impacts on the health of people. One of the significant contributors to this phenomenon is the heat rejected from conventional air conditioning systems. Finding energy efficient alternatives with low heat and greenhouse gas emissions for cooling buildings is critical in the context of glob-

al warming. This study aims to increase knowledge on the feasibility of using groundwater heat pump (GWHP) technology for cooling purposes. Aquifer thermal energy storage (ATES) and free cooling are also explored as options to increase the efficiency and longevity of GWHP systems. A case study in Québec City was conducted in a 30 m thick deltaic sandy aquifer. Field data collected during two heat injection tests are being used for numerical modeling. These data include thermal conductivity and groundwater velocity values, grain-size analyses, static and dynamic water level measurements, as well as temperature measurements. Multiple scenarios were simulated in FEFLOW using a 1000 m x 300 m x 60 m model to assess the performance of hypothetical GWHP and ATES systems in Québec City for archetype buildings and to investigate the influence of free cooling. Due to the medium size of Québec City and the type of urban development, archetypical buildings representing small to medium sized offices and apartments have been selected for the simulations. All modeling scenarios are simulated with the same subsurface conditions based on field, laboratory, and literature data. Model inputs include the following parameters: hydraulic conductivity, effective porosity, and thermal conductivity values of the different units, as well as regional hydraulic gradient. The injection and pumping wells are located 50 m apart. Pumping rates range between 8 and 82 m^3/d. Some of the hypotheses to be tested are whether free cooling technology will perform better in smaller buildings and whether ATES systems will be more suitable for larger buildings. To compare the performance of the modeled scenarios, the size of the heat plume and the temperatures throughout the aquifer are being assessed over the 25-year lifespan of the GWHP system. Preliminary results show that the temperature anomalies do not extend laterally beyond 300 m from the injection well, seasonal temperature amplitudes are limited to 5°C, and drawdowns remain below 1 m at the pumping well. Further analysis will provide more insight into the type of system to install according to a given building's energy needs in Québec City.

NEW CHARACTERIZATION OF THE VULNERABILITY OF GROUNDWATER RESOURCES IN THE QUEBEC PROVINCE WITH A CHEMICAL INDEX OF RESISTANCE

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In southern Quebec, exploding urbanization and climate change are increasing groundwater vulnerability, while 90% of the inhabited territory relies on groundwater for its water supply. Current characterization tools of vulnerability (DRASTIC) rely on strictly vertical perception of aquifer weakness and have limitations that require coupling with new approaches integrating all spatial dimensions of water flow. With the support of the "Ministère de l'Environnement et de la Lutte contre les changements climatiques" (MELCC), a chemical resistance index (CRI) of groundwater to anthropogenic pollution has been constructed. The data (2608 boreholes) collected in 15 regions through different "Projets d'acquisition de connaissances sur les eaux souterraines" (PACES), have been discussed regarding the quality and representativity for mineralization processes characterisation at regional scale. Plotted along theoretical flow lines, the evolutions of water mineralization are considered regarding major processes (dissolution, weathering, dilution, cation exchange, anthropic pollutions) in all the studied regions. Then, an aggregative chemical index of resistance was built considering both the hydrochemical evolution diagram (HED) and sub-indexes for silicate aquifers. These later indexes are supported by modeled minerals weathering trends defined under PHREEQc. Finally, the CRI was normalized to allow comparison of the results obtained over all the studied regions. As the CRI aggregate several indexes, it becomes very sensitive and efficiently in both small granular aquifers and larger water bodies. Considering nitrate levels in groundwater, the CRI showed that only water resources considered to be of low resistance are impacted. Then CRI was included on regional map to discuss the influence of the local context of each well (hydrographic network, recharge areas, DRASTIC maps). Compared to DRASTIC, the CRI appears to be more efficient to identify sites impacted by bank filtration and an upward contribution of regional aquifers or surface water. Where DRASTIC gives good information about the risk of vertical pollution, CRI integrates vulnerability of all flow lines intercepted by the well. Moreover, as it integrates the impact of all processes affecting groundwater, from recharge areas to the pumping well, the CRI gives a fast and clear overview of the capacity of groundwaters to absorb anthropic pollutions wherever it occurs in the watershed. Thanks to the contribution of research teams from PACES, this exploratory work has led to the creation of a new user-friendly, and low cost water protection tool that can be applied in all hydrogeological contexts.

MODELS OF SERPENTINIZED FRACTURE ZONES IN THE TABLELANDS, BAY OF ISLANDS OPHIOLITE COMPLEX, WESTERN NEWFOUNDLAND, CANADA

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Serpentinization is the process by which minerals in ultramafic rocks are transformed into serpentine minerals by interaction with water at low temperature. The process alters the water chemistry, resulting in high concentrations of Ca^{2+} and OH^-. On contact with air, this unusual water reacts with CO_2 to precipitate $CaCO_3$. Ultra-basic springs within ophiolites are of scientific interest both as sites of carbon sequestration and as hosts of extreme life, which may exist in extraterrestrial environments such as Mars. However, the springs can be difficult to locate visually, particularly among boulder strewn canyons, as the carbonate deposits may be small, ephemeral and stained a similar colour as surrounding rocks. Serpentinization can produce magnetite. Magnetic surveys were carried out within Winter House canyon, which is incised into the ultramafic rocks of the Tablelands massif, part of the Bay of Islands ophiolite complex in western Newfoundland, Canada. These surveys were successful not only in locating springs, but also in illuminating the path of groundwater through serpentinized fracture zones crossing the canyon. Potential field modelling of the magnetic data reveals the structure, extent and in some cases offsets of fracture zones in the canyon.

ADAKITIC AND ARCHEAN TTGD AND F1 SUITES: EXAMINATION OF THE ROLES OF REDOX AND GEODYNAMIC SETTING

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Recently there is considerable interest in slab failure related, arc-like volcanic and granitoid suites, relative to discriminants for adakitic and related Archean tonalite–trondhjemite–granodiorite (TTG) and tonalite–trondhjemite–diorite (TTD) intrusive suites (TTGD) and linked F1 dacitic to rhyolitic extrusive suites; they are examined relative to their hypothesized source rocks, i.e. MORB-like slab (MLS), suprasubduction zone mantle (SSZM), lower continental crust (LCC) contributions and transition to extensional geodynamics in SCLM related to subducting slab rollback and failure. Typically, Sr/Y and La/Yb are used to discriminate these igneous suites, which reflect plagioclase inhibited crystallization, and garnet versus hornblende residuum and (or) fractionation in the higher Sr/Y and La/Yb values. However, immobile high field strength key ratios like Nb/Y are greater than 0.4, Ta/Yb > 0.3, and La/Yb values over 10 that are noted to be indicative of slab failure, relative to typical arc granitoids (I-type), so overlap with adakitic, TTGD, and F1 signatures. Using the GEOROC adakite database trimmed to compositions of SiO_2 > 57 wt.%, the high silica adakites (HSA, SiO_2 > 67 wt.%), moderate silica adakites (MSA, SiO_2 = 63–67 wt.%), and low silica adakites (LSA, SiO_2 = 57–63 wt.%) fit well with the criteria for slab failure magmas as well; Al_2O_3 is relatively high. The FeO^t/MgO typically ranges between 1.0 and 3.0 depending on redox and fractionation. The MnO is low (< 0.15 wt.%) with low FeO^t/MnO ranging between 20–120, again reflecting higher redox. TiO_2 ranges from 0.15 to 1.15 wt.%, V is 25 to 250 ppm, and the Ti/V < 100, also typical of arc-like compositions reflecting higher redox; the Eu/Eu^* ~1 also reflects higher redox in arcs and even Archean TTGD and F1 suites. Subalkaline arc rocks were typically known to have Nb/Y less than 0.7, although extends to 2.0 for HSA and TTG and MSA and LSA and TTD and F1. The Zr/Y are consistent with calc alkalic values > 4.5, as are La/Yb > 5.3 and Th/Yb > 0.8. The combined Zr/Y and Th/Yb all fall in the calc alkalic field, including the Th/Y > 0.1. The

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Zr/Th varies between 7 and 25 and Th/Nb varies between 0.1 and 5.0; these reflect variable Th that is typically higher in the evolving crust (UCC and LCC) and subducting sediments (GLOSS). Other than higher redox due to subduction metasomatism, the discrimination of various sources, like MLS (very low Th), SSZM (low Th), and crust (via AFC) (higher Th) relative to fractionation can be discriminated by immobile Th and Nb.

IGCP PROJECTS 161-336-427-479: GENESIS AND LOCALIZATION OF MAGMATIC Ni-Cu-PGE DEPOSITS

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Magmatic Ni-Cu-PGE deposits are the type example of orthomagmatic mineralization and sources of base and precious metals essential to modern civilization and many developing technologies. They were the focus of four IGCP projects: *Project 161 Magmatic Sulphide Deposits in Mafic and Ultramafic Rocks* (1977–1987: AJ Naldrett and H Papunen), *Project 336 Petrology and Metallogeny of Intraplate Mafic and Ultramafic Magmatism* (1991–1995: ML Zientek), *Project 427 Ore-Forming Processes in Dynamic Magmatic Systems* (1998–2002: CM Lesher and S-J Barnes), *Project 479 Sustainable Use of Platinum Group Elements in the 21st century: Risks and Opportunities* (2003–2007: JE Mungall, CF Ferreira-Filho, MJ Ilijina). Our understanding of their genesis was transformed during the course of these projects. Prior models involved exsolution of sulphides from magmas with no explanation for the very high abundances in some deposits. In the 1960s and 1970s the first evidence of crustal S appeared, but as late as the mid-1970s the leading model involved derivation from sulphide-rich parts of the mantle with transport to the surface in olivine-rich magmas. Project 161 showed that partitioning of PGE between sulphide and silicate melts is orders of magnitude greater than previously assumed and that metal tenors of sulphide melts are strongly dependent on the effective magma:sulphide ratio. It was also shown that magmatic Ni-Cu-PGE deposits do not form from magmas containing intratelluric olivine phenocrysts, but that the host units represent dynamic lava/magma conduits that thermomechanically eroded wall rocks prior to flow-through olivine crystallization. This S isotopic evidence for non-mantle S in many more deposits, and new geological, thermodynamic, and fluid dynamic constraints led to models in which sulphide xenomelts are incorporated from wall rocks and dynamically upgraded by interaction with silicate lava/magma. Projects 336 and 427 provided additional geological, stratigraphic, mineralogical, geochemical, and isotopic support for crustal incorporation models. These developments fundamentally changed how we explore for magmatic sulphide deposits, which now involves identifying channelized lavas/sills/dykes/chonoliths that were able to access crustal S in crustal sedimentary/volcanic rocks. Project 479 expanded our understanding of PGE as tracers of geochemical processes, providing further constraints on the formation of Ni-Cu-PGE and PGE deposits. These projects fueled current research on sulphide transport and localization, with some models suggesting upward transport of sulphide droplets from the mantle or crustal "staging chambers" and other models requiring generation at more-or-less the same stratigraphic levels with primarily subhorizontal transport.

HOW TO USE THE GEOPHYSICAL METHOD OF TEM TO DETERMINE THE GROUNDWATER POTENTIAL OF A GLACIAL ENVIRONMENT

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The St-Narcisse morainic complex is a major formation that stretches along the southern margin of the Canadian Shield and extends from the city of St-Siméon in Quebec to the Great Lakes in Ontario, Canada. This vestige of a cooling period dated from the Younger Dryas (12.7–12.4 cal. ka BP) was settle down during a re-advance of the Laurentidian Ice Sheet (LIS) and cuts across the study area (i.e. eastern Mauricie). Groundwater found in these areas is the main source of drinking water and is locally exploited for supplying several municipalities (i.e. St-Narcisse, St-Prosper, St-Maurice, among others), which attests of the local aquifer capacity of the moraine. Here, we present the sedimentary and stratigraphic properties of the St-Narcisse Moraine in eastern Mauricie, Quebec, Canada. The aim of this study is to propose an approach to characterize a regional aquifer of a moraine with TEM method. The objectives were therefore to collect geophysical data in support of hydrogeological mapping to: (1) improve the understanding of the sediment architecture in the moraine, (2) to globally determine the location and delineate the spatial extent of its regional aquifers, and (3) globally define the hydraulic connection of the Saint-Narcisse moraine aquifers in eastern Mauricie. To apply efficiently TEM method, we have defined a calibration chart of electrical resistivity values associated with each of the typical sediment class found inside the Saint-Narcisse Moraine in eastern Mauricie. This chart will allow us to: (1) acquire an equivalence of the electrical resistivity values for the dry and saturated sediments and (2) cover as much space as possible in the study area to use all the TEM results collected during the field campaign, with or without boreholes or piezometric observations.

CYANOBACTERIA-FERRIHYDRITE AGGREGATES, BIF SEDIMENTATION, AND IMPLICATIONS FOR ARCHEAN-PALEOPROTEROZOIC SEAWATER GEOCHEMISTRY

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Banded Iron Formations (BIF) are biochemical sedimentary rocks that are widely believed to have been precipitated from seawater via marine phytoplankton such as anoxygenic Fe(II)-based photosynthesis (e.g. photoferrotrophs) or oxygenic photosynthesis (e.g. cyanobacteria). Previous studies have focused mostly on the importance of photoferrotrophs on Fe(II) oxidation rates, the composition and mineralogy of the iron mineral precipitates, and their rates of sedimentation. Less effort has been devoted to studying cyanobacterially-mediated Fe(II) oxidation because it has typically been assumed that they did not become important of the marine biosphere until immediately preceding the Great Oxidation Event (GOE) around 2.5 billion years ago. Here we present a comprehensive study of cyanobacteria in the context of BIF formation, including: the aggregation of cyanobacteria with Si-rich ferrihydrite, a new constraint on seawater pH and Fe(II) concentration from the settling velocity of cyanobacteria-ferrihydrite aggregates, and the potential diagenesis pathways of primary Fe minerals based on the Fe:Corg ratios from incubation experiments. Unlike photoferrotrophs, cyanobacteria aggregate with ferrihydrite to form flocs in the presence of silica. The settling velocity of cyanobacteria-ferrihydrite aggregates is only sufficiently rapid when the seawater pH is above 7. The Fe:Corg ratios of cyanobacteria-ferrihydrite aggregates that formed in incubation experiments are always smaller than the theoretical value of 4, which infers that there was excess Fe(III) in the primary BIF sediments and the excess Fe(III) was subsequently transformed to hematite through diagenesis. Collectively these new data suggest that oxygenic photosynthesizers were a vital community in the Proterozoic biosphere and made significant contributions to the formation of Proterozoic BIFs.

HOW DOES WEATHERING INFLUENCE GEOCHEMICAL SIGNALS IN PALEOPROTEROZOIC BANDED IRON FORMATIONS? A CASE STUDY FROM AN OUTCROP SAMPLE OF THE BOOLGEEDA IRON FORMATION

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Banded iron formations (BIFs) are iron- and silica-rich chemical sedimentary rocks, with characteristically low abundances of detrital indicators, indicating they are predominantly authigenic chemical sediments. Over the past few decades, BIF have become one of the most important geochemical proxies for constraining Earth's oxygenation and the geochemical evolution of co-eval seawater. Yet, recent studies have suggested that most studied BIFs have been subject to alteration by post-depositional events, such as fluid flow and oxidative weathering. Recent studies have identified outcrop samples, effected by oxidative weathering, that display altered paleo-

redox signals relative to drill core from the same locality. Accordingly, it has been suggested that to investigate paleoredox conditions, drill core samples rather than outcrop samples are essential. Here, we examine outcrop samples from the ~2.45–2.22 Ga Boolgeeda Iron Formation, Hamersley Basin, Western Australia, providing a detailed study of how secondary weathering affects outcrop samples. Thin sections show that BIF outcrop samples have an ~400–700 im thick weathering surface, indicating that the post-depositional weathering penetrates less than 1 millimetre even after prolonged surface exposure. To investigate the effect of weathering on chemical composition, sub-samples were collected from the weathering surface (WS), close to the weathering surface (CWS), and from the sample interior (FS). Results show that WS samples are enriched in trace elements such as Al, Ti, and Th. Similarly, redox-sensitive elements such as Mn and Ce in the WS also have higher concentrations compared to CWS and FS sub-samples. Cerium anomalies in all samples are positive, ranging from 1.1–2.94; however, WS samples have slightly lower average Ce/Ce* values relative to CWS and FS sub-samples. Critically, CWS and FS subsamples share similar elemental concentrations, consistent with the sub-millimetre extent of weathering observed in thin sections. Therefore, we suggest that following close screening, BIF samples from outcrop can provide valuable paleoredox information.

THE MULTIPULSED MAGMATISM AND INSTANTANEOUS MINERALIZATION OF THE GIANT JIAMA PORPHYRY Cu SYSTEM, TIBET, CHINA

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Jiama is one of the largest porphyry-skarn ore systems in the Gangdese metallogenic belt, Tibet. It is composed of porphyry Mo (Cu), skarn Cu-polymetallic, hornfels Cu-Mo, Manto Cu-Pb-Zn, and distal vein Au types ore bodies with associated silver, tungsten, and bismuth. However, the detailed timing of the magmatic evolution and mineralization events at Jiama remain poorly documented. High-precision CA-ID-TIMS U–Pb dating of ore-bearing and post-ore intrusions refine the lifespan of magmatism and hydrothermal mineralization. Monzogranite porphyry dykes were emplaced first as pre-ore intrusion, cut by vein Mo (Cu) mineralization in the deeper part of the system at 15.53 Ma. Later granodiorite porphyry, with an age of 15.37 Ma, cuts the monzogranite porphyry and is a major host of the vein and disseminated chalcopyrite and molybdenite. Both are cut by quartz diorite porphyry dykes at 15.08 Ma, which contains weak, subeconomic Cu, and almost no Mo mineralization. The last, post-ore barren quartz monzonite porphyry intruded at 14.93 Ma. The lifespan of magmatism at Jiama is about 0.61 Myr. The duration of the main ore-related hydrothermal event is constrained by the age of granodiorite porphyry and quartz diorite porphyry at less than 0.29 Myr. The $^{40}Ar/^{39}Ar$ ages of biotite coexisting with molybdenite in monzogranite porphyry and hornfels are 15.3 Ma, slightly younger than the granodiorite porphyry and older than weakly mineralized quartz diorite porphyry. The ages of biotite are consistent with the Re–Os isochron age of molybdenite (15.37 Ma). The age of the ore-related hydrothermal event is about 15.37~15.25 Ma within the 0.29 Myr interval. Thus, Jiama is the product of pulsed magmatism during which a short-lived hydrothermal event formed the Cu-Mo mineralization. Combined with the data from other large and giant deposits (Qulong, Batu Hijau, EI Teniente), Jiama shows a positive correlation between the duration of the ore system and metal endowment, suggesting longer duration (0.1–1.0 Myr) of ore-related fluid events is required to form the larger porphyry copper system.

THE APPLICABILITY OF GEOCHEMICAL SIGNATURES IN THE PALEOENVIRONMENTAL INTERPRETATION OF JURASSIC–CRETACEOUS BLACK SHALES FROM OFFSHORE NOVA SCOTIA, CANADA

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Geochemical proxy analysis for the purposes of creating a paleoenvironmental interpretation is completed using various trace elements, both individually assessed and in conjunction with each other. These proxies will be applied to black shales from well samples spanning the Jurassic–Cretaceous boundary from the Western Bank Group, offshore Nova Scotia (Canada). The paleoenvironmental reconstruction of these cores will be completed using three approaches, the first of which is the determination of paleoredox conditions using the analysis of total organic carbon (TOC) and trace elements such as U, Mo, and Th/U ratios. The abundance and source of terrigenous input will also be considered using information gathered from the analysis of Si, Al, Ca, Th, Sc, Cr and Rare Earth Elements (REEs). Lastly, paleoproductivity patterns will be assessed using C isotope values and trace elements such as Ni, Cu, and P. Providing a more detailed understanding of the depositional conditions in this region during the Jurassic-Cretaceous boundary interval will give insights on source rock viability and petroleum potential, contribute to the development of maps, and add to understandings of local and regional impact, including plate reconstruction and conjugate margins. The aim of creating this paleoenvironmental interpretation is to contribute to the Nova Scotia geochemical database and to define geochemical proxies that indicate favourable depositional conditions for source rock development. Ultimately, the project seeks to answer the question: What can be deduced from a comprehensive paleoenvironmental synthesis of a research site by performing targeted geochemical analysis? The study will be conducted alongside other Offshore Energy Resource Association (OERA) research groups studying in the same area, creating opportunities for data comparison. In collaboration with these research groups, our goal is to build upon previous OERA studies and selectively sample wells to provide complementary data and allow for comparisons between studies. Through this connection, supplemental well data, biostratigraphy, isotope geochemical data, and regional stratigraphy information will be available from research projects conducting studies both at the same locality, and in comparable units exposed in different regions.

EASTERN SOUTH CHINA AS AN APPALACHIAN-STYLE ACCRETIONARY OROGEN

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South China has traditionally been interpreted to have formed by the collision of two blocks, the Yangtze and the Cathaysia. The proposed timing of collision varies from Proterozoic to Mesozoic, corresponding to that of the various tectono-thermal events documented in South China. We propose, as an alternative interpretation, that eastern South China is an accretionary orogen formed by accretion/collision of multiple terranes (i.e. more than two blocks), and each of the major tectono-thermal events corresponds to an accretional/collisional event. The proposed model includes the following components: (1) The Jiangnan Orogen along the southeastern margin of the Yangtze Block formed as a result of collision between the Yangtze Block and the Greater Huaiyu terrane at ca. 820 Ma. Most of the Greater Huaiyu terrane and part of the Jiangnan orogen rifted away from the Yangtze Block soon after the collision. (2) The West Cathaysia terrane is a composite terrane formed by amalgamation of multiple terranes/arcs at ~1.0–0.7 Ga and is interpreted to be a microcontinent originated from a Grenvillian-aged orogen in the Rodinia supercontinent. (3) West Cathaysia and Yangtze were accreted to two different parts of the northern margin of Gondwana in the early Early Paleozoic (the "Caledonian" or Wuyi-Yunkai orogeny in West Cathaysia) and were then juxtaposed through margin-parallel large-scale strike-slip motion along the Jiangshan-Shaoxing Fault in the late Early Paleozoic. (4) The composite Yangtze-West Cathaysia terrane rifted away from Gondwana in the Late Paleozoic. (5) The East Cathaysia terrane, characterized by a ~1.9–1.8 Ga basement and ~250–230 Ma high-grade metamorphism, possibly originated from an Early Mesozoic orogen in the Paleo-Tethyan regime to the south. It was accreted to the east of West Cathaysia in the Mesozoic, through large-scale strike-slip movement along the Northwest Fujian Fault. A comparison with the evolution of the Appalachian orogen indicates that the key features of the above model, including multi-terrane accretion/collision, large-scale strike-slip motion and, in particular, separation of two terranes/continents by rifting following their collision, may be common to many orogens.

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FROM AVALONIA AND CADOMIA TO THE VARISCAN CENTRE OF PANGEA: NEW CONSTRAINTS FOR AN INTERPLAY WITH BALTICA BY U–Pb AGES OF DETRITAL AND MAGMATIC ZIRCON

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New datasets from the Variscan Orogen of Central Europe, especially huge masses of U–Pb ages of detrital zircon, allow new insights into Pangea´s history. Roots of Pangea go back to the assembly of the Gondwana supercontinent, which was formed the collision of West and East Gondwana accompanied by Pan-African orogenic processes culminating at ca. 600 Ma. Gravitational collapse of the Pan-African collisional orogens in the Late Ediacaran, their lateral extrusion, and subsequent onset of subduction zones at the margins of northern Gondwana led to the formation of several peri-Gondwanan terranes (ca. 580–540 Ma). Roll-back induced tension caused enormous thinning of West African cratonic crust and the origin of arc and back-arc systems on stretched continental crust in a style of the recent Western Pacific. Collision of Baltica with NW-Gondwana at ca. 540 Ma closed the Avalonian - Cadomian arc and back-arc system and formed prominent peri-Gondwanan terranes such as Avalonia and Cadomia. Early Cambrian rift-off of Baltica initiated the separation of Avalonia during the Lower Cambrian and a larger part of Cadomia in Lower to Middle Ordovician time. The Tornquist sea and the Rheic ocean became opened. Avalonia collided at ca. 450 Ma with Baltica by closure of the Tornquist sea. Related to this is a jump of the subduction zone from the southern margin of Baltica to the southern margin of Avalonia (Rhenohercynia) where a Silurian magmatic arc over a northwestward dipping subduction zone (ca. 440–420 Ma) was developed. The latter one was terminated under closure of the Rheic ocean by the arrival of Cadomia (Saxothuringia, part of the Armorican Terrane collage) at ca. 420–400 Ma. A jump of the subduction zone to the southern margin of Saxothuringia opened the short-existing Rhenish seaway between Rhenohercynia and Saxothuringia during Eifelian–Givetian time (ca. 393–383 Ma). The Rhenish seaway became closed by a southeastward subduction beneath Saxothuringia. The Mid-German Crystalline zone became formed by arc-related intense magmatism (ca. 360–330 Ma). The main Variscan deformation and the final emplacement of Variscan nappes occurred during Visean and Sepukhovian time.

SEISMICITY OFFSHORE NOVA SCOTIA, CANADA: A PRELIMINARY INVESTIGATION

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Seismicity rates in offshore Nova Scotia are relatively low and attract less attention than the west coast of North America. However, strong earthquakes can still occur in Atlantic Canada. For example, the 1929 magnitude -7.2 "Grand Banks" earthquake generated a massive submarine landslide that triggered a tsunami that inundated southern Newfoundland, killing 28 and creating widespread damage to coastal communities of Nova Scotia and Newfoundland. The recurrence time of such events has not yet been quantified, so assessing earthquake risk in offshore Nova Scotia is urgent to mitigate seismic hazards in the future. Earthquake risk assessments are usually based on high-completeness and high-precision earthquake catalogs. In the past 14 years (2008–2021), however, the routine catalog documents 198 earthquakes with magnitude ranging from 1.9 to 4.4, and only 24 events with magnitude < 2.5. The low number of relatively small earthquakes within the catalog is in part due to poor station coverage, but also to the limitations of routine earthquake detection techniques. In this study, we use 14-years of continuous data coverage on nine stations with distance < 1000 km from the largest earthquake M 4.4 to systematically analyze the long-term seismicity offshore Nova Scotia. The 198 documented earthquakes are selected as template events to scan the continuous data through a widely used template matching technique. Based on a joint detection threshold of 0.2 cross-correlation coefficient and nine times MAD (median absolute deviation), we detect ~600 potential earthquakes, which are about three times more than the routine catalog. After strict reselection of positive detections, the retained earthquakes will be further analyzed (e.g. relocation and b value distribution) to assess the hazard offshore earthquakes pose to Nova Scotia.

SHEAR-VELOCITY AND ANISOTROPIC STRUCTURES OF THE ALASKAN LITHOSPHERE REVEALED BY AMBIENT-NOISE ADJOINT TOMOGRAPHY

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Alaska is one of the most tectonic active regions in North America, and multiple episodes of tectonic processes have shaped the unique and complex structures in the Alaskan lithosphere. In this study, we use the high-quality broadband seismic data recorded by the USArray deployment in Alaska to image the shear velocity as well as the radial and azimuthal anisotropy lithospheric structures of Alaska. Broadband continuous seismic data are collected and processed to extract the three-component empirical Green's functions (EGFs) between station pairs. Frequency-dependent travel-time misfits are measured between the EGFs and the simulated Green's functions and are inverted to obtain isotropic shear-velocity, and radially and azimuthally anisotropic models based on the adjoint tomography method in three successive stages. We also use the multi-component ambient-noise adjoint tomography technique, the forward-wavefield subsampling technique, and the dynamic mini-batch technique to accelerate the inversion process. We present our shear-velocity and anisotropic model from the surface down to ~70 km depth. In our shear-velocity model, a subduction-zone structure is clearly observed in southern Alaska, including slab and mantle wedge. Several regions are characterized by > 4% positive radial anisotropy, potentially a result of extensional deformation history. A southwest-northeast trending alignment of fast axes is present in the southwestern part of Alaska, which is consistent with current tectonic motions. We discuss the tectonic implications of the shear velocity, radial and azimuthal anisotropy models in connection with other geophysical observations and constraints.

COUPLING POROELASTIC STRESS CHANGE AND RATE-STATE FAULT MODEL TO SIMULATE FLUID INJECTION INDUCED SEISMIC AND ASEISMIC SLIP

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Fluid injection in unconventional hydrocarbon resource exploration can introduce poroelastic stress and pore pressure changes, which in some cases may lead to aseismic slip on pre-existing fractures or faults. All three processes have been proposed as candidates for inducing earthquakes up to 10s of kilometres from injection wells. In this study, we examine their relative roles in triggering fault slip under both wastewater disposal and hydraulic fracturing scenarios. We first present modeling results of poroelastic stress changes on a previously unmapped fault near Cushing, Oklahoma. This site hosted over 100 small to moderate earthquakes between September 2015 and November 2016, including a Mw5.0 event at the end of the sequence, due to injection at multiple wastewater disposal wells within ~10 km from the fault. Despite the much larger amplitude of pore pressure change, we find that earthquake hypocenters are well correlated with positive shear stress change, which dominates the regimes of positive Coulomb stress change encouraging failure. Depending on the relative location of the disposal well to the recipient fault and its sense of motion, fluid injection can introduce either positive or negative Coulomb stress changes, therefore promoting or inhibiting seismicity. Our results suggest that interaction between multiple injection wells needs to be considered in induced seismicity hazard assessment, particularly for areas of dense well distributions. Next, we plan to apply the model to simulate poroelastic stress changes due to multi-stage hydraulic fracturing wells near Dawson Creek, British Columbia, where a dense local broadband seismic array has been in operation since 2016. We will investigate the

relative amplitudes, time scales, and spatial ranges of pore pressure versus solid matrix stress changes in influencing local seismicity. Finally, we have developed a rate-state friction framework for calculating slip on a pre-existing fault under stress perturbations for both the disposal and hydraulic fracturing cases. Preliminary fault slip simulation results suggest that fault response (aseismic versus seismic) highly depends on (1) the relative timing in the intrinsic earthquake cycle (under tectonic loading) when the stress perturbation is introduced, (2) the amplitude of the perturbation relative to the background fault stress state, and (3) the duration of the perturbation relative to the fault response timescale governed by the rate-state properties. Our modeling results suggest optimal design of injection parameters could be critical for preventing the onset of seismic slip.

PALEOPROTEROZOIC OROGENIC UNROOFING IN THE RAE CRATON RECORDED BY U–Pb GEOCHRONOLOGY OF THE NONACHO BASIN, NORTHWEST TERRITORIES, CANADA

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Owing to the allogenic controls of tectonics on deposition, sedimentary basins have the potential to record the subtleties of crustal processes related to nearby orogenic events. The detrital zircon record of clastic rocks can, accordingly, provide geochronological evidence of large-scale crustal geodynamics, including orogenic unroofing, which has traditionally been evaluated with thermobarometric, isotopic, and structural data. The Rae craton records orogenesis on both its western and eastern margins related to the 2.1–1.8 Ga amalgamation of the supercontinent Nuna. The Thelon, Taltson, and Snowbird orogens are hypothesized to have undergone rapid exhumation and erosion driven by interior post-orogenic collapse amid ongoing peripheral assembly. The Nonacho Basin (Northwest Territories, Canada) is located proximal to the southwestern Rae margin and thus could preserve detritus produced by the unroofing of nearby orogenic source terranes. Here, we present new geochronological evidence supporting a coeval relationship between the deposition of the Nonacho Group and the orogenic unroofing of the Rae margins. Chemically abraded U–Pb detrital zircon data analyzed with laser ablation inductively coupled plasma mass spectrometry provide a new maximum depositional constraint for the basin. Supported by provenance analysis, the new MDA relates Nonacho Basin development to the unroofing of the Taltson and Snowbird orogens. In contrast to previous hypotheses that attributed the basin to strike-slip kinematics, the newly defined temporal relationship supports a model of crustal relaxation interrupted by a flexural episode. Furthermore, the stratigraphically complete dataset for the Nonacho Group contributes to our understanding of the supracrustal framework of the Rae craton and provides new sedimentary evidence of orogenic unroofing during the Paleoproterozoic. More broadly, the data presented here contribute to the ongoing effort to understand the Paleoproterozoic crustal evolution of the Rae craton during the formation of the Canadian Shield.

CHANGING PARADIGM: THE USE OF FINE-GRAINED HEAVY MINERALS ASSEMBLAGES FOR PORPHYRY EXPLORATION

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The use of indicator minerals has proven successful for the exploration of several types of ore deposits, including diamond, gold, platinum-group elements and base metals deposits. These minerals are generally heavy (> 3 g/cm^3), physically and chemically resistant to weathering and are thus extracted from sediments of various nature. Some indicator minerals are significant based on their sole occurrence (native gold, diamond) whereas others require specific chemical compositions (Cr-diopside, G-series garnets). The use of indicator minerals for porphyry-type deposits is regularly discussed, but still at its infancy in regard of its practicality. Zones of hydrothermal alteration surrounding these types of deposits are characterized by assemblages of common minerals, some of which readily weathered, and the related sulphide mineralization is easily oxidized. Grains of native gold resist weathering but are usually very fine-grained (< 20 μm) and thus difficult to use. The trace element compositions of a series of minerals including sulphides and oxides are currently being documented as potential indicators of porphyry-related mineralization and some silicates with particular chemical and physical characteristics are being considered for the identification of intrusions associated with such deposits. However, the results remain limited. The development of SEM-based Automated Recognition Technologies (ART) by IOS Services Géoscientifiques Inc. has enabled the rapid identification of a large quantity (up to 35,000/hr) of very fine grains (63–90 μm) leading to the identification of a myriad of uncommon, or previously undocumented, minerals surrounding porphyry systems. Here, 23 stream sediment samples from a region of the Andes were processed for the characterization of the fine fraction (63–90 μm). Out of 101 identified minerals, 39 trace minerals such as delafossite ([Cu,Fe]O_2), finnemanite ($Pb_5[AsO_3]_3Cl$)), coronadite ($PbMn_8O_{16}$), and aluminium-phosphate-sulphates (APS) were grouped into assemblages and are being linked to different parts of the porphyry system, including zones of advanced argillic alteration. The use of the very fine fraction enabled the dependable identification of minerals that are distinctive of supergene alteration zone and unlikely to be preserved in glaciated terrain. It allows identification of 600 times more particles per sample than the standard 250–500 μm fraction, therefore increasing the detectability of indicator minerals by as much, and enabling probabilistic modelling and the detection of subtle anomalies.

ASSESSING THE IMPACT OF MINE DEWATERING AND CLIMATE CHANGE ON THE MOBILITY OF TRACE ELEMENTS IN PEATLANDS

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Peatlands cover more than 4 million km^2 on a global scale, with nearly 30% located in Canada. These environments exert significant hydrological and geochemical functions in surface and groundwater flow systems and host important ecosystems. The functions of peatlands rely on a delicate balance between hydrological, chemical, and biological processes and external factors such as human activities and climate change can disrupt this balance. There is thus a growing interest in identifying efficient approaches for ensuring their protection and restoration. Among the challenges associated with peatland protection, evaluating the indirect impacts of human activities on the chemical composition of peatland porewaters represents a major challenge. In the Canadian Shield, the potential impacts of mine dewatering (and flooding) on peatlands represent a major issue. Fitting in this context, the objective of this study is to simulate the thermodynamic equilibrium of trace elements that are sensitive to redox and pH conditions in peatland porewaters and surrounding groundwaters. The focus is set on a boreal peatland of the Canadian Shield, in Abitibi-Témiscamingue located near the Akasaba West mining project (Agnico Eagle Mines). Water samples (n=47) were collected at various depths in the summer and fall of 2019. Samples were analyzed for physicochemical parameters (pH, redox potential, temperature, electrical conductivity, dissolved oxygen), major ions, trace elements, dissolved organic and inorganic carbon (DIC-DOC) and stable isotopes of water (δ^2H-δ^{18}O). Three peat cores were collected as well to allow for chemical analyses of the peat solid matrix. The available chemical data are used to evaluate the speciation and saturation indexes of targeted trace elements under natural conditions, using PHREEQC. The physicochemical conditions used in these simulations are then modified to represent the effects of peatland dewatering, re-flooding and to test the impact of climate scenarios on the mobility of trace elements. Ultimately, this research will provide novel insights on the geochemical response of peatlands faced by human impacts and climate change.

THE LAURENTIAN IAPETAN MARGIN SUCCESSION: INSIGHTS INTO THE EXTENT AND NATURE OF POST-BREAKUP RIFTING AND REACTIVATION

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The Ediacaran to Early Ordovician Laurentian Iapetan margin succession includes strata from the continental to deep marine realms exposed along the northwestern edge of the Appalachians from New England to Newfoundland. Research into sed-

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imentary and igneous strata of the Laurentian platform, margin, shelf, and allochthons reveals a history of protracted extension and post-breakup rift reactivation prior to middle Ordovician Taconic orogenesis. Ediacaran and Cambrian rifting occurred over ca. 90 Myr and developed through three stages: ca. 620–570 Ma magma-rich rifting culminating in the opening of the Iapetus Ocean; ca. 570–525 Ma magma-poor rifting leading to mantle exhumation and breakup and drifting of peri-Laurentian extensional allochthons; and ca. 525–510 Ma localized post-breakup failed rifting and synrift sedimentation. This latter stage is not well understood, but is represented by coarse felspathic clastics in continental rifts (Ausable, Monkton, Jacobsville(?) formations), subsidence and coarse clastic sedimentation on the continental slope (Parker and Irishtown formations), and oxygenation and bioturbation in otherwise anoxic deep marine environments (Middle Granville and Anse Maranda formations). Then, following a tectonically quiescent passive margin lasting only ca. 15 Myr (995–510 Ma), episodic and localized Late Cambrian and Early Ordovician deformation and abrupt sea level fluctuations coincided with the onset and evolution of collisional orogenesis of peri-Laurentian allochthons, including ca. 495 Ma obduction of Iapetus oceanic crust and ca. 485 Ma subduction. Stratigraphic and provenance evidence of localized ca. 495–490 Ma (Furongian) Laurentian margin reactivation includes deformation, unconformity development, and basin reorganization in the Ottawa Graben (Potsdam Group), exhumation and debris flows at the mouth the Saguenay Graben (Saint-Damase Formation), and carbonate platform collapse near the Bonne Bay transform (basal Cow Head Group). Similarly, terminal Cambrian (ca. 485 Ma) unconformity development, sea level fall, basin reorganization and renewed coarse clastic shelf and slope sedimentation is recognized in in the Ottawa Graben (Keeseville Formation), Franklin Basin (Gorge Formation), slope near the Sagenuay Graben (Kamouraska Formation) and near the Bonne Bay transform (middle Cow Head Group). In spite of the widespread evidence of post-breakup rifting and reactivation, existing interpretations of the Laurentian margin succession focus on eustatic rather than tectonic signals through the overall transgressive signal of the Sauk Megasequence. Ongoing stratigraphic, facies, and provenance research on these strata is underway with the goal of deconvolving the tectonic signals from the record of the Sauk transgression, constraining the timing and topographic response of deformation, and understanding links to peri-Laurentian orogenesis.

LEARNING FROM THE PANDEMIC: VIRTUAL FIELD TRIPS DEVELOPED DURING COVID RESTRICTIONS WORK EQUALLY WELL IN-PERSON

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During the shift to online learning in 2020-2021, a set of four locally-focused virtual field trips were developed and employed in Cape Breton University geology courses. These tours were designed to provide a unifying place-based experience during an interval when restrictions made travel impractical and up to 50% of students in geology classes resided outside of Cape Breton. The tours employed a novel approach: using social media posts produced in real time—and then archived—to give students the experience of following their instructor as they travelled around Cape Breton. While originally created for Engineering Geology, the virtual field trips were used the following semester in Petroleum Geology and Introduction to Geology (also delivered online). In end-of-course surveys (n=60), students in all three classes responded strongly to these experiences, reporting increased engagement, interest in geology, enhanced learning, and a desire to visit the sites in person in the future. These tours were used again in Engineering Geology in the fall of 2021 (n=24), after the return to in-person teaching, allowing a direct comparison of student responses under different delivery modalities. Despite students now all residing locally and physical field trips being possible, students taught in-person responded equally or more positively to the virtual field trips in both open-ended and Likert-scale questions, and retained a strong preference for a focus on local geosites over international virtual destinations. These results demonstrate that locally-focused virtual field trips can effectively augment instruction in both in-person and online learning.

DEVONIAN–EARLY CARBONIFEROUS ICHNOLOGY AND THE ORIGIN AND EARLY EVOLUTION OF TETRAPODS

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The primitive pattern of tetrapod walking is an alternating gait (lateral sequence walking), in which the manus of one side is placed forward in sync with the pes of the opposite side, followed by the reverse, with a larger hind limb than forelimb that provides hind-limb-driven propulsion. This pattern is evident in all Carboniferous tetrapod trackways. Devonian tetrapod trackways document lateral sequence walking as early as the Givetian. Living sarcopterygian fishes, notably the *coelacanth Latimeria*, employ an alternating motion of the fins when slow swimming. This suggests that the muscular ability to produce an alternating gait was primitive among sarcopterygians, so it was inherited by tetrapods from their ancestors. The tetrapodomorph fishes, notably *Panderichthys* and *Tiktaalik*, are seen as the closest relatives of tetrapods, but they have robust pectoral fins and girdles, much larger than the pelvic apparatus, quite the opposite of most tetrapods, which have larger pelvic limbs. There is thus a considerable morphological gap between the locomotory apparatus of fully terrestrial tetrapods, driven by hindlimb propulsion, and that of their supposed nearest relatives, driven by forelimb propulsion. The Devonian tetrapod track record suggests this evolutionary gap had already been bridged by the Middle Devonian. This raises the question of whether or not the tetrapodomorph fishes are closely related to tetrapods or simply a group that converged on some tetrapod features. Bona fide Devonian tetrapod footprints indicate an alternating pattern of limb-supported locomotion with a larger hind foot than forefoot, and this pattern of quadrupedal locomotion is well documented by the early Carboniferous (Tournaisian) tetrapod footprint record from the Horton Bluff Formation at Blue Beach, Nova Scotia. The trackmakers of the Devonian and Blue Beach footprints and trackways are essentially unknown, so a major clade, or clades, of early tetrapods have been sampled by the footprint record but not by the body-fossil record. This clade(s) is (are) more likely to have been the main line of tetrapod origins and evolution, not any lineage of stem tetrapod reported from the same formation. Thus, the entire understanding of tetrapod origins as now presented may be merely the understanding of the evolution of an early, dead end radiation of aquatic stem tetrapods from a sarcopterygian ancestry. Other than the footprint record, the Devonian origin and subsequent early evolution of terrestrially adapted tetrapods remains largely undiscovered and unexamined.

TETRAPOD TRACE AND BODY FOSSILS FROM THE MISSISSIPPIAN (TOURNAISIAN) HORTON BLUFF FORMATION AT BLUE BEACH, NOVA SCOTIA, CANADA, CLOSE ROMER'S GAP

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The Late Devonian tetrapods known from body fossils were aquatic animals and apparently appeared long before the oldest clearly terrestrial tetrapods of the Carboniferous. The interval between the Late Devonian aquatic tetrapods and the "terrestrial" tetrapods was long perceived of as much of the Early Mississippian (the entire Tournaisian and first half of the Viséan stages), about 20 million years. This interval was named "Romer's gap," and thought to conceal the poorly known/undocumented transition from the first tetrapods that were not fully terrestrial to terrestrial tetrapods in crown-group lineages. It was thus argued that the Late Devonian tetrapod record is followed by a substantial hiatus in the tetrapod fossil record before tetrapod fossils are found again in middle Viséan strata. Furthermore, this gap was supposedly made striking by the sudden Viséan appearance of several major tetrapod taxa, including temnospondyls, anthracosaurs and amniotes. However, it has recently become clear that Romer's gap was mostly an artifact of ignoring much of the available fossil sample (particularly the tetrapod trace fossils) and is being filled by the description of already known fossils and by new discoveries. Sig-

nificantly, body fossils deemed "consistent" with *ichthyostegids*, *acanthostegids* and *Tulerpeton* have been documented from "Romer's gap" in the Tournaisian Horton Bluff Formation at Blue Beach, Nova Scotia, so these characteristic Devonian tetrapods are now known from the lower Carboniferous. Blue Beach preserves the oldest extensive ichnoassemblage of tetrapod footprints. These tracks can be assigned to the ichnogenera *Batrachichnus*, *Limnopus* (= *Palaeosauropus*), *Characichnos*, *Attenosaurus*, *Hylopus*, and *Pseudobradypus*. Trackmakers were temnospondyl amphibians and reptiliomorphs. Thus, both aquatic and terrestrial tetrapods are present at Blue Beach—the bones of presumed aquatic stem tetrapods and the footprints of terrestrially walking temnospondyls and reptiliomorphs. So, if there was a transition from aquatic to terrestrial tetrapods it must have taken place earlier than the Blue Beach tetrapods, before the middle Tournaisian. This transition thus is not concealed by a temporal gap between fossils of the two groups. We can conclude that the Blue Beach record of tetrapod trace and body fossils closes Romer's gap, and that the concept of this gap should now be abandoned.

GEOSCIENCES FOR THE NEXT DECADE

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IUGS is the global voice of geoscience, and it is in its 60th year (www.iugs60.org). It has played an essential role in defining the standards (stratigraphic, nomenclature, data) for the geological sciences. It also reaches across all the continents and provides a platform for development science with partners in UNESCO and in the International Science Council (ISC). The need to re-define the role of our science for the next decades has never been as important, as our science can help provide solutions to the pressing issue of society, that of climate change. Geological science expertise will be as essential in the energy transition, and it has been on resourcing past generations – for energy, minerals, water and soils. As geological scientists we need to reconnect discovery science, applied science and the translation of science to engender a cultural shift towards a more solutions-based approach to our science. This will be at the interface of geological, environmental, engineering, and social science that responds to the urgent global problems posed by the UN Sustainable Development Goals (UN-SDG). IUGS needs to champion big Earth Science projects that match or exceed those of the planetary scientists and astronomers. Even if these are aimed at geo-engineering of planetary solutions, they will require significant fundamental research and thus provide science platforms that enable discovery and innovation. A significant development will be the creation of data platforms that integrate the entire earth system, which are created from open, reliable, and FAIR data and updated in real time, and include examples of the limitations of the data's application. These should be created in discussion with end-users. IUGS is already showing global leadership in its creation of the Deep-Time Digital Earth Digital Earth project of IUGS (https://www.ddeworld.org/). We will thus need to provide new and varied (non-academic) career paths for geological science students. IUGS can play a vital role as global leader in this challenging transition for the geosciences.

HYPERSPECTRAL IMAGING AS A NEW GEOSCIENCE RESEARCH TECHNIQUE - EARLY RESULTS FROM A DRILL CORE DIGITIZATION PROGRAM IN NEWFOUNDLAND AND LABRADOR, CANADA

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Hyperspectral imaging is a spectroscopic technique that allows for the rapid identification and quantification of mineralogy and mineral chemistry on a variety of rock surfaces. For instance, high-resolution (1mm/pixel) spectroscopic data can be acquired on entire drill core boxes in a matter of seconds without the need for sample preparation. It is thus a technology that is bound to become routinely used in geoscientific research, and more broadly within the extractive industries. In a research environment, hyperspectral data obtained on continuous drill core intervals can provide early mineralogical information that can be used to guide sample selection in drill cores spanning up to hundreds of meters in length. From a mineral industry exploration perspective, hyperspectral data can allow for better vectoring to mineralization by defining large cryptic alteration haloes in drill core, which are often difficult to recognize with conventional techniques. In a production environment, it could allow the detection of potentially deleterious minerals (swelling clays, talc, asbestos, etc.) prior to their introduction into a mining or processing circuit. An ongoing public geoscience initiative at the *College of the North Atlantic* has as its goal the acquisition of hyperspectral imaging data covering several hundred thousand metres of drill core stored in Newfoundland and Labrador's Department of Industry, Energy and Technology Core Storage Libraries using of a full range of hyperspectral instruments. These cameras scan in the Visible-Near Infrared (VNIR, 400–1000 nm), Shortwave Infrared (SWIR, 1000–2800 nm), Midwave Infrared (2800–5400 nm) to the Longwave Infrared (LWIR, 7500–13 000 nm) spectral ranges. Interpreted mineralogical data on a variety of deposit types found across the province will be released in an online public geoscience database, which will facilitate geoscience research in the province. Early datasets for several deposits will be presented, with a focus on the variety of minerals that can be identified across various spectral ranges, including the relatively under-utilized MWIR and LWIR.

USING PETROLEUM INDUSTRY STRATIGRAPHIC ANALYTICAL TECHNIQUES IN THE MINING INDUSTRY?

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The oil and gas industry works on sedimentary basins with proven or possible petroleum potential. Many different techniques have been developed over the last decades to characterize the stratigraphy, thermal evolution, sedimentation environments and many other aspects of these basins. Here we will focus on the application of some of these techniques in other industries, notably in mineral provinces and types of mineralization systems where sedimentary and meta-sedimentary rocks constitute host rocks or play an important role to understand the regional geology. Most biostratigraphic techniques in the petroleum industry fall into a broad definition of micropaleontology, as samples are usually limited to cuttings and more rarely sidewall cores or conventional cores. Three main disciplines are used – micropaleontology s.s. (foraminifera, ostracods, algae, etc.); palynology (spores/pollen, acritarchs, chitinozoans, etc); nannofossils. In the mining industry cores are commonly used and outcrop studies are generally more relevant, thus macropaleontological disciplines can be used (relevant fossil groups include ammonoids, trilobites, brachiopods, graptolites, ammonites, etc.). In non-metamorphic terranes, in principle, all micropaleontological techniques can be used. In metamorphic terranes palynology and conodonts paleontology play a very important role as stratigraphically relevant microfossils can still be extracted up to greenschist facies metamorphism. In the vast majority of depositional environments, even if preservation of microfossils is poor due to the metamorphic conditions they were exposed to, the proportions of different palynomorphs (e.g. marine and terrestrial-derived) and types of microfossils allow us to interpret the original depositional environment. In the coal and petroleum industry the standard technique used to estimate thermal maturity (peak paleotemperatures) is vitrinite reflectance. Although its main use is in the diagenesis range, the same type of analysis allows us to estimate up to temperatures of around 350ºC. The only requirement is that vitrinite (wood particles) are present – usually organic-rich sediments of Devonian or younger age. Other techniques, mostly semi-quantitative, can be used, such as spore, chitinozoan and conodont colouration. All these techniques can be used at several scales, from regional exploration efforts to the characterization of specific mineral deposits. We will present examples from the Iberian Pyrite Belt, greenschist metamorphosed turbidites and carbonates of the Ossa-Morena Zone (Portugal), Appalachians (Maine, USA) among others, which allowed us to clarify regional mapping, refine structural models, correlate wells and generally increase the knowledge of the area.

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SALT PALYNOLOGY: TAPPING A SOURCE OF DATA FOR BIOSTRATIGRAPHY, THERMAL EVALUATION AND PALEOENVIRONMENTAL INTERPRETATION

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Salt (sensu evaporites) is a key element in many petroleum systems as it provides seals, generates several types of traps and influences thermal fluxes. Evaporites are also valuable ores, explored in many areas around the World, providing raw materials for agriculture, chemical industry, and other key human activities. Artificial salt caverns are also used as storage for different types of gases (notably methane and hydrogen) and more recently the usage of salt diapirs as energy storage facilities has been evaluated. Despite this relevance, the geological knowledge of evaporites is frequently limited to aspects of their sedimentology, geochemistry and tectonic deformation as observed in seismic data. In exploration context, salt is seen as a hazard and frequently little information is extracted from it. Here we present several case studies from mine, outcrop and well samples where evaporites and associated sediments allow the interpretation of depositional ages and paleoenvironments using palynology and thermal maturity (vitrinite reflectance). The required sample size varies, but usually 100 g of sediment or less are more than sufficient to obtain significant results, and thus cuttings, side-wall core and core samples are suitable. This is possible by applying refined techniques of organic matter extraction from evaporites. Considerable variations in mineralogy encountered in evaporites may have deterred other workers in the past from obtaining relevant results. We have tested evaporites – halite, gypsum and other evaporites – and associated sediments (mostly mudstones) from different locations: (1) Loulé salt mine in southern Portugal - Early Jurassic mobile salt. Impure halite, coaly shales and dolomitized/silicified gypsum; (2) 'Wieliczka' salt mine in southern Poland – Miocene mobile salt. Several types of salt and interbedded grey to brown shales; (3) 'Kłodawa' mine in central Poland – Permian Zechstein mobile salt: red and grey shales, impure black halite, dolomites and black shales; and (4) Santana gypsum quarry in central Portugal – Early Jurassic mobile evaporites – outcrop samples of recrystallised and re-precipitated white-pink gypsum and primary grey gypsum. The adapted processing technique is now standardized and the success rate for obtaining fossil recovery is similar to non-evaporite samples. Productive sample characteristics (crystal size, colour, evaporite content) are now better understood and even higher success rates are expected in future analyses. Although the results from the investigated localities are variable, most samples are dominated by terrestrial-derived organic particles indicating restricted marine to fully terrestrial settings in most instances.

DIFFERENCES IN SOURCES OF GEOGENIC ARSENIC CONTAMINATION IN WELL WATER RELATED TO GRANITES FROM SOUTHWEST NOVA SCOTIA, CANADA

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Arsenic toxicity in drinking water sourced from groundwater is a global concern. Elevated arsenic in Nova Scotia well water is typically drawn from aquifers with metamorphic or granitic bedrock. In southwestern Nova Scotia, the granitic bedrock is divided into two geochemical and petrological affinities, central (South Mountain and Musquodoboit batholiths) and southern (Port Mouton, Shelburne, and Barrington Passage plutons). Arsenic concentrations in 84% of well water samples taken from the central batholiths are greater than the highest concentrations observed in the southern plutons. Since well water arsenic content does not scale with the whole-rock arsenic concentrations, we hypothesize that the origin of this discrepancy is mineralogical. This study examines the arsenic content of the major and accessory phases of central and southern granites, as well as evaluates the susceptibility of these phases to weathering by calculating the saturation index (SI) of each mineral in the local well water. Analysis by laser ablation ICP-MS was performed on over 292 grains from 8 samples from the central granites (with an additional 472 analyses of primarily apatite and biotite from another 45 samples from a separate study) and 79 grains from 4 samples of the Port Mouton Pluton which represents the southern granites. Major rock-forming silicates contain over 50% of the arsenic budget in all Nova Scotian granites. In the central granites, monazite, pyrite, and cordierite, along with its alteration products, contain 5–9%, 5–8% and, 9–27% of the total arsenic budget, respectively. Additionally, ferric hydroxide and hydrous oxide (FOH) oxidation products of pyrite may contain 0.5–6% of the arsenic budget. Mineral saturation index calculations show that both monazite and the rock-forming silicates are stable in the local groundwater, whereas pyrite and cordierite are unstable and therefore release arsenic upon dissolution. In the southern granitic bodies, pyrite is the only significant source of arsenic other than the rock-forming silicates. This pyrite is largely pristine, in contrast to the oxidized pyrite in the central plutons. The absence of FOH replacement suggests that pyrite does not contribute significant arsenic to the local well water associated to the southern plutons. Thus, the difference in well water arsenic concentration between the southern and central granites is attributed to (1) the absence of cordierite in the southern plutons and (2) different degrees of pyrite oxidation. The lower degree of pyrite oxidation in the southern granites suggests that the sulphide minerals have not reacted with groundwater, likely due to lower permeability.

GEOCHEMICAL VARIATIONS IN BIOTITE COMPOSITION FROM THE DEVONIAN SOUTH MOUNTAIN BATHOLITH WITH CONSTRAINTS ON INTENSIVE PARAMETERS AND THE DEVELOPMENT OF A MAGMATIC VOLATILE PHASE (MVP)

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We report on the composition of biotite from the peraluminous Devonian South Mountain Batholith (SMB) of southwestern Nova Scotia, Canada. Biotite analyses were obtained from 55 unmineralized samples representing 11 plutons. Sample petrography indicates biotite saturation broadly coeval to other rock-forming minerals in the paragenesis inferring that biotite chemistry reflects both within-pluton and batholith-scale variations in crystallization conditions. Biotite compositions are siderophyllitic with Fe/(Fe+Mg) ranging from 0.6 to 0.98, and Al-rich, with ^{IV}Al ranging from 2.2 to 2.9 atoms per formula unit (apfu; 22 oxygen basis), the latter reflecting the coexistence of other Al-rich phases. Biotite anion sites are dominated by OH (> 3 apfu), followed by F (0.1–1.7 apfu) and Cl (< 0.1 apfu), with a general trend of decreasing OH, increasing F and decreasing Cl, with increasing differentiation. The depletion trend in Cl in some samples closely resembles trends exhibited by biotite from other Silurian–Devonian Sn-W-Mo-mineralized granitoid suites in the Northern Appalachian orogen. Pressure-temperature estimates for biotite crystallization (250–400 MPa and 705–625°C) suggest minimum water contents of 6–7 wt.% for SMB magmas when compared to water-saturated granite phase relations. The redox state of the SMB was estimated by comparing measured biotite Fe#-Ti relations with those calculated using the MELTS thermodynamic model. Results indicate that the observed biotite Fe#-Ti variation is consistent with crystallization at FMQ to FMQ-1, with more oxidizing conditions suggested for some samples, particularly the most strongly differentiated. Biotite-melt exchanged coefficients (KD) derived from existing experimental data were used to develop a quantitative model to track the change in biotite OH-F-Cl abundances as a function of crystallization, with or without an extant MVP. Models reproduce the relative OH, F, and Cl abundances in biotite, and suggest that SMB crystallization occurred in the presence of a MVP. Consideration of the factors that control mineral-melt partitioning indicates that at the reduced conditions of the SMB, crystallization of an assemblage dominated by quartz and feldspar with relatively small amounts of biotite and ilmenite (< 5%) will result in a melt enrichment of the granophile element suite U, W, Sn, Mo, and Ta as crystallization proceeds. Although MVP-melt partition coefficients are ~1–20 for Sn, W, and Mo, calculations show that values are not high enough to cause significant magma loss of these elements from an evolving MVP. These results therefore point to extensive crystallization as the important process for concentrating this element suite at the orthomagmatic stage.

DEPOSITIONAL VARIABILITY OF GLACIAL LAKE IROQUOIS VARVES, ONEIDA LAKE, NEW YORK

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Oneida Lake, New York is a modern-day remnant of Glacial Lake Iroquois, a large proglacial lake that delivered fresh water to the Atlantic Ocean during the last deglaciation. The drainage of Glacial Lake Iroquois into the Atlantic Ocean via the Mohawk Valley represented a significant shift in Laurentide Ice Sheet meltwater routing eastward, instead of southward via the Allegheny or Susquehanna Rivers. Catastrophic drainage of Glacial Lake Iroquois into the Atlantic Ocean is interpreted as the meltwater pulse responsible for the Intra-Allerod cold stadial. Thus, an understanding of the evolution of Glacial Lake Iroquois provides valuable details of late-Pleistocene paleoclimate in northeastern North America. Livingstone and Bolivia Coring of Oneida Lake subsurface stratigraphy reveal a well-preserved glacial varve chronology of roughly 150 annual sediment structures. This chronology provides insight on a 150 year period of proglacial Lake Iroquois deposition, revealing trends at both the intra-varve and inter-varve level. Four varves were sub-sampled along end-member and distinctive intra-varve lamina for this study, and subsequently analyzed using Beckman Coulter Grain-Size Analysis (GSA), X-Ray Diffraction (XRD), and X-Ray Fluorescence (XRF). Sampled varves included varves 930, 956, 964, and 1033. Preliminary inter-varve results reveal a thinning-upwards sequence of varves, revealing a reduction in sedimentation rates during the studied period, potentially attributed to an expansion of the depositional basin area and more distal glacial proximity due to glacial retreat. Intra-varve results reveal rapid sedimentation within summer/meltwater season varve lamina of clay-silt sized sediment, and significantly slower sedimentation within winter season lamina, of finest-grained sediment and clay. Comparatively coarse-grained 'pulse' lamina were also observed within summer/meltwater lamina, composed of grain-sizes ranging from clay to sand, potentially representing diurnal meltwater flood pulses of deglaciation, showcasing a reduction in sediment sorting and increase in sediment size. XRD and XRF analysis were employed to understand interbedded red and grey lamina within studied varves. Preliminary results suggest red lamina peaking concurrently with Manganese and Magnesium counts, and grey lamina peaking concurrently with Titanium. Aluminum and Potassium are interpreted as tracking the relative clay proportion. Calcium is interpreted as representing detrital calcite deposition, peaking in summer/meltwater lamina and ceasing during winter lamina deposition. Research on the glacial varve chronology of Oneida Lake is valuable for understanding the evolutionary history of Glacial Lake Iroquois and the deglaciation of the Laurentide Ice Sheet in Central New York and provides insights into the dynamic glacial history of this region during the Late Pleistocene.

LATE CRETACEOUS TO EOCENE EXHUMATION OF THE SOUTHERN PURCELL MOUNTAINS, SOUTHEASTERN BRITISH COLUMBIA, CANADA

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The Purcell Mountains of southeastern British Columbia form part of the hinterland to the Canadian Cordillera and host intrusive granitic rocks that were emplaced during mountain building in the Mid Cretaceous. This region records a protracted history of spatially overlapping tectonic events including two phases of rifting in the Proterozoic, orogenesis in the Mesozoic, and uplift and extension in the Eocene. Despite the importance of the Purcell Mountains to the tectonic evolution of the southeastern Canadian Cordillera, the Late Cretaceous and younger (< 100 Ma) exhumation history remains undetermined in many parts of the region. This study examines the extent and timing of Cretaceous through Eocene rock uplift of the southern Purcell Mountains by utilizing metamorphic petrology and middle to low temperature thermochronology. Detailed petrographic analysis has revealed the sequence of mineral assemblages in the contact aureoles surrounding the Fry Creek and White Creek batholiths, two Late Cretaceous granitic intrusions within the southern Purcell Mountains. We observe cordierite (Crd)-andalusite (And)-bearing mineral assemblages in the White Creek contact aureole and both Crd-And and Crd-staurolite (St)-bearing assemblages in the Fry Creek contact aureole. Phase equilibrium modeling has constrained the pressure of this contact metamorphism to 2.5–3.5 kbars. We dated the age of intrusion of the White Creek batholith, and in turn the age of the contact metamorphism, to 97.9 ± 0.29 Ma using U–Pb zircon geochronology. Together, the pressures of metamorphism and the age of the intrusions provide a point in depth and time upon which the low to mid-temperature thermochronology can be built. Existing $^{40}Ar/^{39}Ar$ biotite (closure temperature ~350°C) and new apatite and zircon (U–Th)/He (closure temperature ~60°C and ~180°C) data from five samples across the Purcell Mountains are then used to elucidate the Late Cretaceous to Eocene exhumation history of the region following the emplacement of the Fry and White Creek batholiths. The low-temperature T-t paths indicate rapid Eocene cooling (~25°C/Ma) on the western flank of the southern Purcell Mountains located in the footwall of the Eocene Gallagher Fault Zone and slower cooling (~5°C/Ma) on the eastern flank in the hanging wall of Rocky Mountain Trench fault. Further thermochronology work is planned to examine the timing and extent of exhumation across these two extensional structures.

GEOLOGY OF THE POST CA. 2.8 GA METASEDIMENTARY ROCKS OF THE WINTER LAKE GREENSTONE BELT, SLAVE CRATON, CANADA

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The Winter Lake greenstone belt (WLB) is located within the Slave craton, ~250 km northeast of Yellowknife. This belt consists of polydeformed ca. 3.3–2.5 Ga metavolcanic and metasedimentary rocks encased in basement gneisses and granitoids. The WLB neighbours the eastern margin of the Central Slave Basement Complex, some of Earth's earliest preserved continental crust, and is bound by the anastomosing crustal-scale Beniah fault zone. The metasedimentary rocks of the WLB can provide insight into early Earth evolution and Slave craton formation. Thus, this project aims to: (1) determine the depositional and tectonic settings of metasedimentary rocks of the Itchen Formation (turbidite-like) and the Sherpa Formation (Timiskaming-like) in order to piece together the architecture of the WLB and (2) reveal the geological history of the eastern Central Slave Basement Complex and the grater Slave craton through coupled Lu–Hf/U–Pb isotope analysis on detrital zircon grains. Fieldwork in 2021 consisted of sample collection for geochemical and geochronological analysis, as well as 1:2000 scale mapping to assess facies, stratigraphy, and contact relationships. The Itchen Formation consists of extensive pelite and semipelite, with intervening psammite, with graded bedding, planar bedding, and flame structures preserved. These attributes are consistent with suspension sedimentation, debris flows, and sandy submarine fan deposition within a marine environment, correlatable to facies A–E of the Bouma sequence. Previously documented contacts between the Itchen Formation and volcanic units outline contemporaneous deposition at ca. 2.6 Ga. The Itchen Formation has been metamorphosed from chloritoid-bearing greenschist facies to sillimanite-bearing granulite facies; however, mapping identified areas where low-grade regions are juxtaposed against high-grade segments, suggesting a unique tectonic history. The Sherpa Formation is dominated by polymictic conglomerates, consistent with sedimentation in a fluvial-alluvial environment. Frequent reversals in younging indicators and abundant faulting suggest extensive erosion off fault scarps into pull-apart basins, possibly related to the protracted formation and evolution of the Beniah Fault Zone ca. 2.5 Ga. The Sherpa Formation unconformably overlies volcanic units of the Snare and Credit formations, confirmed by the presence of a newly identified paleosol and mafic conglomerate clasts. A hiatus exists between the two sedimentary formations, demonstrated by an erosive contact and the presence of Itchen Formation detritus. The Sherpa Formation has been metamorphosed to actinolite-bearing greenschist facies metamorphism with some areas displaying wispy leucosomes, suggesting anataxis. Both clastic units indicate the erosion of local sources; however, the difference in dominant lithologies between the two formations suggests changing erosional patterns over time.

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REVISING THE GENETIC MODEL FOR THE WORLD-CLASS AGS FLUORITE DEPOSIT, ST. LAWRENCE, NEWFOUNDLAND, CANADA

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Fluorite mineralization in the St. Lawrence area is associated with the polyphase hypersolvus peralkaline to metaluminous St. Lawrence Granite (SLG). Veins of the AGS deposit cut metasedimentary rocks, a porphyritic phase of the SLG, and the main granitic phase of the SLG at ~300 m below the surface. The fluorite mineralization, characterized by banded and breccia textures, is divided into three stages (early, main and late), which are further subdivided into 10 phases. New data from the deposit are presented: (1) REE-Y data, Nd–Sm dating, and fluid inclusion analysis of the fluorite; (2) C and O isotopes for calcite intergrown with fluorite; and (3) S isotopes for sphalerite. A new fluorite Nd–Sm age of 360 ± 14 Ma postdates the youngest known phase of the SLG at 374 ± 2 Ma (U–Pb zircon), although they do overlap. The age difference may reflect the SLG being a high-heat production (HHP) granite, which experienced protracted related hydrothermal activity; alternatively, fluorite may be associated with an unexposed phase of the SLG. REE-Y data and patterns for early stage fluorite are typical of those associated with magmatic-hydrothermal fluids. Fluid inclusion data (Th, Tfm, $Tm_{(ice)}$) suggest mixing of low-temperature (100–170°C; P corrected to < 200°C), variably saline (10-30 wt. %), H_2O-NaCl-$CaCl_2$-$FeCl_2$-$MgCl_2$ fluids. Hematite co-genetic with fluorite indicates oxidizing conditions, as do the negative Eu* anomalies for fluorite. Sphalerite, restricted to the main- and late stages, has $\delta^{34}S$ values of -33.4 to -31.4‰ and -1.6 to -1.0‰, respectively. This variation in $\delta^{34}S$ values suggests either variable reservoirs (i.e. biogenic versus magmatic) and/or changing fluid chemistry (high to low fO_2). That latter is permissive with a decrease in the size of the Eu anomaly in later stage fluorite. Calcite, present only in the early and late stages, has similar $\delta^{13}C$ values between -6.5 and -5.6‰ and equates to $\delta^{13}C_{CO_2}$ values of -8 to -7‰ (for 150–200°C). These values are less than expected for a purely magmatic reservoir. The $\delta^{18}O$ data for calcite vary widely (8.6 to 19.3‰) and equate to $\delta^{18}O_{H_2O}$ values of -4 to 10‰ (for 150–200°C), thus implicating the involvement of an ^{18}O-depleted reservoir, as was suggested from previously published $\delta^{18}O_{quartz}$ analyses. Collectively the data presented clearly indicate that fluorite formed in a setting involving fluid mixing and that different reservoirs were involved. There is no evidence, however, for fluid boiling as earlier work suggested.

GARNET AND PYROXENE MEGACRYSTS FROM CENOZOIC ALKALINE BASALTS OF TARIAT VOLCANIC PROVINCE, CENTRAL MONGOLIA: PRESSURE-TEMPERATURE CONDITIONS, ORIGIN AND EVOLUTION OF LITHOSPHERIC MANTLE

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Mineralogical, geochemical, and pressure-temperature (P-T) data of garnet and pyroxene megacrysts are presented from the Cenozoic Tariat volcanic province (Shavaryn tsaram and Togo Uul volcanoes) in Central Mongolia. Volcanic eruptions are composed of basaltic trachyandesite, basanite, phonotephrite and trachyandesite, that contain mantle xenoliths of garnet and spinel lherzolite, websterite, pyroxenite, granulite (from 0.5 to 6 cm in size) and megacrysts of garnet, pyroxene, olivine, sanidine and ilmenite. Garnet in lherzolite is rimmed by orthopyroxene, clinopyroxene, plagioclase or spinel association. Lherzolites are enriched in LILE and HFSE, slightly depleted in U and Th and formed in P-T conditions of 1.7–1.96 GPa, and 1070–1090°C. Elemental mapping analyses have demonstrated that megacrysts are homogeneous in terms of Ca, Mg, Al, Si, Ti, and Mn, except for kelyphite rim and fractures. Garnet megacrysts (up to 10 cm in size) are fractured and the fractures are filled by symplectites of orthopyroxene, plagioclase, ilmenite, and spinel. Fractures in pyroxene (augite) megacrysts (up to 5 cm in size) are filled with diopside, ilmenite and plagioclase. Garnets of Shavaryn Tsaram megacrysts have X_{Mg} 0.54 ± 0.02, and Togo Uul megacrysts X_{Mg} 0.56–0.62 and are poor in Cr_2O_3 (1.1–1.4 wt.%) and the Mg# [Mg/(Mg+Fe)] of the Shavaryn Tsaram megacrysts is uniform, 0.76 ± 0.01, whereas that of two Togo Uul pyroxene megacrysts show different values of 0.69 and 0.76. The Togo Uul pyroxene shows enrichments from LREE to MREE with HREE depletion.The thermobarometer based on REE exchange between garnet and clinopyroxene for both megacrysts from Shavaryn tsaram and Togo Uul volcanoes yielded similar P-T conditions of 3.6 GP and 1150–1270°C. The REE geothermobarometry demonstrated that garnet-pyroxene megacrysts in Mongolian alkaline basalts were formed at a depth of 60–80 km and formed in higher temperatures in comparison with garnets from lherzolite. The parent alkali-basaltic magma may be derived as a result of partial melting of garnet-bearing pyroxenite or eclogite-like material. Late Cenozoic volcanism in Central Mongolia may be a response to stress propagation and gravity instability in the mantle associated with the India-Asia collision or mantle plume.

THE AGE AND PETROGENESIS OF GRANITIC PEGMATITES IN THE NORTHEASTERN MEGUMA TERRANE, NOVA SCOTIA, CANADA

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As Canada moves towards a renewable energy-based future, critical elements that are essential for green technologies will only increase in demand. Of the 31 elements that Canada has deemed to be critical, many of them can be concentrated by igneous rock-forming processes, including the processes that result in the formation and emplacement of granitic pegmatites. Pegmatite-forming processes can concentrate elements such as lithium, cesium, and beryllium. The pegmatites in this study were discovered in 2020 in the northeastern Meguma terrane of Nova Scotia and are associated with voluminous Devonian, peraluminous granitoid plutons. These pegmatites are being studied to determine their age, extent, tectonic setting, and petrogenesis. The northeastern Meguma terrane has a favourable geology including voluminous leucocratic and peraluminous granite. In addition, lithium-cesium-tantalum (LCT) pegmatites are found elsewhere in the Meguma terrane (e.g. Brazil Lake spodumene-bearing pegmatites). The pegmatites mainly intruded coeval peraluminous granite and metasedimentary host rocks as dykes and irregular blobs. The granite had abundant septa, rafts, and xenoliths of the metasedimentary rocks that were metamorphosed to amphibolite facies during the Devonian. Their mineralogy indicates that these pegmatites are LCT pegmatites and that they can be divided into three groups. Group 1 pegmatites contain large (up to 6 cm in diameter) euhedral beryl, especially near the northern margin of the Meguma terrane adjacent to a major, dextral transpressive fault zone (Cobequid-Chedabucto Fault Zone). In addition to beryl, Group 1 pegmatites contain tourmaline, garnet, both feldspars, muscovite, apatite, and several minerals yet to be identified. Group 2 pegmatites have the same mineralogy as Group 1 pegmatites but lack visible beryl while tourmaline and garnet are more common. Group 3 pegmatites are "barren" and have a simple mineralogy of quartz, both feldspars, and muscovite. Additional mineralogical and geochronological ($^{40}Ar/^{39}Ar$, U–Pb and Sm–Nd) data from the pegmatites and associated granite plutons will better constrain the ages, assist in evaluating the origin of the pegmatites, and provide a better understanding of their significance to the broader tectonic evolution of the Meguma terrane.

TAPHONOMY OF EARLY TONIAN MACROALGAE FROM THE DOLORES CREEK FORMATION, YUKON, CANADA

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Eukaryotic macroalgae evolved and diversified during the late Mesoproterozoic to early Neoproterozoic resulting in dramatic changes in biogeochemical cycles and benthic habitats, forever altering ecosystems to host more complex life. However, the preservation of these non-mineralizing organisms remains poorly understood, which impedes our interpretations of the early evolution of eukaryotic macroalgae. Here we describe the preservation of the Tonian Dolores Creek (ca. 950 Ma) macroalgae of northwestern Canada (Yukon Territory) and propose a taphonomic model to explain the variation in their preservation. We use analytical microscopy, including scanning electron microscopy and tomographic X-ray microscopy, to assess the fossil preservation and identify three taphonomic grades. The macroalgae preservation is similar to accessory mineralization observed in Paleozoic Burgess

Shale-type preservation with a combination of pyritization and aluminosilicification found in the well and moderately preserved fossils. Well-preserved specimens are defined by uniseriate and filamentous cellular organization, while moderately preserved specimens show identifiable cellular boundaries (cross walls) and lateral cell walls (side walls) for most of the thallus. Poorly preserved specimens are pyritized with infrequent preservation of cell walls. The preservation of the Dolores Creek macroalgae was aided by rapid burial and early templating by clays and pyrite. Investigating the taphonomy of well-preserved macroalgal deposits will aid in identifying target environments where fossils recording the evolution of early eukaryotes can be preserved.

MAGNETIC AND RADIOMETRIC SIGNATURES OF GOLD MINERALIZATION IN NORTHERN NEW BRUNSWICK, CANADA: CONSTRAINTS FROM NUMERICAL AND SPATIAL TECHNIQUES

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The Mid Paleozoic basin fill of northern and western New Brunswick termed the Matapédia Cover Sequence (MCS) is a Late Ordovician to Mid Devonian, i.e. post-Taconic to broadly syn-Acadian cover sequence that oversteps major zones of deformed Cambrian to Mid Ordovician strata, namely the Humber and Notre Dame zones to the west, and Ganderia to the east. Clastic and carbonate sedimentary rocks of the Grog Brook and Matapedia groups of the MCS were deposited in the Matapédia forearc basin between the Laurentian margin and the accretionary wedge. The major Acadian dextral transcurrent faults in northern New Brunswick are, from north to south, the Restigouche, Rocky Brook–Millstream, McCormack-Ramsay Brook, McKenzie Gulch, and Moose Lake faults. Preliminary studies indicate that Early Devonian dextral movement along the Rocky Brook-Millstream fault and its splays, including the McCormack-Ramsay Brook fault, during Acadian orogenesis exert substantial control over gold mineralization in the region. The study area hosts some 37 gold occurrences/deposits. A majority of these deposits have quartz-carbonate veins associated with fractures and shear zones. Some of these occurrences, including Williams Brook, have features of low sulphidation epithermal deposits; however, the study area is covered by glacial sediments of various thicknesses impeding effective exploration. This study examines a set of airborne radiometric and aeromagnetic data to identify geophysical signatures that might represent gold mineralization in this area. Examination of airborne radiometric signatures, namely maps of total potassium content, equivalent uranium, and equivalent thorium, can be utilized to identify areas of hydrothermal alteration spatially related to the gold mineralization to localize felsic intrusions rocks containing elevated contents of radioactive elements such as potassium. In addition, we employ three sets of historical aeromagnetic data acquired between 1976 and 1999 with line spacing of 200, 1000, and 5000m to identify various magnetic features that might be linked to gold mineralization, e.g. structures, intrusive bodies, or altered sequences. We apply a suite of edge enhancement filters, including the analytic signal of the Reduced to Pole, first vertical derivative, the total horizontal derivative of upward (THD) continued filter, and tilt derivative (TDR), to these data. We further present the process of integrating these datasets into predictive models that represent potential mineralized zones using conceptual and empirical frameworks, namely machine learning and fuzzy-logic-based methods. These can help guide further exploration surveys.

LI IN COMMON PEGMATITIC MINERALS AS AN INDICATOR FOR CRITICAL METAL MINERALIZATION

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The Li concentration of ubiquitous pegmatitic minerals, such as quartz, alkali feldspar, and muscovite, can be used to distinguish between common granitic pegmatites and pegmatites hosting critical Li-aluminosilicate minerals. It also serves as a reliable guide to facilitate targeting of Li-aluminosilicate mineralization within individual zones of a pegmatitic body. Experimental studies demonstrate that crystals of nominally Li-free minerals growing in Li-enriched melts incorporate elevated amounts of Li (up to 250 ppm in alkali feldspar at 600°C and 500 MPa). In contrast, the Li content of crystals growing in typical granitic melts does not exceed 10 ppm under the same experimental conditions. As magma cools with decreasing temperature, pegmatite-forming melts continue to crystallize alkali feldspars, quartz ± muscovite until the appearance of minerals that incorporate Li as an essential structural component. Experimental results show that there is a substantial delay in the nucleation of the critical Li-aluminosilicate minerals spodumene and petalite, leading to extreme enrichment of the melt in Li; in the melt, Li often exceeds the saturation value of Li-aluminosilicate phases by 11 000 ppm before crystallization of spodumene or petalite commences. The combination of delayed nucleation and simultaneous supersaturation of Li-rich phases in pegmatite-forming melts may explain the high crystal growth rates observed in pegmatites as well as the large size of Li-aluminosilicate crystals grown in such environments. Comparison of experimental products with natural samples from different pegmatite types corroborates the elevated Li concentrations measured in common minerals formed in Li-enriched melts before the appearance of Li-aluminosilicate phases. We propose that Li concentrations exceeding 40 ppm in alkali feldspars, 30 ppm in quartz and 500 ppm in muscovite can be used as reliable indicators for the presence of Li-aluminosilicate mineralization in a pegmatite. The proposed thresholds are particularly useful in the case of hidden deposits or where outcrop exposure to the surface is limited and the presence of Li-aluminosilicate minerals cannot be used for a preliminary assessment of the economic potential of a pegmatite.

THE LYCOPOD FORESTS OF NOVA SCOTIA VERSUS THE SCRUBBY THICKETS OF SCOTLAND: INTERPRETING CONTRASTING VEGETATION THROUGH ROMER'S GAP

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The TW:eed Project on tetrapods in Romer's Gap has provided a continuous quantitative record of spores and pollen through the Tournaisian. This clearly shows the recovery of the vegetation following the end Devonian forest collapse. The vegetation then dominated by two phases of lycopod thicket development separated by an interval dominated by seed ferns. Lycopod trees are present in the Scottish Tournaisian sections but are relatively rare with only a few known instances of the in situ lycopod stump *Stigmaria*. In contrast horizons with in situ lycopod stumps are relatively common both at Blue Beach in Nova Scotia and in New Brunswick. There is much quality palynological data available for the Tournaisian of Nova Scotia from the work of Utting. However, this data is not quantitative and gives few clues as to the identity of the lycopod forest spore. Fieldwork was undertaken at Blue Beach to palynologically profile through lycopod forest stump horizons. This was to enable the relevant spore to be identified in Scotland and the relative abundance of the lycopod forests quantified.

THE MAGMATIC-HYDROTHERMAL EVOLUTION OF A SUBMARINE ARC VOLCANO: DEEP-SEA DRILLING OF THE BROTHERS VOLCANO, KERMADEC ARC, NEW ZEALAND

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Our understanding of metal enrichment processes in seafloor hydrothermal deposits is largely based on studies of sulphide chimneys or grab samples collected from the seafloor. Only very limited data exist characterizing sub-seafloor processes in seafloor hydrothermal deposits due to the expense and technical challenges associated with deep-sea drilling. Here we present results of mineralogical and geochemical analyses of core samples collected during the International Ocean Discovery Program's Expedition 376 from up to 453 m below the seafloor (mbsf) of the hydrothermally active Brothers volcano to provide insights into sub-seafloor metal transport processes. We focus on Brothers NW Caldera (IODP Site U1530), an area

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of high-temperature (up to 320°C) black smoker venting on the inner wall of the caldera. Below a depth of 189 mbsf, chlorite-rich alteration associated with the circulation of seawater-derived hydrothermal fluids overprints pyrophyllite-rich alteration formed from earlier reactions with a magmatic volatile-influenced fluid. The scavenging of magmatic brines that exsolved directly from a volatile-saturated magma by seawater-derived hydrothermal fluids is thought to be a critical process in arc-related hydrothermal systems and is linked to the enrichment of some metals (e.g. Cu) in these systems. We show that evidence of brine dilution is preserved deep below the seafloor (314 mbsf) in pyrite. In pyrophyllite-rich samples, pyrite is coarse-grained, anhedral, and contains relict Co-rich cores. High-resolution analytical transects across the grain core show excursions in sulphur isotope ratios ($\delta^{34}S$) from -2.1 to 4.1‰ that represent the pulsed influx of a seawater-derived hydrothermal fluid deep below the seafloor at the NW Caldera, probably related to the initial formation of caldera bounding fault networks and associated seawater ingress. Decreased salinity of the brine destabilized Co-bearing Cl complexes, resulting in precipitation of Co-rich pyrite. This provides direct evidence supporting the occurrence of magmatic brines below the seafloor at Brothers and further highlights the importance of brine liberation during seawater overprinting in the formation of metal-rich seafloor hydrothermal precipitates.

THE TECTONICS OF INTROVERSION AND EXTROVERSION: REDEFINING INTERIOR AND EXTERIOR OCEANS IN THE SUPERCONTINENT CYCLE

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The amalgamation of continental fragments into supercontinents has been described by the end-member processes of introversion - the closure of interior oceans, or extroversion - the closure of exterior oceans, or orthoversion - amalgamation 90° from the centroid of the previous supercontinent. However, individual supercontinent formations are often ascribed to contradictory mechanisms; for example, Pangea has been variously argued to have formed by introversion from Pannotia, and by extroversion from Rodinia. Conflicting interpretations arise, in part, from attempting to define an ocean as interior or exterior based on paleogeography, or the age of the oceanic lithosphere relative to the time of supercontinent breakup. We argue that interior and exterior oceans should be defined relative to the geometry of the external subduction ring and its associated accretionary orogens that surround the amalgamated supercontinent. The subduction ring broadly divides the Earth into two cells, which conform to degree-2 mantle structure: one cell dominated by continental lithosphere with minor oceanic lithosphere, and the other containing almost exclusively oceanic lithosphere, whose subduction is prerequisite to the genesis of external accretionary orogens at the margin of a supercontinent. All oceans within the cell containing continental blocks are interior oceans, as they are interior to the continental cell of the degree-2 planform. By contrast, the exterior ocean is antipodal to that of the continental cell, separated from the interior oceans by the subduction ring and bordered by external accretionary orogens. Subduction and collision kinematics within the continental hemisphere are dominated by Wilson Cycles and asymmetrical subduction. However, subduction of the exterior ocean is doubly vergent and lacks continent-continent collision. For the exterior ocean to close, the subduction ring must collapse upon itself, leading to the juxtaposition of long-lived accretionary orogens within the core of the supercontinent. Employing this definition for interior and exterior oceans, Rodinia formed by extroversion, but all other supercontinents formed by introversion which always includes orthoversion.

INSTABILITY OF FORSTERITE AS A RESULT OF MELTING IN UHT DOLOMITIC MARBLE, LENADORA, SRI LANKA

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Forsterite and diopside are expected products of prograde metamorphism of a dolostone. Diopside appears first by reaction of dolomite with quartz to give diopside + CO_2. At the highest grade achieved, forsterite appears: 3 Dol + Di = 4 Cal + 2 Fo + 2 CO_2. The highest grade achieved in the area of the Lenadora quarry, near Matale in central Sri Lanka, is well established by classical geothermometry and geobarometry. The temperature of equilibration was in the range 900–950°C, i.e. UHT conditions, and the confining pressure was in the range 0.9–1.1 GPa. Metamorphism occurred in a collisional setting during the assembly of the Gondwana supercontinent approximately 560 million years ago. The quarry lies in the Highland Complex within 1 km of the suture with the overriding Wanni Complex. How did dolomitic marble fare in such a UHT environment? We imaged polished thin sections using a Carl Zeiss Sigma HD VP field-emission scanning electron microscope and the Zeiss Atlas 5 software to acquire high-resolution large-area image mosaics. We focused on fifty areas of interest. As expected, diopside and forsterite porphyroblasts appeared during prograde metamorphism. The forsterite grains are subhedral to euhedral, suggesting that deformation had ceased when the UHT conditions were achieved. We did not anticipate to see forsterite porphyroblasts mimetically replaced by diopside + dolomite, roughly in a 3:1 ratio. The conversion could have involved a fluid phase or a carbonate melt. We believe that the forsterite reacted with a hydrous Ca-dominant carbonate melt to give Di + Dol. Its presence accounts for composite calcite + dolomite globules trapped in forsterite. Dolomites remained stable. A carbonate melt is a powerful flux able to destroy silicate frameworks. Both phlogopite and pargasite were strongly resorbed, as was zircon, and refractory phases like rutile, corundum, zirconolite, lakargiite and magnesiobeltrandoite appeared. We believe that the enhanced Si content of the melt caused the destabilization of the forsterite. Also present are hydroxylapatite, pyrrhotite, and calcite as a minor phase, partly of a second generation. Unreplaced relics of forsterite were partially serpentinized at a retrograde stage. The evidence of melting is circumstantial; carbonate systems are notorious in self-erasing evidence during their cooling and decompression. The presence of an interstitial carbonate melt in the marble units and of an interstitial silicate melt in the pelitic units surely facilitated the formation of large-scale open folds of interlayered metamorphic units prominently displayed in the Highland Complex.

Cs ENRICHMENT IN WHITE MICA FROM MANITOBA LI-BEARING PEGMATITES: IS IT ALWAYS A PRODUCT OF FRACTIONAL CRYSTALLIZATION?

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Manitoba is known for its many Li-rich pegmatites of economic importance, particularly the world-class Tanco pegmatite at Bernic Lake. Other examples include the pegmatites from the Wekusko Lake pegmatite field in central Manitoba and the Red Cross Lake pegmatites in central east Manitoba. Whereas Tanco and the pegmatites at Red Cross Lake are Archean in age, the pegmatites at the Wekusko area are of Trans-Hudson age. Canada released its critical minerals list in 2021, and among them, Li is particularly important for its use in battery technology as well as glass and ceramics, lubricants and medical applications. Cesium is another good example, being currently mainly used in oil and gas wells in form of cesium formate, but also in multiple specialty applications in high technology. Manitoba is currently a producer of both of these elements. Pegmatites are host to economic deposits of a variety of elements, including Li and Cs, which puts Manitoba in a very good position to be a supplier of raw materials, essential to fuel and maintain our current lifestyle and use of technology, economic growth and at the same time in taking serious steps for decarbonizing of our economy. In pegmatites, spodumene is the main Li ore mineral followed by petalite and lepidolite, and pollucite is the main Cs ore mineral. Many other minerals are capable of hosting Li, Cs, and other incompatible elements, which can be used to understand fractionation and enrichment process. White mica geochemistry along side with petrographic observations are commonly used to establish the nature and evolution of enrichments in pegmatites. Three examples from Manitoba will be used to elucidate different types of enrichments possibly caused by different episodes and even multiple sources. In general, the K/Rb ratio decreases in micas with fractionation, whereas values of incompatible elements such as Cs, Rb, Tl, Ta, and Li increase. However, high concentrations of Cs contents of micas at the latest stages of pegmatite evolution can be decoupled from these other trace elements. Thus, the high enrichment of Cs, at least in the pegmatites of the Wekusko Lake field can be explained by a secondary metasomatic event.

PRELIMINARY RESULTS FROM THE FIRST STUDY FOR OFFSHORE GROUNDWATER EXPLORATION IN ATLANTIC CANADA

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Groundwater represents the world's largest freshwater resource and provides drinking water for two billion people globally and over 10 million Canadians. The Maritime Provinces host the largest proportion of Canada's population reliant on groundwater, with Prince Edward Island (PEI) 100% dependent on groundwater for both irrigation and drinking. Groundwater resources on PEI, which also sustain surface water ecosystems, have faced compounding stresses in recent years due to the extensive agricultural industry and the impacts of climate change on sea-level and the hydrological cycle. Freshened Offshore Aquifers (FOAs) can represent a new freshwater resource for PEI, and for similar island settings worldwide. SOURCE is an exploratory study of fresh submarine groundwater resources and of the interaction between submarine groundwater discharge (SGD), ocean biogeochemistry and benthic ecosystems offshore from Prince Edward Island, in the northwestern Atlantic Ocean. Here, the growth and collapse of the Laurentide Ice Sheet during Pleistocene glacial and interglacial cycles led to the formation of extensive networks of paleo-channels and lakes, superimposed on a Carboniferous substrate of fractured continental sandstones. Our overarching hypothesis is that ice sheet dynamics and landscape evolution during the last glacial-interglacial cycle(s) contributed to recharge of FOAs hosted in fractured consolidated clastic sediments. To test this hypothesis and answer first order questions about the functioning of offshore groundwater systems, a 9-week long research expedition (PRINCE) on board of the *RV Maria S Merian* was conducted in the fall of 2021. Geophysical data, sediment gravity cores, and water column profiles were collected along the continental shelf north and east of PEI (Gulf of St. Lawrence) to explore FOAs in the area. This talk presents an overview of the SOURCE project and preliminary findings from the PRINCE expedition.

ACTIVE MODIFICATION OF WATER CYCLE FOR THE MUTUAL BENEFIT OF AGRICULTURE AND THE ENVIRONMENT: CASE STUDY OF THE RUISSEAU ROUSSE WATERSHED IN QUEBEC, CANADA

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This study aims to assess the dynamics the groundwater-surface water interactions at a series of irrigation ponds and to plan optimization of their design for mutual benefit of the agriculture and the environment. Excavated from the sediments, it is expected that irrigation ponds rely not only on snowmelt but also on groundwater. However, over time fine sediments may settle at the surface water-aquifer interface and limit the subsurface fluxes (i.e. groundwater inflows and outflows). We hypothesize that by performing a dredging of the fine sediments, irrigation ponds can locally increase the recharge of the aquifer during high-water level periods and, in turn, contribute to enhance the support from groundwater resources during low-water level periods. An isotope mass balance approach is planned to be used to characterize the water balance at some of the 39 irrigation ponds over the Ruisseau Rousse watershed, a highly anthropized and agricultural basin. A continuous sampling campaign will be carried to perform a first-order estimate of the annual water balance. Based on defined criteria (geological context and irrigation practices), a subset of 3 to 5 irrigation ponds will be selected for further investigation. Transient water balances models will be developed prior and after dredging of the fine sediments. It is expected that groundwater – surface water exchanges will be more important for the post-dredged condition. Also, groundwater quality and contribution to the river is expected to improve locally on the short-term due to dilution of ambient groundwater with snowmelt recharge waters. A watershed-scale numerical groundwater and surface water flow will be used to explore the basin-wide and long-term implications (i.e. water availability and quality) of active modification of the water cycle at the irrigation ponds. Simulations will be performed under actual and future climate conditions to assess the sustainability of such managed aquifer solutions. This study represents the first step of a five-year project for solving water quantity and quality issues at the Ruisseau Rousse watershed. The success of this study partly relies on a close collaboration with local water managers (e.g. watershed organizations and agri-environmental clubs) and water users (e.g. producers), as the dredging is to be performed on existing irrigation ponds.

DEPOSITION AND DIAGENESIS OF THE PRAIRIE EVAPORITE, SASKATCHEWAN, CANADA: IMPLICATIONS FROM CLAY MINERALOGY

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The Middle Devonian Prairie Evaporite Formation of central Canada contains prolific basin-scale potash-deposits that are responsible for approximately one third of global potash production annually. Despite its economic significance, fundamental questions remain regarding the origin of this world-class deposit. There remains ambiguity in the primary mineralogy (sylvite vs. carnallite), the chemistry of basinal waters, the environmental changes between deposition of successive potash members, and the conditions that led to the cessation of evaporite accumulation. Challenges in addressing these issues have centred around difficulty in disentangling depositional and diagenetic controls on the current composition of the highly soluble evaporite minerals. A conspicuous and understudied component of the potash members are insoluble minerals (i.e. clays mixed with anhydrite, dolomite, quartz, and hematite) found disseminated interstitially between evaporite crystals, as distinct decimetre-scale seams of basinal extent, and irregularly distributed in features associated with post-depositional alteration, dissolution, and collapse. Historically, these clay minerals were interpreted to be of purely detrital origin. However, more recent research on evaporite deposits globally suggests that clay minerals in evaporites are often authigenic (i.e. syn-sedimentary precipitates), having formed through direct precipitation from hypersaline fluids (neoformation) or transformation from detrital precursors. In addition, the abundant evidence for extensive brine-driven burial alteration of the Prairie Evaporite leaves open the possibility for diagenetic clay minerals similar to those formed authigenically (depositionally). As such, the Prairie Evaporite insolubles represent a previously unrecognized repository of information regarding the climatic and chemical conditions during deposition, as well as the Prairie's complicated diagenetic history. Here, we present preliminary results of ongoing work to characterize the mineralogy, chemistry, and petrology of clay minerals in the Prairie Evaporite through in-mine observations, core logging, optical and SEM petrography, and XRD. The purpose of this study is to characterize the relative importance of detrital, authigenic, and diagenetic clay mineral sources and their relationship to evaporite mineralogy. This will provide novel constraints on deciphering the ubiquity and magnitude of diagenetic alteration while also shedding light on outstanding questions regarding paleoenvironmental conditions, including the causes of mineralogic disparity between insolubles in the oldest versus youngest potash members and secular trends in insoluble abundance through deposition.

NUMERICAL MODELLING OF GROUNDWATER FLOW AND RESIDENCE TIME IN AN APPALACHIAN AQUIFER SYSTEM

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Between 2018 and 2022, a regional groundwater assessment was carried out over a 10,695 km^2 area covering the Estrie region in southern Quebec ("Projet d'acquisition de connaissances sur les eaux souterraines en Estrie" or "PACES Estrie"). The study area has a relatively low population density (330,000 inhabitants) and its territory is mostly forested (79%) in the highlands, culminating at elevations of 600–800 m, with some areas dedicated to agriculture (17%) and a few urban centers (4%), mostly found in valleys at 100–200 m elevations. Although groundwater represents only 21% of all water use in the study area (134 mm^3/y), it provides 38% of residential water use (11 mm^3/y) and 88% of agricultural water use (4 mm^3/y). The fractured bedrock in the area is made up of sedimentary and volcanic metamor-

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phosed rocks that are sparsely fractured, leading to low hydraulic conductivities. The main aquifer potential is associated with buried valleys, with sediment accumulations exceeding 30 m. The groundwater geochemistry has shown the widespread presence of modern recharge-type Ca-HCO_3 groundwater, especially in topographic highs, but geochemically evolved groundwater is also quite prevalent, with residence times ranging from 3000 to 10,000 yBP (corrected ^{14}C ages). More than 25% of samples belonging to the most evolved water types exceed the maximum concentration limits (MCL) for arsenic or manganese. This paper documents the results of numerical hydrogeological modelling that was carried out to improve the understanding of regional groundwater flow and to better define the spatial distribution of groundwater residence time in the area. A 3-D hydrogeological model was developed in the Saint-François River watershed with the FEFLOW simulator. The modelling is based on a 3-D geological model of the unconsolidated deposits, on a spatial distribution of recharge obtained with the HELP infiltration model and on estimates of the hydraulic conductivity of the regional fractured rock aquifer as well as the unconsolidated aquifers. The initial parameters used for the 3-D hydrogeological model were based on previous 2-D section models. The simulated groundwater levels and simulated ages were compared to a potentiometric map and ^{14}C corrected ages to validate the model. Simulations thus provide the spatial distribution of groundwater residence time, which was compared with the ranges of arsenic and manganese concentrations. This correlation between simulated groundwater residence time and the ranges of arsenic and manganese concentrations provided a map of the probability of exceeding the MCLs for arsenic and manganese in the study area.

ROCK AVALANCHES - HOW COMMON ARE THESE GEOHAZARDS IN THE EASTERN CANADIAN ARCTIC?

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In 2017, a coastal rock avalanche along a fjord in Western Greenland triggered a tsunami that devastated a fishing village. Two years earlier, on the Alaskan Coast, a rock avalanche below the Tyndall Glacier in Taan Fjord triggered a tsunami that reached heights over 190 m above sea level. In the last century, similar disasters have been recorded in the fjords of western Norway. In fact, over 70% of tsunamis with heights greater than 50 m were trigged by large landslides, typically rock avalanches, in glaciated terranes. We do not know whether these large, catastrophic, and often cascading geohazards happen in the fjords of northeastern Canada. If they do – where and when did they occur? What are the most important controlling factors for their occurrence? Here we investigate these questions. Despite the recognized hazard potential, few studies have focused on coastal geohazards in the eastern Canadian Arctic. Northeastern Baffin Island, between the Inuit hamlets of Clyde River and Pond Inlet, is located directly across Baffin Bay from the 2017 Greenland event, with similar fjord physiography. The region is potentially vulnerable to rock avalanches and tsunamis given the steep coastal cliffs, active seismicity, ongoing deglaciation, and thawing permafrost. Given these conditions, the area is well-suited to investigate current knowledge gaps around controlling mechanisms of rock avalanches in high-relief glaciated terrane. The first stage of this research aims to develop an understanding of the prevalence, location, and characteristics of rock avalanches in the region. Systematic mapping of onshore rock avalanche deposits was carried out using high-resolution (2 new deposits have been confidently identified). A key challenge in studying rock avalanche in fjord terrain is that coastal deposits are often concealed by deep fjord waters. The next stage of this research will expand the mapping to include potential submarine deposits and secondary marine landslides using available multi-beam bathymetry. Given the established prevalence of rock avalanches in fjords worldwide, questions remain as to why comparatively fewer rock avalanche deposits are observed among the fjords of Baffin Island. Are they hidden in the marine record, or have frozen ground conditions reduced their frequency? Does rock mass quality and seismicity play a role? And can we expect to see more in the future?

CELEBRATING 25 YEARS WITH THE CANADIAN GEOSCIENCE EDUCATION NETWORK (CGEN): REFLECTING ON THE PAST, EXAMINING THE PRESENT AND CHARTING A COURSE FORWARD

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The Canadian Geoscience Education Network (CGEN) celebrates its 25th anniversary. Founded in 1996 to increase public awareness of Earth Science, CGEN is the education assembly of the Canadian Federation of Earth Sciences (CFES). Directed by a national network of volunteers, CGEN aims to improve Earth science literacy across Canada. CGEN also promotes and supports Earth Science education, and fosters Earth scientists in education and outreach activities that increase public appreciation of the study of our planet. CGEN welcomes members who share a common vision to advance its goals in Canada. Membership includes industry, academia, government, education, communication, and non-profit organizations. CGEN provides a forum for information exchange and a place to share ideas and challenges within a coordinated network. EdGEO Canadian Earth Science Teacher Workshop Program is a principal activity of CGEN, supporting teacher professional development workshops, providing funding and teaching resources for locally organized, curriculum-specific teacher training. Since 1976, EdGEO funding has enabled teachers to gain knowledge, resources and confidence to teach Earth science components of the curriculum. EdGEO grants are awarded annually to Local Organizing Committees for workshops and field trips designed for teachers in their respective region in conjunction with the GAC-MAC conference. The Geoscientists in Canadian National Parks is a new initiative in partnership with Parks Canada. Although many of Canada's National Parks were selected and inscribed due to their exceptional geological heritage, geology is not always the focus. This pilot program will place geoscience expertise within our National Parks and assist interpreters to incorporate geology-focused interpretation as part of public programming and presentations. The first pilot project is scheduled to occur at Pukaskwa National Park in Ontario during the Summer 2022. The successful applicant will assist the Park's staff in identifying and interpreting its geological assets. Volunteer expenses are funded by a grant from the Association of Professional Geologists of Ontario (APGO) Education Foundation. CGEN anticipates this pilot will encourage other National Parks to adopt this program. CGEN is undertaking a strategic planning process to chart a course forward. At a time when geoscience faces public perception crisis, geoscientists are needed more than ever to support Canada's response to global challenges, Earth science communication, education and outreach. CGEN invites stakeholders to reflect on the past, examine the present and to chart a new strategic framework to guide our way forward.

EQUITY, DIVERSITY, AND INCLUSION INITIATIVES IN THE GEOSCIENCE DEPARTMENT AT THE UNIVERSITY OF CALGARY WITHIN AN ALBERTA CONTEXT

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Calgary is Canada's third-most diverse city. The University of Calgary's Office of Equity, Diversity, and Inclusion (EDI) is committed to providing an equitable, diverse, inclusive, and accessible campus environment. Equity census results from 2016–2020 reveal that visible/racialized minorities, Indigenous peoples, and persons with disabilities are underrepresented in both the student and employee populations. To accelerate the pace of EDI change, the Department of Geoscience formed an EDI committee, comprising students, faculty, and staff. In Summer 2021, the committee hosted a 2-hour workshop on access and inclusion in fieldwork for people in geosciences with disabilities. A department-wide discussion on harassment in academia in Fall 2021 focused on Statistics Canada findings that the majority of perpetrators are men, while women with disabilities and Indigenous women are the most likely targets. All Department Council meetings now have an EDI moment. In Winter 2022, a geoscience graduate student received a major award for promoting positive EDI changes at the University of Calgary, and department members participat-

ed in the Unlearning Racism in Geoscience program. The EDI committee is currently drafting a Code of Conduct for all department members. The entire Faculty of Science is taking many actions including policy changes, education and engagement, and recognition. The Faculty hosted a virtual screening of the documentary Picture a Scientist on the UN International Day of Women and Girls in Science (2021), with a discussion about making science more inclusive and equitable. The Faculty's EDI committee hosts Coffee Chats on topics such as contrapower harassment, the impact of culture on supervisory interactions, and unlearning racism. The Faculty also has a wellness committee that supports mental health for faculty and staff. In the wider geoscience community in Alberta, binary gender is the most-studied dimension of EDI. Women represent 21.2% of professional geoscientists in Alberta. A recent survey by the Association of Professional Engineers and Geoscientists of Alberta (APEGA) revealed that the biggest barriers faced by women are the male-dominated work environment, career development, discrimination, and harassment. Early in their careers, women are hired and paid at almost the same rate as men. However, with experience, the promotion rate decreases and the pay gap widens, reaching > 3 x attrition rate and 11.6% pay gap at the executive level. Recommendations from APEGA include family leave changes, pay and promotion changes, education and awareness campaigns, and mentoring and sponsorship.

ASSESSING THE GANDERIAN AFFINITY OF PRECAMBRIAN AND EARLY PALEOZOIC ROCKS IN SOUTHEASTERN IRELAND

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The Precambrian and early Paleozoic rocks of southeastern Ireland have been considered part of Ganderia because they include a thick Cambrian arenite sequence similar to Gander Group rocks from the type area. Published detrital zircon age data for these arenites indicate a provenance similar to other Ganderian rocks. Overlying Ordovician–Silurian sequences, however, differ from type Ganderian, in that they include volcanic arc rocks that record an active margin until Early Silurian and they preserve a Darriwilian deformation. We present new U–Pb zircon dating and review existing regional geological data to assess the Ganderian affinity of rocks in southeast Ireland. Within the Precambrian Rosslare Complex, felsic orthogneiss of Cryogenian age (ca. 700 Ma) with a Proterozoic inherited-zircon age spectrum typical of an Amazonian source area is intruded by mafic gneiss with a magmatic age of ca. 636 Ma. A mylonite belt that separates the Rosslare Complex from Paleozoic metasedimentary and metavolcanic rocks includes mafic schist ultramylonite and granitic and garnet-gneiss mylonite. The mylonite zone may represent a tectonized Ganderian basement-cover relationship. U–Pb detrital zircon age spectra for Ordovician Ribband Group metasedimentary rocks include prominent Neoproterozoic age peaks, a spread of Mesoproterozoic ages and significant peaks at 2.2–2.0 Ga. These data suggest mixed sediment provenance from Amazonian and African sources, as seen in some Ganderian successions, and are consistent with published data from regional Cambrian arenites. The Ribband Group metasedimentary rocks have no clear Cryogenian peak, suggesting the adjacent Rosslare Complex was not a significant source of sediment. A sample of Tagoat Group Ordovician cover to the Rosslare Complex has a zircon age spectrum with a main late Neoproterozoic peak, minor Paleoproterozic peaks (ca. 2 Ga), but very sparse Mesoproterozoic zircon, similar to rocks from the Meguma terrane. Aeromagnetic data from the recent Geological Survey Ireland Tellus survey indicate a crustal block of higher magnetic intensity in southeastern Ireland, the edges of which are oblique to the general northeast-southwest grain of the surface geology. This block may be a sub-surface continuation of the Precambrian Rosslare Complex, overlain by structurally detached Paleozoic rocks. Granites that intrude within or above this block have higher magnetic intensity than other intrusions outside the area. Isotope geochemistry of these intrusions is generally consistent with a Ganderian signature.

IMPACT OF MICROBIAL ACTIVITY ON METAL MOBILIZATION AND REMEDIATION AT A HISTORIC PYRITE MINE

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Microbial activity has the potential to both exacerbate and remediate the environmental hazards associated with historic mine sites. Progression of these opposing microbial processes depends on site mineralogy, geochemistry, and hydrology. This study examined the range of microbial processes occurring at the Canada Pyrite, Hungerford, and Ontario Sulphur Pyrite Deposit near Tweed, Ontario that was historically mined for pyrite (FeS_2). Iron and sulphur oxidizing bacteria were detected in the legacy tailing and waste rock piles containing partially oxidized sulphide minerals. Both iron and sulphur oxidizing microbes were present in cell concentrations in excess of 1.6×10^5 cells per gram of tailings. These microbes successfully leached metals (Cr, Co, Cu, Fe, Ni, and Zn) from the tailings in laboratory column experiments, thus demonstrating their ability to increase metal mobility and generate acid mine drainage. Metal leaching by iron and sulphur oxidizing bacteria is likely occurring at the study site, as indicated by elevated concentrations of dissolved metals measured in the wetlands adjacent to the subaerially stored tailings. In contrast to iron and sulphur oxidizing bacteria, other microbes including sulphate reducing bacteria and cyanobacteria can aid metal immobilization and help reduce metal contamination of the surrounding environment. Sulphate reducing bacteria collected from the site were used to remediate the laboratory generated acid mine drainage in column experiments through metal precipitation and acid neutralization. These processes are reflected at the mine site, with the wetland hosting the sulphate reducing bacteria exhibiting low concentrations of dissolved metals. Finally, the ability of cyanobacteria collected from the site to bind dissolved metals (Cu, Co, and Zn) and remediate acidity was tested in laboratory batch experiments. Collectively, these results demonstrate the variety of microbial processes that can occur at even a small mine site, and that the associated geochemical reactions can persist for decades after mining activity has ceased. By understanding the biogeochemical processes taking place, it is possible to discourage the activity of microbes perpetuating the release of hazardous metals from historic mine tailings while encouraging the activity of those that can contribute to site remediation.

UNRAVELING PALEOPROTEROZOIC SEAWATER CHEMISTRY FROM EARLY DIAGENETIC DOLOMITE OF THE BELCHER GROUP, NUNAVUT, CANADA USING $\delta^{26}Mg$

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Distinguishing diagenetic alteration is critical to gleaning paleoenvironmental information from the elemental and isotopic compositions of marine carbonate rocks as proxies for reconstructions of Earth's ancient oceans and atmosphere. Of particular interest is understanding the evolution of atmospheric oxygen during the Paleoproterozoic, a time in Earth's history where atmospheric oxygen was in a state of flux. The Paleoproterozoic (Orosirian) Belcher Group located on the Belcher Islands of Nunavut, Canada records a ~200 Myr sequence of mixed siliciclastic and carbonate formations deposited after the end of the Lomagundi carbon isotope excursion. Here, using petrographic analysis (including CL-imaging) and geochemistry, we test whether dolostones belonging to the Belcher Group preserve geochemical signals reflecting alteration in a contemporaneous marine environment. A total of 60 bulk carbonate samples spanning 500 m of stratigraphy through the stromatolitic dolostone of the Mavor Formation and rhythmically-bedded dolomicrite of the Costello Formation were measured for stable isotopes of Mg, C, and O ($\delta^{26}Mg$, $\delta^{13}C$, $\delta^{18}O$), and major and trace elements. At least two phases of dolomite growth were identified with the primary dolomite phase characterized by unimodal, medium crystalline, planar-s dolomite with no zonation and dull to moderate luminescence. Cross-plots

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of Mg/Ca vs. δ^{26}Mg indicate a positive shift in δ^{26}Mg with a corresponding increase of the Mg/Ca ratio, while Sr/(Ca+Mg) vs. δ^{26}Mg show a loss of Sr with an increase in δ^{26}Mg. These geochemical shifts, along with petrographic indicators, are consistent with dolomitization occurring in a fluid buffered marine environment. It further suggests the Mavor and Costello formations were not recrystallized by a later fluid, indicating these dolomites may serve as archives for the elemental and isotopic compositions of contemporaneous seawater. If the primary dolomite is taken to reflect coeval seawater chemistry, then Orosirian seawater (ca. 2.0 to 1.9 Ma) can be characterized by a δ^{26}Mg signature of ~ +0.3‰, about 1.1‰ heavier than modern seawater.

HIGH TEMPERATURE (> 800 °C) BRINE AND SULPHIDE MELT INTERACTION DURING THE FORMATION OF NORTHERN BUSHVELD MAGMATIC SULPHIDE Cu-Ni-PGE DEPOSITS

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The role of volatiles in the development of layered intrusion-hosted magmatic sulphide deposits is still poorly understood. We present petrological and fluid inclusion evidence that an aqueous brine phase was present during the formation of Ni-Cu-PGE mineralization throughout the northern Bushveld Complex, which hosts some of the largest and most valuable Ni-Cu-PGE orebodies on Earth. This brine phase was present while the system was at least partially molten and we present direct evidence of brine – sulphide melt interaction. Fluid inclusions were identified in cumulate magmatic silicates (feldspar, olivine, and pyroxene) in the Aurora, Waterberg PTM, Troctolite Unit and Platreef deposits. These comprise brine and vapour inclusions which do not crosscut crystal boundaries. Optical microscopy and confocal Raman spectroscopy show that the brine inclusions contain multiple daughter minerals (including halite and carbonates), 10–15% vapour and 15–25% liquid water; whereas vapour inclusions contain CH_4 and N_2. Microthermometry shows that brine inclusions homogenize to liquid by vapour disappearance between 819–1000°C in the Aurora deposit (n = 281), between 877–994°C in Waterberg (n = 256), between 860–942°C in the Troctolite Unit (n = 428) and between 829–988°C in the Platreef (n = 227). Halite dissolves between 521–697°C, giving salinities of 61–87 wt.% NaCl equivalent. Examples of coeval interaction and entrapment of brine and Cu-rich sulphide melt are observed in all deposits, implying this was a common factor during their development. The PGE in the Aurora project and the T zone at Waterberg are hosted in platinum group minerals (PGM) that are spatially removed from magmatic sulphides and hosted in late silicate minerals such as quartz, suggesting PGE remobilization by hydrothermal processes. The petrological similarity between inclusions in all Northern Limb deposits suggests the high temperature fluids had a similar origin, either from late magmatic degassing or possibly from volatiles released from assimilated dolomite country rock.

THE DOORS OF PERCEPTION: INTEGRATING ROCK-WIDE MINERAL TRACE-ELEMENT SYSTEMATICS TO GUIDE METAMORPHIC PETROCHRONOLOGY

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Metamorphic rocks preserve a record of their journey through the crust, manifested as sequential variations in mineralogy, texture, chemistry, and isotopic ages. The challenge of petrochronology is to integrate all of these variations into a holistic reconstruction of the thermobarometric, kinematic, and temporal evolution of a rock sample. This discipline is now at a threshold where rock-wide trace-element zoning and in situ beta-decay geochronology measured by laser ablation (MS/MS)-ICP-MS can be added as a data layer. Importantly, trace-element zoning collected for a large number of minerals in a variety of key textural settings provides another dimension for phase equilibria studies and in situ geochronology. This talk will demonstrate a new petrochronology workflow enabled by a variety of technical innovations. Example applications to greenschist-, amphibolite-, and granulite-facies metamorphism in metapelitic rocks reveal the importance of tracking trace-element budgets and critically assessing diffusive length-scales that contract with progressive dehydration and ultimate partial melting. Trace-element zoning for key element suites recorded in chlorite (Li, Ni, Zn), muscovite (Cr, V), biotite (Sc, Rb, Ba, Co), plagioclase (P, Sr, Eu) and Fe-Ti-oxides (Nb, Ta, W) help constrain sequential net-transfer reactions as recorded by core-to-rim zoning in aluminosilicate porphyroblasts and peritectic overgrowths. This trace-element data, including zoning for Eu/Eu*, helps constrain thermodynamic forward models using isochemical P-T diagrams. Step-function zoning in trace-element ratios is shown to faithfully record the onset of nucleation and growth and subsequent net-transfer and partial-melting reactions. Major- and trace-element zoning measured by laser ablation complements micro-XRF maps that reveal the size and distribution of accessory minerals and their relationship with major minerals. A variety of in situ isotope measurements can now be deployed to target different parts of the P-T-D path. In addition to very high spatial resolution U–Pb geochronology of accessory minerals, beta-decay chronometers measured by MS/MS-ICP-MS (Rb-Sr, K-Ca, and Lu-Hf) can now be applied to different textural and compositional generations of fabric-forming micas and complexly-zoned garnet. These chronometric data must be contextualized in terms of proposed closure temperature for daughter diffusion to accurately assign ages to specific legs of a P-T-t-D path. Coherent patterns of trace-element sequestration and redistribution are not yet clear; nor is the robustness of in situ beta-decay chronometers. But the groundwork is now in place to interpret orogenic time-space evolution within a significantly larger data-cube than previously possible.

3-D GEOLOGICAL CHARACTERIZATION AND NUMERICAL MODELING OF FLUID FLOW RELATED TO THE MIDWEST TREND URANIUM MINERALIZATION IN THE ATHABASCA BASIN, CANADA

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Reactivated basement faults are the main control on most unconformity-related uranium deposits in the Athabasca Basin. However, not all reactivated faults contain uranium mineralization and only a small portion of the ore-hosting structures is mineralized. This study aims to further the understanding of why mineralization exists in certain areas but not in others along the same trend with seemingly the same system and structural/lithological framework. The research is focused on the Midwest Trend, which contains typical unconformity-related uranium deposits along a NE-trending reverse-offset structure, and has been described as a uranium deposit occurring as 'beads on a string', separated by intervening barren areas within a deformation zone. By examining the uranium deposits along this trend (Midwest Main, Midwest A) and the barren segments between them, this work will aid in identifying the factors that control the placement of mineralization, which is critical in uranium exploration, particularly for determining where mineralization may be located within a given fault system. The 3-D geological characterization of the Midwest trend has revealed several spatial patterns: (a) the mineralization is associated with the NNE-trending, steeply dipping Midwest structural fault trend which is bound by the graphitic pelitic gneiss lithologies on both sides throughout the trend; (b) the basement faults can be traced to over 100 m into the overlying Athabasca strata and have reverse offset on the unconformity surface; (c) the unconformity hosted mineralization consists of a near-massive, high grade core surrounded by lower-grade, dispersed mineralization in the sandstone and basement, surrounded by an alteration halo; (d) crosscutting, E-W trending faults on the Midwest A deposit limit the extents of the high grade mineralization to the east and west, whereas on the Midwest Main deposit, the high grade and basement extension of the mineralization are localized at the intersection of the crosscutting structures with the main shear zone, and (e) high concentrations of Co, Ni, As, Cu and Zn overlap with U mineralization, consistent with a model in which U and polymetallic mineralization took place at the same time. Numerical modeling of fluid flow suggests that both ingress and egress flow may be developed along the fault zone in relation to compressive deformation and/or thermally driven fluid convection. Locations with egress flow from the basement in combination with lateral flow from the basin are favourable for mineraliza-

tion, whereas areas with dominant ingress flow appear to be unfavourable, probably due to lack of effective reducing agents.

GEOLOGICAL WORLD HERITAGE - A REVISED GLOBAL FRAMEWORK FOR THE APPLICATION OF CRITERION (VIII) OF THE WORLD HERITAGE CONVENTION AND A COMPARISON WITH UNESCO GLOBAL GEOPARKS

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In 2005, the International Union for Conservation of Nature (IUCN) published a report entitled Geological World Heritage: A Global Framework. The aim of that report was to discuss and advise on the role of the World Heritage Convention in recognizing and protecting geological and geomorphological heritage. The report identified 13 themes and, since its publication, an additional 22 geological and geomorphological properties have been inscribed on the World Heritage List under criterion (viii). Furthermore, in 2015, the United Nations Educational, Scientific and Cultural Organization (UNESCO) adopted the new International Geoscience and Geoparks Programme (IGGP), which recognizes a new site-level designation, the UNESCO Global Geoparks, as territories of internationally significant geological heritage. As of June 2021, there are 169 UNESCO Global Geoparks in 44 countries. In 2019, IUCN at the request of the World Heritage Committee commissioned the authors, aided by a global group of experts, to fully revise and update the 2005 report and to look at the potential impact of the new UNESCO Global Geopark designation on future inscriptions to the World Heritage List under criterion (viii). Central to this task is a discussion on the concept of Outstanding Universal Value, and reiteration that not all sites of significance can be included on the World Heritage List. This aim of the report has been achieved through a thorough review of the 2005 report, and in particular the thematic approach to geology that the report used. Published in 2021, the new report has led to the proposal of a rationalized set of 11 themes to guide the application of criterion (viii). Finally, the new report looks in detail at the differences and similarities between geological World Heritage Properties recognized under criterion (viii) and UNESCO Global Geoparks. It examines each designation and presents a pathway to help States Parties / Member States to determine whether one of these two UNESCO designations might be appropriate for any possible new territories, and in particular to distinguish sites with the potential for inscription on the World Heritage List. This presentation summarizes the key findings of the study.

THE CANADIAN FEDERATION OF EARTH SCIENCES: WHO WE ARE AND WHAT WE DO

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CFES is the Canadian Federation of Earth Sciences. We are an umbrella organization that represents a federation of approximately 15 000 geoscientists working in Earth Science societies and associations across Canada. Established in 2006 as the successor to the Canadian Geoscience Council, CFES brings together 14 organizations of Earth scientists in industry, government, and academia. We cooperate with observer organizations and other relevant Canadian non-member organizations on issues of public education and professional registration. Nationally, we advocate on behalf of the Canadian Earth Science community with government and the Canadian public through our memberships in the Partnership Group for Science and Engineering (PAGSE), and the Science Media Centre of Canada (SMCC). Internationally, we advocate through our membership in the International Union of Geosciences (IUGS) and United Nations Educational, Scientific and Cultural Organization (UNESCO). Our mission is to be the coordinated voice of Canada's Earth Science community, ensuring that decision makers and the public understand the contributions of Earth Science to Canadian society and the economy. CFES strategic priorities come from our member organizations, guiding our activities in support of those mutual goals. We coordinate overlapping efforts among member organizations to maximize efficiency and impact. CFES strategic objectives are determined by the Council of Member Organizations. These are to coordinate and provide a common voice for member organizations and the Earth Science community in Canada; to coordinate public policy advocacy on Earth Science in Canada; to facilitate public awareness of Earth Science and support Earth Science literacy; to represent and promote Canadian Earth Science internationally; to provide service to member organizations and the Earth Science community; to coordinate support for professional and academic organizations in Canada. The Canadian Geoscience Education Network (CGEN) is the education arm of CFES, working to increase public awareness of Earth Science. Founded in 1996, CGEN is a national network of volunteers supporting Earth Science literacy at all levels of education through various initiatives. EdGEO Canadian Earth Science Teacher Workshop Program is one of CGEN's primary initiatives, providing financial support, volunteers and resources for locally run teacher professional development programs. The Canadian Federation of Earth Sciences invites you to join us in advocating for the important role geoscience can play in creating a sustainable future for Canadian society.

THE HIGH-GRADE GOLD ORE PARADOX OF THE BRUCEJACK DEPOSIT, NW BRITISH COLUMBIA, CANADA: INSIGHTS FROM NANOSCALE IMAGING OF ELECTRUM AND HIGH-RESOLUTION TRACE ELEMENT AND SULPHUR ISOTOPE ANALYSES OF PYRITE

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It has been long accepted that epithermal gold deposits form as a result of gold precipitation from hydrothermal fluids in which gold is present as dissolved species. A major weakness of this hypothesis is that it fails to explain the formation of ultra-high-grade or bonanza gold veins. Gold concentrations in the fluids responsible for epithermal mineralization are typically on the order of 10–30 ppb, which are far too low to explain the occurrence of bonanza-grade epithermal deposits like Brucejack, where drilling has returned grades up to 41,582 g/t Au over 0.5 m intervals. Formation of such high-grade veins by direct precipitation of native gold or electrum from the ore fluids would require that fractures remain open for unreasonably long periods of time or that fluid fluxes be extraordinary. A potential solution to the paradox of ultra-high-grade gold deposition, in a geologically realistic time-frame, is offered by colloidal transport. We have studied the high-grade gold mineralization from the Valley of the Kings (VOK) zone of Brucejack, a large and exceptionally high-grade, intermediate-sulphidation epithermal gold-silver deposit in BC's Golden Triangle, to evaluate this possibility. Images obtained using transmitted electron microscopy show that: (1) gold commonly occurs as < 1–10 nm spherical nanocrystals of electrum embedded within a calcite matrix; (2) larger (100-500 nm) particles of electrum, also embedded in calcite, are composed of hundreds of nanoparticles, each displaying distinct crystal lattice plane orientations; and (3) the margins of > 1-μm-wide electrum masses surrounding the calcite matrix comprise nanoparticulate electrum partially crystallized to massive monocrystalline electrum. Strong positive shifts in $\delta^{34}S_{pyrite}$ values (> 20.0‰) from in situ SIMS analysis of VOK hydrothermal pyrite suggest that seawater mixed with hydrothermal fluids during the late stages of ore formation contemporaneous with the deposition of electrum. We present a model in which the high-grade epithermal gold mineralization is due to the development of a boiling-induced colloidal gold suspension in a carbonate fluid originating from a porphyry source at depth and its flocculation during the incursion of seawater. According to this model, colloidal and flocculated gold particles are mechanically transported into networks of nano-veinlets that they block, producing millimetric to centimetric knots of electrum in centimetric carbonate veins. Our model offers a solution to the longstanding problem of high-grade gold transport and deposition in epithermal vein systems, as well as an explanation for the extraordinary and challenging grade variability, or 'nugget effect', often encountered during the mining of these deposits.

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EVIDENCE FROM GEOMORPHOLOGICAL MAPPING AND TERRESTRIAL COSMOGENIC NUCLIDES FOR RELICT GLACIAL TERRAINS PRESERVED UNDER THE KEEWATIN ICE DIVIDE, NUNAVUT, CANADA

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Relict glacial terrains were recently identified in large areas formerly covered by the northern portion of the Keewatin Ice Divide in the Kivalliq Region of Nunavut west of Hudson Bay, Canada. A gradual transition in the preservation of these relict terrains, based on geomorphology, elevation, drainage network, lake density, weathering, and terrestrial cosmogenic nuclide (TCN) abundances in bedrock, till, and boulder samples, is linked to differential glacial erosion. The unprecedented and comprehensive documentation of these preserved landscapes in central mainland Nunavut is based on the mapping of glacigenic features using high-resolution imagery (ArcticDEM and Landsat 8), ground-based observations, and surface materials composition. Between Baker Lake and Repulse Bay, extensive areas of uplands form a continuum ranging from weathered bedrock, blockfields, and diamictons with little to no evidence of glacial erosion to terrains with moderate glacial erosion, rare streamlined landforms, ice-marginal channels and discontinuous eskers. High proportions of secondary clay minerals and amorphous Fe-oxides in the clay fraction of the most weathered diamictons are observed. In contrast, along and on either side of the ice divide zone between Baker Lake and the Manitoba border to the south, warm-based assemblages of glacial features, thick glacial deposits, and palimpsest glacial landscapes reflect mobile outflow centres during the last glacial cycle(s). Our mapping and classification of these land systems is supported by relative TCN abundances. Paired ^{10}Be and ^{26}Al abundances are relatively high in relict terrains where apparent ^{10}Be ages of surface bedrock vary from 21.9 ± 0.5 ka to 61.9 ± 1.2 ka (n = 10; LSDn Age ± 1s int). These apparent ages reflect the persistence of cosmogenic nuclides formed during prolonged exposure prior to burial and preserved through incomplete erosion under a variably cold-based ice divide and suggest that the uplands in the north have largely escaped the effects of the last glaciation(s). The presence of rare glacial erratics over the weathered bedrock suggests full glacial coverage with sporadic warm-based conditions. South of Baker Lake, five apparent ^{10}Be ages on bedrock varying between 6.9 ± 0.5 ka and 9.0 ± 0.6 ka indicate no exposure inheritance or burial. The exposure ages, however, generally suggest that deglaciation occurred at least 1 kyr earlier than radiocarbon-based reconstructions. All these characteristics can help to evaluate the significance of inheritance for glacial erosion and to understand differences in the composition and provenance of surface materials between the fully cold-based relict landscapes and the adjacent fully warm-based glacial terrains.

Mg-CARBONATE FORMATION POTENTIAL OF SULPHATE-REDUCING BACTERIA

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Biologically induced mineralization due to microorganisms' reactive surfaces and metabolisms can form microbialites. Sulphate-reducing bacteria (SRBs) produce negatively charged extracellular polymeric substances (EPS) which aid growth in ion-rich environments, and functional groups in EPS can bind positively charged ions from solution, leading to mineral precipitation. These anaerobic bacteria couple sulphate reduction and the oxidation of organic matter. While SRBs are well-known to precipitate sulphide minerals by reducing sulphate ions, they also generate alkalinity, resulting in a pH increase and directly contributing to the precipitation of carbonate minerals by inducing supersaturation conditions. Through their metabolic processes, they are also capable of storing trace metals and reducing harmful ion concentrations. Previous studies indicate that SRBs play a role in Ca-carbonate mineral precipitation, but their ability to form Mg-carbonates is not well understood. SRBs were selected from a circumneutral tailings pond, situated next to limestone treated pyrite (FeS_2) tailings at a historic mine site near Sulfide, Ontario. These bacteria were specifically targeted as they are well adapted to tolerating metal-rich tailings ponds. Media replicating Ca^{2+} and Mg^{2+} concentrations of synthetic mine wastewater were inoculated with SRB enrichment cultures created with the SRBs found at Sulfide. The development of Ca- and Mg-carbonates were monitored using light and scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), ion chromatography (IC), and inductively coupled plasma optical emission spectroscopy (ICP-OES). Comparing this data to abiotic vials, provides insight into the role of SRBs in carbonate mineral formation. Hydromagnesite ($Mg_5[CO_3]_4[OH]_2 \cdot 4H_2O$) and magnesite ($MgCO_3$) were of particular interest, as these were the expected species of Mg-carbonates to form in this environment. Findings from this study will have implications in large scale carbonation wetlands and the bioremediation of sites contaminated with ultramafic wastes.

PRECIPITATION TIME SERIES INTERPOLATION USING FOURIER KRIGING

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Precipitation time series is one of the key inputs for hydrological and geo-hydrological models. Because of its importance for models and also high variability in time and space, different methods and models have been developed to interpolate or generate precipitation time series. Kriging as a geostatistical tool can estimate the values in spatial surface for scattered data points. These points can be also located in a different point than the measured points. In this study, we present a spectral form of kriging which is based on the Fourier transform. In Fourier kriging, input values are the power and phase spectrum of the observed time series. Based on the described continuity of power and phase spectrum of transformed data, kriging of the precipitation time series is conducted. Fourier transform enables us to observe and detect long term and short term wavelengths of time series in frequency domain. For this purpose, all the interpolation process has been done in frequency domain. Backward transformation of Fourier is applied to transform the interpolated values from frequency domain to time domain. By utilizing the Fourier transformed values and investigating the power spectrum separately and then rebuilding the time series, we will be able to interpolate the precipitation time series for desired location. The proposed approach is tested and evaluated for the selected points and precipitation stations in Baden-Württemberg, Germany.

MELT PRODUCTIVITY OF ALUMINOUS ANATECTIC ROCKS OF THE CENTRAL GRENVILLE PROVINCE AND CHARACTERIZATION OF POTENTIAL ANATECTIC GRANITE LAYERS

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Partial melting commonly occurs in high-temperature metamorphic terranes and its understanding plays a crucial role in decoding the history of tectonic regimes. This is particularly important for large hot orogens such as the Grenville Province, an exceptional location to study high-T processes due to the wide exposure of middle to lower crust, dominated by granulite-facies and other high-grade rocks. This project evaluates the melt productivity of aluminous anatectic rocks of the central Grenville Province, primarily focused on metapelites from the Plus Value Complex (PLV). Petrographic evidence of partial melting of these rocks includes the main mineral assemblage consisting of quartz, garnet, K-feldspar, plagioclase, biotite, and Al-silicate, along with microstructures indicating melt-loss and melt crystallization. This is consistent with the melting of biotite through the dehydration reaction: Bi + Als + Qtz = Grt/Crd + Kfs + melt. Results from phase equilibria modelling suggest P-T paths with moderate pressure/temperature gradient and maximum conditions achieved at ~10.8 kbar and 880°C. Additionally, it predicts that up to 45% of the produced melts would have escaped. The composition of such melts would be monzogranitic, peraluminous in open-system models, and less peraluminous in closed-system models. Previous research in the area suggests that magmas of broadly granitic composition would have been produced and migrated away from their source to form granitic bodies during anatexis. However, such bodies have not been identified yet (probably because they moved to higher structural levels, now eroded), except for rare metric scale granitic layers of potentially anatectic origin associated with the PLV analyzed in this study. These granite layers have ages similar to those

of the metamorphic ages of the aluminous rocks and show peraluminous, monzogranitic compositions.

GROUNDWATER FLOW MODELING OF A 700 KM² WATERSHED IN THE FOX CREEK AREA, ALBERTA, CANADA

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Oil and gas development has been ongoing in the Fox Creek area, west-central Alberta, for the last 50 years. Assessing its potential impacts on water resources requires, among other things, the study of subsurface hydrodynamics. To this end, a 3-D finite element model was developed in FEFLOW for the 700 km² watershed, which includes four bedrock units and four surficial sediment units (totaling about 1000 m thickness) to simulate groundwater flow, in order to corroborate previous parameter estimates including recharge and hydraulic conductivity of the different units. The regional aquifer in this area is the Paskapoo Formation, a succession of interbedded mudstone and siltstone with sandstone channels. Since the first 100 m of this formation is considered to be more fractured and therefore more permeable, this formation was divided into an upper and lower part. The model used unconfined (free surface) and steady state conditions. Low hydraulic conductivities (K) of the surficial sediments (10^{-7}–10^{-8} m/s) and high evapotranspiration rate result in low recharge. Imposed constraints include Dirichlet conditions assigned on the three main streams and a null flow assigned almost everywhere along the watershed boundary, except in the extreme western part where interbasin groundwater flow is assumed and is represented as a Dirichlet source term. Model calibration was performed using 162 hydraulic head measurements in shallow wells from the provincial database and in nine new monitoring wells. Simulations using a uniform recharge of 70 mm/y produced a RMSE of 6.2%. These early results reveal moreover that zonation for the upper Paskapoo Formation (using nine distinct zones of K values) inferred from pumping test analyses and specific capacity estimates significantly improved the RMSE. The Scollard, Battle, and Wapiti formations appear to contribute little to the overall system hydrodynamics. The model confirmed that groundwater can be very shallow in the lowlands, where the surface hydrographic network is well developed. A fully coupled surface water/groundwater model (SW/GW) will be developed in CATHY in the coming months based on insights from the FEFLOW modeling. This model will help us evaluate the interactions between SW and GW and, in particular, the variations of the various water budget components over time. Subsequently, a coupling between CATHY and the land surface model NoahMP, together with hydrogeological and hydrometeorological data from various sources, will allow us to understand the watershed hydrology in a more integrated manner, in particular with regards to soil moisture, soil freezing/thawing, and evapotranspiration processes.

PEGMATITE – WALLROCK INTERACTIONS AND THEIR ECONOMIC IMPLICATIONS

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Although it has long been known that some pegmatites are surrounded by metasomatised country rocks, extending metres to decametres from contacts, these geochemical halos have received much less attention from researchers than the mineralogy and geochemistry of the pegmatites themselves. This is surprising because halos are records of elemental loss from, and gain to, pegmatites during their crystallization and have exploration value. We present the results of ongoing research on geochemical halos around rare metal pegmatites. Lower Palaeozoic spodumene pegmatites in south Leinster, Ireland, are characterized by halos enriched in Li, Rb, Cs, Be, Ta, Nb, and Sn, with mica-schist wallrocks apparently supporting thicker and more intense halos than granite wallrocks. Variscan lithium and simple pegmatites in the Fregeneda-Almendra (FA) pegmatite field, central-western Spain and Portugal, have wide Li and Cs halos and less extensive Rb and Sn halos. The Iberian study highlights the difficulty in distinguishing the halos of pegmatites intruded in close proximity to each other. Lithium and Cs concentrations are found to be progressively higher around more chemically evolved pegmatites compared to simple pegmatites in the FA pegmatites. In Tysford, arctic Norway, Proterozoic pegmatites enriched in Th, F, and REE have developed Th-rich halos detectable by handheld scintillometer. These pegmatites were subject to lower Palaeozoic amphibolite-facies metamorphism, adding to the complexity of interpreting their halos. Siderophyllite, tantalian rutile and tourmaline are developed within a few centimetres of pegmatite contacts in the Irish pegmatites and these are the likely hosts of Li-Rb-Cs, Nb-Ta-Sn and B, respectively. In all pegmatites studied, halo enrichments tend to fall exponentially with distance from pegmatite contacts. There is evidence in the Irish spodumene pegmatites that halo formation results from unmixing of pegmatitic fluids during pegmatite crystallization. The transition from coarse pegmatitic to much finer-grained albite-dominant crystallization is contemporaneous with breakdown of spodumene, K-feldspar and columbite group minerals. Loss of a magmatic-hydrothermal fluid carrying the elements seen in halos may be the trigger for this transition from pegmatitic to millimetre-scale crystallization. From an exploration perspective, halo formation is controlled by the extent to which these elements are concentrated before expulsion. However, in the case especially of Li and Cs, halos indicate their substantial loss from the crystallizing pegmatite and consequent reduction in economic potential, unless halo rocks themselves become prospective.

GOLD IN NUNAVUT, CANADA: ARCHEAN VERSUS PALEOPROTEROZOIC

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In 2019, Nunavut became Canada's third-largest gold producer, after Ontario and Quebec. Approximately 17 tonnes (~547,000 ounces) of gold were mined in Nunavut in 2019 from the Meadowbank complex (Portage, Vault, and Amaruq deposits), Meliadine complex (Tiriganiaq deposit) and Doris mine (Hope Bay belt). Nunavut, which accounts for approximately one-fifth of Canada's total landmass, has a rich geological history spanning about four billion years. Apart from the Hadean Acasta Gneiss, the oldest rocks in southern and eastern Nunavut are of Archean age and belong to two distinct cratons, the Slave Province (west) and the Churchill Province (east). The Slave and Churchill are characterized by gneissic and plutonic basement rocks overlain by several belts of more or less well preserved (i.e. strongly deformed and metamorphosed) volcano-sedimentary rocks and extensive turbidites. In addition to Archean deformation events, several major tectono-metamorphic events affected and altered the rocks of the Churchill and, to some extent, those of the Slave during the Paleoproterozoic. The Archean volcano-sedimentary belts, and in particular the banded iron formations within these belts or in the overlying turbidites, host many of Nunavut's gold deposits, prospects and occurrences (e.g. Lupin, Back River and Hope Bay in the Slave, and Meadowbank, Amaruq, Meliadine and Three Bluffs in the Churchill). Although gold is commonly hosted in the Archean volcano-sedimentary rocks, the age of gold deposits varies from Archean to Paleoproterozoic. Peak orogenic gold deposits formed at ca. 2.6 Ga in the Slave Province, as shown by previous research and in agreement with ongoing Re–Os geochronology at the Back River deposit, whereas significant orogenic and BIF-associated gold in the Churchill deposited at ca. 1.9–1.85 Ga in association with the Trans-Hudson orogeny. However, ongoing research indicates that what was previously considered a simple early Proterozoic gold metallotect in the Churchill Province rather appears to be a long, possibly multiphase hydrothermal history associated with orogenic phases older than the Trans-Hudson. Preliminary Re–Os analyses on ore-associated arsenopyrite from the Amaruq deposit suggest a major time span from late Neoarchean to early Paleoproterozoic. Such a long ore-forming history is in agreement with results obtained in the Meliadine district where arsenopyrite Re-Os ages range from 2.3 Ga to 1.8 Ga. These results indicate that part of the orogenic gold in the Churchill is Archean (and later variably affected by the Paleoproteozoic orogenic events), and that Archean rocks and structures might have influenced the formation and location of Paleoproterozoic gold deposits.

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THE OUTER HEBRIDES FAULT ZONE, NW SCOTLAND: GEOCHRONOLOGICAL EVIDENCE FOR ITS INITIATION DURING THE ASSEMBLY OF RODINIA

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The Outer Hebrides Fault Zone (OHFZ) extends for ca. 170 km along the eastern seaboard of the Outer Hebrides, NW Scotland. Seismic profiling indicates that it dips moderately to the east and penetrates to a depth of at least 25 km. It is developed entirely within the Archaean–Palaeoproterozoic Lewisian Gneiss Complex which forms the Laurentian foreland of the Caledonian orogen further east. However, the lack of piercing points either side of the OHFZ means that the amount of displacement is unknown. The OHFZ records a protracted deformation and reactivation history, with the earliest phase of deformation associated with top-to-the-NW ductile thrusting which developed a metamorphic belt of upper-greenschist facies mylonites. The age of ductile thrusting is unknown and initiation of the OHFZ has been assigned variously to supercontinent assembly at ca. 1700 Ma (Laxfordian orogeny; Nuna cycle), ca. 1000 Ma (Grenvillian orogeny; Rodinia cycle), and ca. 430 Ma (Caledonian orogeny; early stage of the Pangaea cycle). We have utilized SEM and LA-ICP-MS techniques to facilitate micro-textural analysis and in-situ U–Pb dating of syn-kinematic apatite grains hosted within mylonites at three separate localities along the northern segment of the OHFZ. The mylonitic fabrics are defined by a recrystallised assemblage of quartz + plagioclase + sericite + actinolite + epidote + apatite, consistent with deformation temperatures of ca. 450–500°C. The closure temperature of apatite within U–Pb systems is within the range of 350–575°C and thus close to the estimated deformation temperatures of the mylonites. U–Pb ages obtained from the apatite grains produce a minimum range, within uncertainty, of ca. 1010–989 Ma, placing the timing of early, top-to-the-NW ductile thrusting, and hence initiation of the OHFZ, firmly within the time window of the Rodinia cycle. We envisage that the OHFZ was initiated during the collision of Laurentia and Baltica which also reworked Archaean-Palaeoproterozoic basement within the Scottish Caledonides. This was followed by the collision of Amazonia with the combined Laurentia-Baltica to form the Grenvillian-Sveconorwegian orogen. The late Mesoproterozoic to early Neoproterozoic sedimentary rocks of the Stoer and Torridon groups on the Laurentian foreland of Scotland are separated by an unconformity and interpreted as the foreland basin deposits of these successive collisional events.

CONNECTIVITY OF COASTAL WATER RESOURCES, SUBMARINE GROUNDWATER DISCHARGE, AND OFFSHORE FRESHENED GROUNDWATER

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Recent advances have expanded our understanding of offshore freshened groundwater systems and highlighted their potential as a resource along coastlines worldwide. Evidence suggests that offshore freshwater was emplaced within continental shelves during previous sea-level lowstands, but its persistence may reflect a land-sea disconnect which results in disequilibrium with present-day sea level, an active land-sea connection with fresh discharge offshore, or some combination of the two. This functioning – the nature of the land-sea hydrologic connection – is a critical factor in understanding the potential future use of the resource. Using numerical simulations of variable-density groundwater flow and salt transport through aquifers extending from onshore to offshore, we explore the functioning of onshore-offshore groundwater systems and explore their potential for exploitation. We show that preferential flow through connected high-permeability subsurface conduits results in freshened groundwater tens of kilometres offshore in some cases. These systems host active discharge of both fresh and saline groundwater, the latter of which is enhanced in the presence of heterogeneity. Incorporation of onshore and offshore pumping shows that geologic connectedness is a critical factor in assessing and managing the potential use of the resource, which may be vulnerable due to unpredictable onshore-offshore connections. We suggest that understanding the nature of the onshore-offshore hydrogeologic connections is a critical frontier in exploration of offshore freshened groundwater systems.

COMBINING ANALYTICAL SOLUTIONS TO ISOTOPE TRACERS TO UNDERSTAND THE HYDROGEOLOGICAL BEHAVIOUR OF AN UNCONFINED AQUIFER

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Sustainable use of groundwater for agriculture purpose requires an accurate understanding of the aquifer hydrogeology behaviour. The objective of the present study consists of characterizing a complex aquifer, undergoing commercial wild blueberry field, by (i) estimating groundwater recharge and (ii) assessing transit time of groundwater through the aquifer system. This study was carried out at an experimental site "Bleuetière d'Enseignement et de Recherche (BER)" located in Normandin region of Quebec (Canada). This site is overlying an unconfined Quaternary paleo-deltaic aquifer. Seven boreholes were drilled over the studied site, from where continuous soil cores were collected and submitted to laboratory volumetric water content measurements and grain-size analyses to estimate their hydraulic conductivities. The collected data were integrated in a Dupuit-Forchheimer analytical model to estimate groundwater recharge, while the groundwater transit time was assessed using a closed-form analytical model developed for Dupuit-type flow systems. Furthermore, stable isotopes-based approach, including the analyses of $\delta^{18}O$, $\delta^{2}H$, and $^{13}C_{(DIC)}$ accompanied by the analyses of hydrogen radioactive isotope ^{3}H was used to validate the results from analytical solutions and to constrain the field observations. This study not only provides an estimated rate of groundwater recharge (198 mm/yr) and an assessed groundwater travel time (7 years) from ground surface to the discharge zones of the aquifer, based on robust analytical solutions integrating realistic field data, but also constrains the field observations in terms of interactions between groundwater and surface water. Ultimately, the outcomes of the present study contribute to effective and sustainable water resource management at the BER, and also may improve scientists' ability to predict the hydrogeological behaviour of humid continental sites undergoing similar features.

INCORPORATION OF EMULSIFIED VEGETABLE OIL IN ORGANIC-CARBON PERMEABLE REACTIVE BARRIERS TREATING MINE DRAINAGE: COLUMN EXPERIMENTS

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A permeable reactive barrier designed to promote biologically-mediated sulphate reduction can provide a long-term passive solution to treat mine-impacted groundwater. Compost, sawdust, wood chips or a combination thereof are often utilized due to their low cost and local availability but may not provide the optimal substrate for microbial-sulphate reduction for long-term treatment performance. Injections of emulsified vegetable oil (EVO) have been shown to be effective in promoting bioremediation but have not been evaluated in combination with solid organic substrates as a remediation strategy. Four flow-through columns experiments treating simulated mine impacted groundwater, characterized by high concentrations of sulphate, iron and nickel, were conducted over 45 weeks. The purpose of these experiments was to evaluate the incorporation of EVO into an organic-carbon permeable reactive barrier (PRB) through two methods: soaking and injection. The addition of a second injection of EVO to re-invigorate treatment performance after a decline occurs was also evaluated. Treatment performance was measured through sampling the column effluent for metal concentrations and other geochemical parameters. Potential effects of incorporating EVO on the microbial populations were characterized through DNA extraction of solid samples taken along the column profile during the experiment and amplicon sequencing of the 16S rRNA genes. Aqueous geochemical results demonstrate clear performance benefits as a result of EVO additions in prolonging treatment system lifespan. The β-diversity of the entire BACs significantly differed in each treatment type demonstrating that incorporation of EVO and the method of EVO incorporation can greatly affect microbial populations. In summary, the results from this study will provide a strong conceptual model of how a PRB with EVO functions to remediate acid mine drainage and on the potential performance benefits of incorporating EVO into an organic matter PRB treatment system.

LA-ICP-MS GARNET U–Pb DATING: METHOD AND APPLICATIONS

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Garnet is an exceptionally versatile petrochronometer, as it has an extensive pressure-temperature (P-T) stability field for a wide variety of rock compositions, and changes in P-T conditions are recorded in compositional changes during garnet growth. Due to these properties, garnet is essential for constraining, e.g. the P-T-time evolution of metamorphic rocks, and compositional variations of the subcontinental lithospheric mantle. Whereas garnet has traditionally been dated using the Lu–Hf or Sm–Nd isotope systems, the time- and labor-intensiveness of these techniques impede their more wide-spread application. U–Pb dating of garnet by LA–ICPMS, on the contrary, represents a recent addition to our geochronology toolbox which allows for a much higher sample throughput and may yield geologically meaningful U–Pb dates even for low-U (~1–100 ng/g) garnet. In this contribution we evaluate the benefits and drawbacks of this method by discussing examples of skarn garnet from Whitehorse, Canada and Dal'negorsk, Russia, and regional metamorphic garnet from the Menderes Massif, Turkey. The latter sample has previously been dated by Lu-Hf isotope dilution technique. Highlighted benefits of LA-ICP-MS U–Pb dating are the ease of sample preparation, high spatial resolution, rapid data acquisition and processing, and relatively low costs. Challenges include the commonly very low U and variable common Pb content of garnet, the presence of U-rich mineral inclusions, and a scarcity of matrix-matched reference material. The selected garnet samples formed in diverse geological settings and cover a range of U contents, emphasizing the versatility of this method. While this method is still in its infancy the chemical complexity of garnet and its formation in widely varying geological milieus provide an immense geochronological potential that is currently being explored.

GEOLOGY OF NEWFOUNDLAND'S BONAVISTA PENINSULA: A TRAIL OF DISCOVERY THROUGH THE EDIACARAN MUSGRAVETOWN GROUP OF AVALONIA

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The Bonavista peninsula of northeastern Newfoundland, Canada, is underlain mainly by the Ediacaran Musgravetown Group, an extensional volcano-sedimentary unit that sits unconformably above the 620–605 Ma turbiditic Connecting Point Group and below the transgressive, subtidal, quartz arenite-dominated, Cambrian Random Formation. The base of the Musgravetown Group is an angular unconformity constrained between 605 ± 2 Ma and 600 ± 3 Ma by tuffs below and above the contact, respectively. Basal units include ca. 600 Ma calc-alkaline mafic volcanic flows intercalated with pebble, cobble and boulder conglomerate (Cannings Cove Formation) and a bimodal sequence of tholeiitic basalt, alkaline rhyolite, abundant pyroclastic and lesser epiclastic rocks deposited ca. 594–590 Ma (Bull Arm Formation). Small volumes of at least two distinctive alkaline basalt suites occur within the overlying, mainly coarse clastic Rocky Harbour Formation. These occur both below and above the Trinity facies, a glaciogenic diamictite and regional marker horizon consisting of massive to crudely laminated, matrix-supported polymictic conglomerate correlative to the 580 Ma Gaskiers glaciation. Three main lithofacies associations occur within the Rocky Harbour Formation. Of these, the coarse-grained lithofacies (FA1) occur mainly below the Trinity facies, whereas fine-grained lithofacies (FA2) predominate immediately above it; but all three, including the heterolithic (FA3a, b) facies association, occur throughout the Rocky Harbour Formation. Stratigraphic relationships between these facies associations are not yet well established. FA1 consists of pebbly, massive, trough cross- and planar- stratified arkose with rare interbedded red siltstone, recording high-energy, channelized and unconfined fluvial sedimentation. Fine-grained FA2 includes laminated mudstone and siltstone, with low-relief wave and current ripples, rare Bouma turbidites, and localized soft-sediment deformation recording mainly distal, quiescent subaqueous shelf and slope sedimentation. Rare cross-stratified, megarippled and hummocky cross-stratified coarse-grained sandstone in FA2 record storm- and/or flood-related sedimentation events. Heterolithic FA3 consists of medium- to coarse-grained arkose interbedded with mudstone and siltstone. FA3a contains graded massive layers, local cross-stratification, and soft-sediment deformation, collectively suggesting a delta front environment influenced by high sedimentation rates. FA3b, in contrast, contains abundant bidirectional cross-stratification, mud drapes, and coarse-grained megaripples suggesting tide- and storm-dominated conditions. The uppermost Crown Hill Formation, its base contested and nowhere age-constrained, comprises mainly conglomeratic and arkosic red beds. Future investigations aim to define the stratigraphic arrangement of the Musgravetown Group with initial focus on Rocky Harbour facies associations to resolve the details and character of glaciogenic and periglacial sedimentation.

DEEP BOREHOLE HEAT EXCHANGERS, AN UNCONVENTIONAL GEOTHERMAL SYSTEM TO OFFSET DIESEL CONSUMPTION IN REMOTE NORTHERN REGIONS OF CANADA

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Deep borehole heat exchangers (dBHE) may be suited to develop geothermal resources of cold climate regions with negligible permeable subsurface. dBHE can potentially offer greater thermal energy output than shallow conventional BHE as temperature increases with depth. Thus, a technological feasibility study was undertaken to assess the annual energy extraction potential with dBHE in northern regions located over crystalline Shield rocks. The community of Kuujjuaq in Nunavik (Canada) was used as a case-study and an example for the remaining remote settlements. Numerical simulations were carried out with FEFLOW, and three scenarios were considered for the initial bottom hole temperature (16ºC, 44ºC and 76ºC). Two kilometre deep coaxial BHE with an inner pipe made of high-density polyethylene was assumed. An anti-freeze solution was used as the heat carrier with an injection temperature of -5ºC. Several flow rate scenarios (1–70 L/s) were simulated and the optimal value found by subtracting the electric energy consumed for pumping to the energy extracted from the subsurface. The annual average energy delivered to the buildings considered the heat pump COP and the energy required to run the compressor. The preliminary results of this assessment suggest that the optimal flow rate considering head loss is 15 L/s. Additionally, 71% increase was observed in the energy extraction between the low and the high subsurface temperature scenarios. A 2-km-depth BHE with a flow rate of 15 L/s and a bottom hole temperature of 16ºC has a thermal output of 61 kW and is capable to annually produce about 537 MWh. The same dBHE installed in a medium with bottom hole temperature of 76ºC can have a capacity of 212 kW and can annually produce 1856 MWh. These results suggest that one single dBHE coupled with a heat pump can provide space heating to 11 to 35 residential dwellings in a low to high subsurface temperature setting. These calculations assumed an annual average heating demand of 71 MWh per dwelling. Thus, a community with 973 homes and a total annual average heating demand of 69 GWh would need about 28 to 88 2-km-depth BHE to fulfill the annual heating needs. In conclusion, this first-order technological assessment suggests that dBHE may be a solution to offset diesel consumption in remote northern communities.

IMPACTS OF THE ARSENIC TRIOXIDE OCCURRENCE ON THE MECHANICAL AND GEOCHEMICAL PROPERTIES OF THE CEMENTED PASTE BACKFILL

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Cemented paste backfill (CPB) technology, a densified mixture of binding material, dewatered tailings, and water, thickens to form a non-settling paste that has to be transported to fill mined cavities. CPB could provide environmental advantages by reducing the reactivity potential of sulphides and the release of pollutants through hydraulic binder stabilisation/solidification. Up to now, few studies have been carried out to examine the feasibility of arsenic fixation within cemented paste backfills.

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A project is under way to manage gold roaster waste containing arsenic trioxide to prevent As leaching into the environment. The main objective of the current research is to assess the impacts of incorporating arsenic trioxide on the mechanical and geochemical properties of the cemented paste backfill. Drained CPB samples were prepared using pure ground silica (Sil-Co-Sil®) mimicking mine tailings, general use (GU) cement, deionized water, and reagent-grade pure As_2O_3 (purity > 99.5%) at different arsenic contents (0, 5, 10, and 15%). The samples were cured for up to 28 days and unconfined compressive strength (UCS) tests were conducted after 7 and 28 days. Moreover, mixtures of GU cement, pure As_2O_3 (0 to 15%), and deionized water with the same proportions of the CPB samples were prepared and mixed up to 28 days. The variations of the pH, oxidation-reduction potential (ORP), and electrical conductivity (EC) of these mixtures were measured, and some samples were collected after filtration for chemical analysis. Results showed that the addition of the pure arsenic trioxide (as a substitution of the pure silica) lead to a substantial decrease of the mechanical strength of the CPB samples. However, this adverse effect was more substantial for the arsenic content of 5%. The strength of the samples did not improve significantly after 7 days of curing, and the samples reached their maximum strength in the initial days. The addition of arsenic lowered the pH of the solutions, and this declining trend was continued during the 28 day time period. The ORP and EC of the arsenic-containing solutions were lower than the mixture with 0% of arsenic. Moreover, the arsenic release rates were significant at the initial mixing times (first 30 minutes) and the maximum concentrations were reached after 7 days.

MICRO-SCALE MAGMA IMMISCIBILITY AND LOCAL RARE EARTH METALS MINERALIZATION WITHIN CRYSTALLINE PRECURSOR INTRUSIONS TO THE STRANGE LAKE DEPOSIT IN NORTHERN QUEBEC-LABRADOR, CANADA

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The Mesoproterozoic Strange Lake (1.24 Ga), one of the richest rare-metal deposits (REE-Zr-Nb) in the World, occurs near the Nekuashu intrusion (2.55 Ga) and intrudes the Pelland intrusion (2.32 Ga) in northern Canada (Quebec and Labrador). These Neoarchean to earliest-Paleoproterozoic intrusions, forming part of a more regionally extensive plutonic 'suite', are composed of hypersolvus hornblendite, gabbro, monzogabbro/monzodiorite, monzonite, syenite/augite-syenite, and tonalite/granodiorite. Detailed petrographic study of the Nekuashu intrusion reveals evidence of micro-magma immiscibility in monzonitic suites significantly enriched in rare earth metals. They are defined here as Fe-rich end-member globules and are divided into two types; (1) Fe-rich globule Type I (FeO + MgO + CaO + TiO_2 + P_2O_5) and (2) Fe-rich globule Type II (FeO + TiO_2 + CaO + P_2O_5 + REE), in which the second type is enriched in REE. The globules are characterized by irregular to rounded-shaped textures (a few mm to cm) with abundant magnetite + ilmenite + augite + orthopyroxene + apatite in the first group and an assemblage of magnetite + ilmenite + apatite in the second type. Apatite, zircon, and allanite-(Ce) with minor Hg-rich chalcopyrite/pyrite are accessory minerals within the first group, however, the second group contains abundant REE-bearing minerals, including bastnäsite-(Ce) and allanite-(Ce) with zircon, titanite, and sulphides (pyrite + sphalerite + barite). The whole cluster of the globules is surrounded by secondary biotite, hornblende, and actinolite attributed to chemical reactions between late stage, residual hydrous melts and the hosting silicate minerals, suggesting separation of a volatile-rich, iron-oxide melt from a silica melt that was responsible in forming the Fe-rich pockets. The liquid immiscibility process and separation of Fe-rich liquids possibly happened during magma fractionation along an evolution trend initiated from a basaltic parental magma toward more evolved granitic compositions. The high REE content of the Fe-rich pockets together with the reaction rims around the assemblage reflect a metasomatized mantle origin and forming from water-enriched pockets of magma which is confirmed by whole-rock geochemical data. This evidence suggests that the Neoarchean to earliest-Paleoproterozoic intrusions may be the product of an earlier, more regionally extensive mantle metasomatic event that triggered an initial REE and incompatible element enrichment, preparing the ground for the subsequent, ultra-high enrichment in the Strange Lake. Although micro-scale liquid immiscibility in the monzonitic members is observed in the area, the overall effect on the whole pluton and its mineralization, and any evidence for large-scale immiscibility at depth remain unclear. Further study is therefore recommended for REE exploration in this region even though the micro-scale still may suggest that immiscibility could occur repetitively in a basal boundary layer.

THE ROLE OF FLUID-ROCK REACTIONS ON GOLD-ENDOWMENT AT THE MELIADINE GOLD DISTRICT, NUNAVUT, CANADA: A SULPHUR ISOTOPE STUDY

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Orogenic gold deposits are the main source of gold in Canada, but these deposits generally form ore zones that are only metres wide, making them difficult exploration targets. As a result, the mining industry needs to develop methods to increase its ability to detect a deposit's footprint. The aim of this project is to complete the $\delta^{34}S$ of gold-associated sulphide minerals in orogenic gold veins, in order to track the evolution of fluids over time and space to test vectors to mineralization. Recent advances in isotope geochemistry provide an opportunity to study the role of fluid-rock reactions for gold concentration by tracing the in situ $\delta^{34}S$ signature of sulphide minerals. Auriferous fluids primarily transport gold in solution as $Au(HS)_2^-$ complexes in the orogenic gold deposits context. As fluids travel through the crust, physicochemical changes such as oxidation can trigger the decomplexation of $Au(HS)_2^-$, resulting in the precipitation of gold and associated sulphides. The $\delta^{34}S$ of these gold-associated sulphides can vary by a magnitude in excess of 10‰, and thus may have considerable application in detection and predictive targeting for exploration. The Meliadine gold district, located in the Rankin Inlet greenstone belt of Nunavut, presents an excellent opportunity to explore chemical controls on sulphide-related gold precipitation in an Archean greenstone belt. Mineralization occurs as native gold associated with sulphides near quartz-ankerite veins in various iron rich metasedimentary host rocks. One field season and preliminary petrography indicate that two distinct mineralization types are recognizable and are associated with at least two sets of crosscutting veins. Type 1 is hosted by alternating chloritic siltstone and banded iron formation (BIF) with arsenopyrite ± (pyrrhotite-pyrite-chalcopyrite-galena), and type 2 is hosted in heavily folded and silicified BIF displaying more abundant pyrrhotite and arsenopyrite in high grade ore zones. Previous work indicates a strong control on the sulphide assemblage and gold grade by the different host rocks. The more iron-rich lithologies (e.g. BIF, iron-rich turbidite) seem to act as buffers for mineralization, induced by the presence of magnetite alteration. By characterizing the hydrothermal events and their associated sulphide paragenesis, further microanalytical techniques including in situ sulphur isotope and trace element chemical composition of sulphides through the paragenetic sequence will provide insight in the mechanism responsible for gold precipitation. We aim to track this fluid rock reaction in time and space using S isotopes.

DISTRIBUTION OF ALTERATION FACIES, DEPOSIT TYPES, METALS, AND CRITICAL MINERALS IN METASOMATIC IRON AND ALKALI-CALCIC (MIAC) MINERAL SYSTEMS

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Metasomatic iron and alkali-calcic (MIAC) mineral systems are hydrothermal systems with regional extents of tens to hundreds of kilometres that are significant but challenging targets for mineral exploration. They can host iron oxide-copper-gold

(IOCG) deposits, and a large variety of critical and precious metal deposits in which Ag, Au, Bi, Co, Cu, Fe, Mo, Ni, P, Pb, REE, U, W, and Zn are the primary commodities or by-products. New research suggests that the diversity of mineral deposits occurring in MIAC systems relates to the evolution of voluminous saline fluid plumes with diverse fluid and metal sources including the leaching of metals from compositionally diverse country rocks. Iron oxides (magnetite and hematite) prevail in many mineralization zones of MIAC systems to form iron-oxide-rich deposit types. However, in some MIAC systems, iron oxides occur in low abundance or are absent from the zones of mineralization. This can result in the formation of iron-oxide-poor to iron-poor mineralization and deposit types. In iron-oxide-poor but iron-rich mineralization zones, iron resides in silicate, sulphides, or carbonate minerals. Conversely in iron-poor mineralization zones, alkali-calcic alteration with variable amounts of quartz and carbonate minerals is associated with metal deposition. A new framework based on alteration facies has been established to characterize the relation between mineralization and alteration in MIAC systems. Alteration facies are defined by systematic sets of mineral assemblages associated in time and space and formed under comparable physicochemical conditions. Facies are labeled using their diagnostic major element associations as well as high and low temperature ranges. Each alteration facies can be related with specific types of mineralization and metal assemblages. Using the alteration facies approach, a predictive model based on alteration mapping and the identification of major corridors of fluid circulation can be developed to guide mineral exploration in each system and define the types of deposits that may be in reach of exploration drilling. Examples from Australia, Canada, China, South America and the United States illustrate the diversity of deposit types possible in MIAC systems and reframe IOCG deposits as one of many deposit types with various major, minor and critical commodities. We recognize two groups of mineral deposits in MIAC systems: (1) metasomatic iron (MI) deposits that are associated with an iron-rich alteration facies, and (2) metasomatic alkali-calcic (MAC) deposits that are associated with iron-poor alteration facies.

THE STUDY OF ELECTRICAL POTENTIAL, REMOTE SENSING, AND PRESERVATION OF BIOSIGNATURES AT SITES OF SERPENTINIZATION (SERP)

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A water-rock reaction known as serpentinization has the potential to support life on other worlds. Detecting life (extinct or extant) at sites of serpentinization requires the ability to find serpentinization sites (active or in-active), and to detect biosignatures. The purpose of SERP was to develop methods to detect subsurface flow of groundwater related to serpentinization, to find sites at surface where these groundwaters emerge as springs, and to identify biosignatures of current life and biomarkers of past life. This study was conducted on Mars analogue sites of serpentinization within the Bay of Islands Ophiolite Complex (BIOC), Newfoundland and Labrador, Canada. The main objectives of SERP were to discover isotopic and organic indicators of microbial life and their preservation in active and inactive springs; to develop, deploy, and validate spectral and remote sensing (RS) methods to detect surface expressions of serpentinization; and to simulate an end-to-end mission to Mars to look for serpentinized springs, map subsurface serpentinized groundwater flow using electrical potential and magnetic geophysical surveys; and to search for signs of microbial life (extinct/extant) in serpentinized springs. In the first year of SERP, we developed RS methods (using satellite and unmanned aerial vehicle (UAV) data) for detecting serpentinite-hosted springs at a training site known for its springs, the Tablelands, in Gros Morne National Park, Newfoundland and Labrador. Subsequently, we applied these methods to locate new potential sites of serpentinite-hosted springs in unexplored canyons of the Tablelands and canyons in a second ultramafic massif known as Blow Me Down. Follow-up work included two field trips, one for conducting an areal survey using a UAV, and a second to ground-truth our satellite and UAV observations. This work led to discovery of a new serpentinite-hosted spring in the Blow Me Down massif. This spring was characterized for its lipid biosignatures, IR spectral characteristics of associated carbonate minerals present, and its magnetic and electrical potential geophysical response. This presentation provides an overview of the SERP research project to date and highlight the geochemistry and lipid biomarkers of the Tablelands and Blow Me Down serpentinite-hosted springs. The methods developed in this study can be applied to searching for serpentinite-hosted springs, and life within these springs, elsewhere on Earth and other planets and moons.

GROUND PENETRATING RADAR METHODOLOGY FOR SITE INVESTIGATION – LESSONS FROM THE FIELD

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Ground penetrating radar (GPR) is a versatile remote sensing method used to study the shallow subsurface. Objects in the subsurface, which are obscured by overburden, can be detected via GPR. This method detects electrical discontinuities by the generation, propagation, reflection, and reception of pulsed high-frequency electromagnetic energy, the results of which are directly related to water saturation, salinity, porosity, and mineralogical variations. Since GPR is non-destructive and non-invasive, it has been applied successfully in numerous disciplines and environments including utility locating, forensics and law enforcement, infrastructure, mining, quarrying, geotechnical, environmental, archaeological, military, agriculture/forestry, and ice/snow. 2-D GPR allows for the detection of objects and their depth, while 3-D GPR goes further and allows for interpretations such as the lateral extent and shape of objects. The use of 3-D visualization software became possible nearly three decades ago and while GPR use has grown significantly in its applicability, 3-D visualization applied to GPR has not been universally adopted or incorporated into forensic sciences. In this presentation, we will review GPR methodology and workflows we have employed in two different studies: (1) a cemetery survey (Lakelands), and (2) investigation of the emergence of sinkholes on karstic terrane (Slade Lake). In our Lakelands study, we have demonstrated a novel workflow method to optimally visualize data in 3-D. At Slade Lake we applied GPR to investigate a potential series of caverns to gain understanding on the interconnectedness of the sinkholes. Lessons learned in the field shaped our methodologies and suggestions for GPR application in future studies, to hopefully set a new standard for future modelling of GPR surveys.

GEOCHEMICAL STUDY, HEALTH RISK ASSESSMENT, AND WATER QUALITY INDICES FOR DRINKING AND IRRIGATION SUITABILITY OF GROUNDWATER OF A COASTAL AQUIFER IN DJEBENIANA REGION, TUNISIA

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The coastal aquifer of the semi-arid Djebeniana Region, located in Southeast Tunisia, North Africa, is increasingly stressed due to groundwater abstraction. Groundwater salinity has increased in the coastal aquifer for several years, causing major concerns with respect to water quality. This study was thus carried out (1) to determine the origin of groundwater mineralization in the shallow aquifer of Djebeniana basin, and (2) to evaluate suitability of groundwater for irrigation and drinking purposes. To this end, 25 groundwater samples were analyzed for major/minor ions, trace metals, nitrate, stable isotopes of the water molecule (δ^2H-δ^{18}O), and stable isotopes of chloride and bromide (δ^{37}Cl, δ^{81}Br). Water suitability for irrigation and drinking purposes was evaluated using water quality indices (WQI) and total hazard indices (THI). The chemical and isotopic data suggest that groundwater mineralization in the shallow coastal aquifer is the product of a tripolar mixture among (1) current recharge, (2) recharge from the deep Miocene aquifer, and (3) seawater intrusion. Na-Cl mineralized waters are observed mainly in the coastal agricultural area, whereas more diluted Ca-SO_4 waters are observed further inland. According to the calculated WQI, six wells located near the coastal fringe present "poor" to "very poor" water quality for drinking purposes and one coastal groundwater sample is characterized by "poor" water quality for irrigation purpose. Moreover, the calculated total hazard indices (THI) related to nitrate, fluoride and strontium for adults and children suggest that 91% and 63% of samples exceed criteria for adults and chil-

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dren, respectively. Nevertheless, the calculated hazard quotients values (HQ) for Cu, Zn, Cr, Pb, Cr, Fe, Cd, and Mn were < 1, suggesting that these trace elements were within an acceptable level of non-carcinogenic health risk. These results allow for proposing recommendations for groundwater management in the coastal area. The methods used for identifying the sources of mineralization are broadly applicable and could be used in other coastal areas.

CAMBRIAN THREE-EYED RADIODONTS WITH FOSSILIZED NEUROANATOMY ILLUMINATE THE ORIGIN OF THE ARTHROPOD HEAD AND SEGMENTATION

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In addition to being among the most iconic and bizarre-looking Cambrian animals, radiodonts are a group that offers key insights into the acquisition of the arthropod body plan by virtue of their phylogenetic divergence prior to all living members of the phylum. Nonetheless, radiodont fossils are rare and often fragmentary, and contentions over their interpretation have hindered resolution of important evolutionary conundrums. We describe over 250 specimens of the hurdiid radiodont *Stanleycaris*, including many exceptionally preserved whole-body specimens, from the Mid-Cambrian Burgess Shale, allowing reconstruction of unprecedentedly fine morphoanatomical details. The trunk region of *Stanleycaris* has up to 17 segments plus two pairs of filiform tail blades. The frontal appendages are composed of 14 podomeres, variously differentiated by their possession of comb-like endites, mono- to trifurcate medial gnathites, and outer spines. The oral plates are tetraradially organized and can be uniquely distinguished by the presence of 28 smooth tridentate plates. In addition to the pair of stalked lateral eyes, the short head unexpectedly bears a large median eye situated behind a preocular sclerite on an anteriorly projecting head lobe. Upon re-evaluation, similar median eyes can be identified in other Cambrian panarthropods, demonstrating a deep evolutionary continuity. Phylogenetic analysis finds *Stanleycaris* in a grade of hurdiids retaining plesiomorphic raptorial appendicular functionality alongside derived adaptations for sweep feeding and large, bilaterally opposed gnathites. We conclude that the latter performed a masticatory function, convergent with jaw-like structures such as mandibles in various panarthropods. *Stanleycaris* provides an extreme example of the evolution of division of labor within the appendage of a stem euarthropod and we suggest that this innovation may have facilitated the functional transition, from raptorial to sweep feeding, at the origin of the hurdiid clade. More broadly, the recognition of dorsal segmentation of the cuticle and possible unganglionated nerve cords provides new insight into the timing of acquisition of these aspects of segmentation, the epitome of the arthropod body plan. The exquisitely preserved brain of *Stanleycaris* is consistent with an innervation of the frontal appendages from the second brain neuromere, reconciling neuroanatomical evidence with external morphology in support of an ancestrally bipartite head and brain for arthropods. We propose that the integration of this bipartite head prior to the acquisition of a suite of segmental characters exclusively in the trunk may help explain its developmental differentiation.

THE YUKON, CANADA: WHERE NORTHERN HYDROGEOLOGY MATTERS MOST

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Climate change is disproportionately impacting the Yukon, which relies on groundwater for domestic use more than any jurisdiction in Canada aside from Prince Edward Island. This oral presentation will report on Yukon Government's efforts to better understand and manage groundwater in the Yukon and will provide potential research partners with an overview of opportunities to conduct foundational hydrogeological research in the territory. Almost the entire population of the Yukon (43,568 as of September 30, 2021) is dependent on groundwater as a potable water supply. Groundwater supplies important industrial (chiefly mining), agricultural, and other undertakings in the Yukon with critical water resources. Groundwater serves essential functions for ecosystems in the Yukon, such as maintaining baseflows, modulating temperatures, influencing water quality, and providing refugia for fish and other aquatic life. Despite the clear and critical importance of groundwater to the Yukon's environmental and economic wellbeing, fundamental hydrogeological information is lacking in the territory. Few aquifers have been mapped, there are limited hydrogeological baseline data, very few hydrogeological research projects have been conducted, and many public drinking water systems do not have source water protection plans or aquifer and wellhead protection plans in place. The Yukon Government has been working to develop a robust groundwater program to strengthen understanding of the territory's groundwater resources. In 2014, the Yukon Government launched the Yukon Water Strategy and Action Plan, which committed the Government to "better understand and manage Yukon's groundwater." The strategy led to the creation of new scientific and technical roles in the territorial Department of Environment. The relatively new groundwater team has significantly enhanced the Yukon Observation Well Network, formalized the Yukon Water Well Registry (a web mapping application that allows users to search for water well records across the territory), initiated a series of aquifer mapping projects in key municipalities, and partnered with various universities and other collaborators on a variety of initiatives to improve stewardship of groundwater in our cold region. Yukon Government recognizes that only through strategic partnership can it continue to broaden and deepen its understanding of groundwater in the Yukon. This presentation seeks to inspire potential research partners to support the generation of fundamental hydrogeological information to strengthen decision-making concerning a vital resource to Yukoners and ecosystems in the Yukon.

REFINING HYDROTHERMAL ALTERATION FOOTPRINTS AT THE HAMMOND REEF GOLD DEPOSIT IN ONTARIO, CANADA, USING HYPERSPECTRAL IMAGING

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Conventional core logging often proves to be a bottleneck in the mineral exploration process and can provide inconsistent data without proper guidance. In the case of disseminated mineralization, subtle alteration is commonly a key characteristic that can be easily overlooked. The use of automated hyperspectral core scanning solutions that can provide high-resolution imaging data with < 1 mm pixel size have shown success in mapping mineralogy and mineral chemistry in various geologic environments, and are investigated here as tools to define vectors to gold mineralization at the Hammond Reef deposit. The Hammond Reef deposit in northwestern Ontario, lies within the western Wabigoon subprovince and is hosted in the tonalitic to gneissic Marmion "batholith". The deposit is primarily controlled by high-strain zones that relate to the regional-scale Marmion deformation zone. Other controls on mineralization are thought to be the presence of mafic dykes, which provide local competency and chemical contrasts with the host tonalite. Disseminated mineralization is associated with a sericite-dominant alteration assemblage. Reserves of 3.3 Moz Au at 0.84 g/t Au, plus additional measured and indicated resources of 2.3 Moz Au at 0.54 g/t Au, highlight the low-grade-high-tonnage nature of the deposit. We present preliminary results from a 12 000 m core scanning program on the Hammond Reef gold deposit, focusing on the variability of the mineral chemistry of white mica, biotite, and chlorite. Measures from the commonly investigated 2200 nm and 2250 nm absorptions are considered in conjunction with conventional analytical methods. Distal sampling to the deposit aims to identify regional metamorphic gradients that could overprint part of the deposit signature. Integration of petrographic and hyperspectral datasets from deposit-scale and regional-scale sampling will develop site-specific metrics for the mineralization within the hydrothermal footprint of the deposit. Understanding the potential use of these metrics may provide additional constraints to improve 3-D geological domaining, vectors towards mineralization and/or ore-sorting metrics.

THE MORWICK G360 FRACTURED ROCK OBSERVATORY (FRO): A BEDROCK BOREHOLE NETWORK TO ADVANCE HYDROGEOLOGIC INSIGHTS, METHOD DEVELOPMENT AND COLLABORATIONS

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This study presents insights from the Morwick G360 Fractured Rock Observatory on the University of Guelph campus in Guelph, Ontario, Canada, built to better understand flow through the regionally important dolostone aquifer and to test new borehole tools and techniques through collaboration. This research station includes a cluster of 9 continuously cored bedrock boreholes (6 vertical, and 3 inclined) in a 75 × 75 m area. The boreholes are drilled to a vertical depth of 73 m where they terminate in the Cabot Head Formation at the base of the aquifer sequence. Each borehole has been well characterized with detailed core logging to capture lithology and fracture information, and extensive borehole testing including a broad suite of borehole geophysical and hydrogeophysical logs, depth-discrete packer and borehole dilution testing as well as FLUTeTM transmissivity profiling. The site is ideal for assessing new technologies and methods with comparison to established techniques. Specifically, we have developed and refined the fibre optic active distributed temperature sensing (A-DTS) method deployed with FLUTeTM liners for quantifying depth discrete flow direction and magnitude without altering the natural flow system. Each borehole has a dedicated fibre optic cable, and the boreholes are connected at the surface with a trenched cable (1751 m total) to allow simultaneous temperature measurements at hundreds of depths in 8 of the 9 boreholes. The A-DTS data demonstrates highly variable flow magnitude and direction through the vertical sequence, with flow occurring primarily in fractures and some dissolution channels. Flow direction based on hydraulic gradient and the A-DTS data demonstrates drastic changes with depth suggesting hydraulic influence of a nearby river and buried bedrock valley. Nuclear magnetic resonance (NMR) logs also provide insight into the proportion of bound and mobile water, that can be interpreted with the other porosity datasets collected at the site. The location on the University of Guelph campus, complex hydrogeological setting in the centre of a municipal wellfield, and the diversity of collected datasets make the FRO an excellent avenue for advancing the science, hands-on education, public outreach, and collaborations to develop new technologies.

THE PROVENANCE OF AVALONIA AND ITS TECTONIC IMPLICATIONS: A CRITICAL REAPPRAISAL

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The late Neoproterozoic–Cambrian interval is characterized by global-scale orogenesis, rapid continental growth, and profound changes in Earth systems. Orogenic activity involved continental collisions spanning more than 100 million years, culminating in Gondwana amalgamation. Avalonia is an example of arc magmatism and accretionary tectonics as subduction zones re-located to Gondwana's periphery in the aftermath of those collisions, and its evolution provides significant constraints for global reconstructions. Comprising late Neoproterozoic (ca. 650–570 Ma) arc-related magmatic and metasedimentary rocks, Avalonia is defined as a composite terrane by its latest Ediacaran–Ordovician overstep sequence; a distinctive, siliciclastic-dominated cover bearing "Acado-Baltic" fauna. This definition implies Neoproterozoic Avalonia may consist of several terranes, and so precise paleomagnetic or provenance determination in one locality need not apply to all. On the basis of detrital zircon and Nd isotopic data, Avalonia and other lithotectonically-related terranes such as Cadomia, have long been thought to have resided along the Amazonian-West African margin of Gondwana between ~650–500 Ma, Avalonia connected to Amazonia, and Cadomia to West Africa. These interpretations have constrained Paleozoic reconstructions; many imply that departure of several peri-Gondwanan terranes led to the early Paleozoic development of the Rheic Ocean whose subsequent demise in the late Paleozoic led to Pangea amalgamation. Since these ideas were proposed, several new lines of evidence have challenged the Amazonian affinity of Avalonia. First, there is evidence that some Avalonian terranes may have been "peri-Baltican" during the Neoproterozoic. Baltica was originally excluded as a potential source for Avalonia because, unlike Amazonia, arc-related Neoproterozoic rocks were not documented. However, subsequent recognition of Ediacaran arc-related sequences in the Timanides of northeastern Baltica invalidates this assumption. Second, detailed paleontological and lithostratigraphic studies have been interpreted to reflect an insular Avalonia, well removed from either Gondwana or Baltica during the Ediacaran and Early Cambrian. Third, recent paleomagnetic data have raised the possibility of an ocean (Clymene Ocean) between Amazonia and West Africa in the late Neoproterozoic, thereby challenging conventional reconstructions that show the "peri-Gondwanan" terranes as a contiguous belt straddling the suture zone between these cratons. In this presentation, we critically re-evaluate the provenance of the so-called "peri-Gondwanan" terranes, the contiguity of the so-called "Avalonian-Cadomian" belt, and the validity of the various plate tectonic models based on the traditional interpretation of these terranes. In addition, we draw attention to critical uncertainties and the challenges that lie ahead.

PHYLLOSILICATES FOR GOLD EXPLORATION

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Gold is mobile through magmatic- and metamorphic-hydrothermal fluids as well as meteoric waters. When dissolved, the precious metal is transported at the ppb level mainly as chlorides and hydrosulphides in hot/acidic and warm/neutral hydrothermal fluids, respectively. In meteoric waters, gold may additionally be transported as thiosulphates, cyanides and other complexes. However, recent research show that up to 10^6 times more gold can be transported in the colloidal form, and that flocculation of colloidal gold is responsible for ultrahigh-grade (bonanza) gold veins. Phyllosilicates are prone to adsorb metals. In addition to structural Si^{4+} and Al^{3+} in tetrahedral layers (T) and $(Mg,Fe)^{2+}$ and Al^{3+} in octahedral layers (O), TOT+C-type phyllosilicates also incorporate cations (C) in loosely bonded interlayer space. For example, K-micas have interlayer K^+ bonding the TOT stacks together along their cleavage planes. This interlayer K^+ is 'exchangeable' and easily displaced by other metals (e.g. Au). Given that K^+ and Au^+ have very similar ionic radii (1.52 Å and 1.51 Å in 6-fold coordination), Au^+ is expected to substitute for K^+. Phyllosilicates also have other negatively charged surfaces where exchangeable metals are adsorbed. Lithium isotopes were used to study the behaviour of gold in phyllosilicates because Li is fluid-mobile, it is very compatible in phyllosilicates, and it possesses two stable isotopes that fractionate primarily during fluid-rock reactions. Any fluid-mediated adsorption of Au^+ in phyllosilicates should thus in principle also affect their Li isotopic compositions (δ^7Li). The major/trace element and Li isotopic composition of hydrothermal alteration was measured at the Kirkland Lake, Hemlo, and Red Lake world-class Au deposits, Ontario. As predicted, good correlations were found between δ^7Li and gold concentrations [Au], suggesting that they were controlled by the same process. Furthermore, δ^7Li and [Au] correlated over distance, when approaching the ore, suggest that phyllosilicates can effectively be used to find Au mineralization. Given that measuring Li isotopes is costly and lengthy, a simpler method was developed to trace Au using phyllosilicates. The method was tested at the Hardrock gold deposit, where primary Au was remobilized as a colloid in groundwater downstream along the hydrologic gradient, and eventually trapped into chlorite.

IN SITU SENSOR-BASED MONITORING STRATEGIES FOR BIOGEOCHEMICAL REACTIONS IN CIRCUMNEUTRAL Au TAILINGS ENVIRONMENTS: MONITORING THE REMEDIATION OF THE MONTAGUE HISTORICAL MINE SITE, NOVA SCOTIA

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Mining waste has significant environmental impacts, which require ongoing monitoring and management of wastewater, waste rock, and tailings, long after a site is closed. The biogeochemical reactions between water and tailings, which contribute to the long-term physicochemical properties of a water body, are generally well-characterized. These reactions are typically carried out by a consortium of microbes. Existing approaches to characterize site chemistry and evaluate microbial activity

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normally involve a combined effort of geochemical and biological field sampling efforts, with significant lab-based analysis using mass spectrometry and culturing techniques. However, the recent advances in sensor-based ecology and geophysical studies have created significant opportunities for exploring the use of electrodes as sensors to monitor in situ biogeochemical activity. Specifically, time series analysis of aperiodic signal components from open-circuit potential environmental time series has been linked to specific geochemical pathways. In situ characterization of these pathways would dramatically improve the success of remediation efforts by reducing the time required to evaluate the effectiveness of a particular treatment, as well as provide significantly better spatial- and temporal-resolution than can be achieved by periodic or annual site visits. This sensitivity paves the way for integrating near-surface geophysical surveys targeting subsurface water, and techniques for detection of quality and chemical characteristics in situ. Here, we will use open-circuit potential measurements from a suite of sensors, including ion-selective electrodes, conductivity and pH, to study the remediation of circumneutral gold tailings. Circumneutral mine waste environments are dominated by carbonate minerals, rather than sulphide mineral ores. These tailings, and the water that saturates them, have high concentrations of arsenic and mercury, which make them a perpetual environmental risk to the surrounding wetland. Using a series of lab-based microcosms to carefully constrain the sensor response to a biogeochemical reaction following a known geochemical pathway, we will develop a framework for evaluating environmentally significant biogeochemical reactions in both pristine and contaminated groundwater and saturated sediment environments. These experiments support the development of new, in-situ methods for long-term management of contaminated sites, which require less in-person attention and provide better data quality to managers and regulators.

SUPERCONTINENTS, OROGENIC PROCESSES AND MAGMATISM: A CELEBRATION OF THE CAREER OF BRENDAN MURPHY

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Brendan Murphy needs no introduction to the earth science community of Canada and is a household name to much of the community worldwide. Over the past four decades, he has pioneered numerous major advances in the geosciences and has used the field geology of Atlantic Canada, Mexico, Ireland, the UK, Spain and elsewhere to advance and test global tectonic models that have stimulated the earth science community around the world. Brendan cut his teeth on the Avalon terrane of mainland Nova Scotia and the geochemistry and tectonic setting of its igneous rocks, and went on to use the geologic history of Avalonia to advance a host of innovative models. An early convert to the supercontinent cycle, he used the Avalonian-Cadomian belt to introduce the notion of peripheral and interior orogens and their link to supercontinent amalgamation and breakup, and the concepts of introversion and extroversion as end-member processes of supercontinent assembly. He also spotlighted appinite and lamprophyre intrusions as mantle windows and ironstone as a record of coastal upwelling, and pioneered the use of isotope geochemistry as keys to the evolution of the Iapetus and Rheic oceans, and windows to the interconnection of mantle processes and the supercontinent cycle. Always a field geologist at heart, Brendan has made fundamental contributions to our understanding of orogenic processes, igneous geochemistry, the evolution of oceans, mantle dynamics and the causes and consequences of the supercontinent cycle. His body of research is extraordinary, his influence has been global and his legacy is immense. He has also championed the cause of geology at every conceivable level, as mentor, editor, leader, promoter and spokesman. But most important of all, the unbounded enthusiasm, limitless generosity, and honest congeniality he has shown throughout his professional career to countless colleagues and generations of students have been an inspiration to all who have crossed his path.

IGCP SEDIMENTARY AND PALEONTOLOGICAL PROJECTS: 50 YEARS OF EVOLUTION FROM "STRATIGRAPHIC CORRELATION" TO "DEEP-TIME GLOBAL CHANGE", WITH A PERSPECTIVE FOR THE FUTURE

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IGCP was established during the International Geological Congress in Montreal in 1972, and from its inception was instrumental in promoting East-West dialogue by researchers on both sides of the "Iron Curtain" that later extended to North-South and South-South dialogue among geoscientists worldwide. The word "Correlation" in the original name of the program emphasized the importance of trans-national stratigraphic correlation, a concept and mission that meshed well with the designation of the first Global Stratigraphic Section and Point (GSSP) established at the base of the Devonian System in 1972, and this produced ongoing connections between IGCP and the IUGS International Commission on Stratigraphy that are substantially enhancing the geologic timescale. An example of this synergy can be seen in the 2004 ratification of the Ediacaran Period, the first new period added to the geologic timescale in more than a century, that resulted from fruitful interactions between the IUGS-ICS Neoproterozoic Subcommission and IGCP Project 320: Neoproterozoic Events and Resources. The Ediacaran Period was also the first pre-Cambrian geologic period ever defined, and thus part of an increasing recognition that deep-time global change in the cryosphere (e.g. 'Snowball' glaciations), hydrosphere (as reflected in seal-level changes and secular changes in the isotopic composition of seawater), and atmosphere (oxygenation events) were important in recognition of globally correlatable stratigraphic events. At the same time, studies of mass extinction events that punctuated the Phanerozoic showed the effects of global change in triggering profound collapses in the biosphere. Over the past decade, IGCP global change projects have increasingly added new dimensions to their outreach and impact by providing deep-time information relevant to the possible magnitude, timeframe, and geoscience linkages for present and future global change. Examples include sea level change (IGCP 588 – Preparing for Coastal Change; IGCP 639 – Sea-level Change from Minutes to Millennia), ocean anoxia (IGCP – 655 Toarcian Oceanic Anoxic Event), the relationship between global change and biotic crises (IGCP 630 – Permian–Triassic Climatic and Environmental Extremes and Biotic Responses; IGCP 632 – Continental Crises of the Jurassic), and discussion of a proposed GSSP for a formally recognized Anthropocene (IGCP 732). Stratigraphic correlation continues to provide a fundamental contribution to the geologic timescale that links much of geology, and increasing recognition that many stratigraphic events in deep time reflect the response of the biosphere to coeval global change, and also provides an opportunity to shed light on present and future challenges facing the Earth and society.

IDENTIFYING SOURCES OF MERCURY IN PERUVIAN AMAZON AQUATIC SYSTEMS USING MERCURY STABLE ISOTOPES

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Mercury (Hg) is a toxic global pollutant that affects both humans and wildlife, especially those dependent on aquatic food webs. In many developing parts of the world, Hg is used to extract gold from sediment and ore during artisanal and small-scale gold mining (ASGM). ASGM is currently estimated to be the largest primary source

of Hg to the atmosphere and to freshwaters. In the Amazon ASGM is often the source of downstream contamination in many ecosystems, but this can be complicated by other potential sources of Hg such as increased soil erosion from land-use change (e.g. deforestation) since soils are a large reservoir for Hg. Mercury stable isotope geochemistry is a particularly powerful tool for source differentiation in regions where ASGM is prevalent due to differences in the isotopic compositions of ASGM-derived Hg versus Hg from soils and erosion. For example, elevated Hg in Amapá, Brazil, was consistent with mobilization of Hg from soils, whereas elevated Hg downstream of Portovelo, Ecuador, was from ASGM Hg. Understanding the source of elevated Hg in ecosystems is key to implementing effective mitigation strategies. In this study, we assessed the sources of Hg in aquatic ecosystems in Madre de Dios (MDD), Peru, a region with prevalent ASGM and local populations affected by Hg contamination. In addition to Hg use during ASGM, the ASGM in this region is also associated with deforestation and land disturbance. Aquatic sediment samples collected upstream and downstream of ASGM were analyzed for Hg and Hg isotopes along with soil in forested and deforested areas along the MDD river system. Initial results show that ASGM signatures are found near some mining areas, but that sources of Hg are more mixed farther downstream and near other mining areas. Results will be discussed in the context of locations and types of ASGM operations as part of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) International Geoscience Program (IGCP) project objective to better understand how Hg pollution from ASGM is impacting Amazonian ecosystems.

CHARACTERIZING CA. 2.5 GA MAGMATISM IN THE NONACHO LAKE AREA OF THE SOUTHWESTERN RAE CRATON, NORTHWEST TERRITORIES, CANADA

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There is growing evidence for widespread and voluminous ca. 2.5 Ga magmatism in the Rae craton, but the temporal extent and tectonic setting(s) of this magmatism are uncertain. In the Nonacho Lake area of the southwestern Rae craton, we have identified a relatively complete record of ca. 2.54 to 2.43 Ga (meta)granitoid rocks. Based on field relationships, geochronology and geochemistry, these rocks have been separated into two preliminary suites. The first suite is an older group of granitoid rocks that are metaluminous, calc-alkaline and range from 52 to 70 wt.% SiO_2. This suite is characterized by moderate HREE depletion (La_N/Yb_N = 10–40) and consistently chondritic initial εNd values. The second suite comprises weakly peraluminous leucogranite and local leucotonalite, both with SiO_2 > 70 wt.%. These rocks are characterized by strong HREE depletion (La_N/Yb_N = 50–260) and initial εNd values of 0 to -5. Apart from the leucotonalite, both suites are distinct from Archean TTG (tonalite-trondhjemite-granodiorite) in that they are potassic (K_2O/Na_2O = 0.6–2.4) rather than sodic at SiO_2 contents > 60 wt.%. One possible explanation for these observations is that the first suite of rocks was generated in a continental arc setting, whereas the second suite of rocks is crustal melt produced during or after orogenic thickening. However, the consistently chondritic Nd isotope composition of the first suite is inconsistent with the mixing and assimilation processes that characterize continental arc magmatism. To test this model, further geochronology and isotope tracer work is being conducted, along with petrochronology of partially melted metasedimentary and metaigneous rocks that may be coeval with the two granitoid suites.

FROM CONTAMINANT TO COMMODITY: SELENIUM REMEDIATION, RECOVERY AND REUSE

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Selenium (Se), while an essential nutrient for many life forms, is a serious environmental concern at elevated concentrations. Se contamination poses a significant threat to wildlife in aquatic environments due to its mobility, and ability to bioaccumulate and magnify across the trophic levels, and occurs because of industrial anthropogenic activities, including mining (coal, copper, uranium), metal refining, power generation, and agriculture. Environmental regulations continue to be reviewed and developed for Se across North America, and existing industrial projects have been subject to historically large environmental fines due to Se release into the environment. Furthermore, proposed projects of considerable economic value have been rejected over Se-related challenges. Thus, the ability to manage and treat Se has become essential to several critical industries across North America. While full-scale Se treatment has been developed, each treatment method has inherent strengths and weaknesses, and the treatment of Se in complex industrial water remains challenging. Additionally, current Se treatment processes invariably result in Se-laden treatment residuals, such as biogenic sludge or concentrated brines, which are often sent to landfills or sequestered underground via deep-well injection. The use of sequestration-based strategies for residual material management may pose a potential long-term environmental liability. While Se is an environmental contaminant in many industrial operations, it is also a commodity element in finite supply with wide-ranging applications in electronics, metallurgy, glass production, and chemicals and pigments. As a result, environmentally sustainable industrial waste management and opportunities to recover Se for reuse are strategic interests towards a circular Se economy, in addition to minimizing environmental liability on industrial sites. This work first reviews the conventional supply of Se, as well as its current and emerging commercial uses. Next, key conventional and emerging technologies developed to remove Se from industrial (waste)waters, and their resultant Se-laden residuals, are discussed. Finally, promising methods to recover Se in commercially useful form from treatment residuals towards a circular Se economy are identified and evaluated.

PARTNERING FOR STUDENT SUCCESS: HOW ACADEMIC DEPARTMENTS AND PROFESSIONAL GEOSCIENCE REGULATORS CAN WORK TOGETHER TO PREPARE STUDENTS FOR CAREERS

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The Earth Sciences represent a broad suite of disciplines that continue to evolve and grow. Students need information about the scope of the Earth Sciences to select their preferred area of study and to plan their careers. This includes information on the disciplinary scope of, and processes for, licensure as a professional geoscientist within geology, environmental geoscience or geophysics. A study was conducted to explore best practices for managing the communications between academic Earth Science departments and the provincial/territorial professional geoscience regulatory bodies. Data were gathered using written surveys of Canadian Earth Science department heads, departmental contacts for regulators, senior regulator personnel, and the regulator contacts for departments. Departmental and regulator contacts also participated in 1:1 appreciative inquiry interviews. The findings indicate that more regular and formal contact helps support students better. Professional geoscience licensure uses a syllabus model where the academic background of applicants is assessed on an individual basis against an approved suite of courses. This means individual students need to be well-informed partners in a three-way communication structure, with departments and regulators responsible for providing students with the information they need. When choosing a program, students need to know about geoscience licensure and whether program graduation requirements are aligned to the licensure requirements. Students in diverse programs need information early on to be able to decide whether to align their studies to the scope and requirements of geoscience licensure, or if their interests are in the broader Earth sciences. Students benefit from clear information on whether particular courses in their chosen university program are acceptable to regulators. The departmental role of being the regulator contact is a key service position in a department to ensure continuity of information to students, with faculty serving in some departments, and staff in others. Departments with faculty who participate in the self-regulation of the geoscience profession by serving on regulatory committees report greater student and faculty knowledge of licensure requirements and greater student success. Departments with supportive faculty and university administrations report greater resources to support students. An accompanying business meeting at the conference will give departmental participants an opportunity to meet departmental contact people, program advisors and department heads, and to plan out better communication practices in their own departments.

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INTEGRATION OF MINERAL AND FLUID PARAGENESIS WITH THE FIRST COMPARISON OF IN SITU Rb/Sr AND IN SITU Ar/Ar GEOCHRONOLOGY OF MICAS IN THE BRAZIL LAKE PEGMATITE AND EAST KEMPTVILLE SN-GRIESEN: A NEW APPROACH FOR INVESTIGATING THERMAL AND FLUID EVOLUTION IN CRITICAL MINERAL DEPOSITS OF SOUTHERN NOVA SCOTIA

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Devonian granite-hosted ore systems (~390–375 Ma) in southern Nova Scotia have complex thermal and fluid histories, including a post-magmatic regional tectonothermal event that disturbed geochronometers at ca. 315 Ma. As such, reconstructing the geological processes leading to mineralization and alteration events in these systems is challenging, and requires high spatial resolution dating methods. Geochronologic mapping of age domains within minerals with multiple in situ approaches can potentially be used to distinguish intra-grain age patterns reflecting thermal diffusion, open-system behaviour or recrystallization events. In this study, we compare in situ $^{40}Ar/^{39}Ar$ age mapping of micas with newly developed in situ Rb/Sr age mapping of the same or adjacent grains to characterize the tectono-thermal evolution of mica in two mineralized systems, the Brazil Lake lithium-cesium-tantalum pegmatite and the East Kemptville tin greisen complex, Yarmouth County, Nova Scotia. Preliminary petrography of the Brazil Lake pegmatite has revealed six mica textures that may relate to distinct mineralization events. Mica chemistry in the pegmatite shows variations in Ti, Rb, and Mn content between textural groups. The observed textural and chemical variations will be explored with in situ Rb/Sr via tandem mass spectrometry and in situ Ar/Ar geochronology, two thermochronometers with different closure temperature conditions, to reconstruct mica mineralization and alteration events during the emplacement and alteration of the Brazil Lake pegmatite. These geochronological data will be reconciled with fluid inclusion systematics to resolve the nature of mineralizing or post-mineralization fluids. Major contributions from the ongoing work will be to (1) provide insight into the use of in situ Rb/Sr geochronology, an emerging method that makes use of state-of-the-art tandem mass spectrometers separated by a reaction cell; (2) inform critical mineral exploration and mining in the Canadian Appalachians; and (3) produce a framework for interpreting mica geochronology in systems with complex thermal histories.

CATASTROPHIC DRAINAGE FROM THE NORTHWESTERN OUTLET OF GLACIAL LAKE AGASSIZ DURING THE YOUNGER DRYAS

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Catastrophic meltwater drainage from glacial Lake Agassiz has been hypothesized as a trigger for large-scale ocean circulation change initiating the Younger Dryas cold reversal. Here we quantify the flood discharge that formed the northwestern outlet of Lake Agassiz using a one-dimensional step-backwater model and a zero-dimension gradual-incision model. Applying these two independent models, we estimate a peak discharge range of 1.8–2.5 × 10^6 m^3 s^{-1} and a flood volume of ~21,000 km^3. Such a discharge can only be derived from Lake Agassiz rather than one of the two smaller regional glacial lakes, Churchill or Meadow. When coupled with existing ice margin chronologies, these results demonstrate that the northwestern outlet of Lake Agassiz provides a viable link for catastrophic meltwater to drain to the Arctic Ocean over a 6–9 month period during the Younger Dryas, though it is unclear whether this was near its beginning.

GLACIAL EROSION: CONTROLS AND GLOBAL DISTRIBUTION

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Glacial erosion has often been parameterized as proportional to glacier sliding velocity, while the role played by local geology, hydrology and climate remain largely unquantified. As a result, our understanding of the links between global climate, tectonics and glacial erosion is limited. To address this shortcoming, we present a comprehensive synthesis of previously published Quaternary glacial erosion rates from six different measurement techniques integrated over 10^{-2} to 10^6 years: (i) instrumental measurements beneath active glaciers, (ii) sediment fluxes derived from meltwater streams or (iii) ice-marginal deposits, (iv) terrestrial cosmogenic nuclide dating (TCN), (v) luminescence thermochronometry, and (vi) relief generation of chronologically constrained surfaces. Our synthesis includes 1065 empirical data points and 465 erosion rates from ice sheets, ice caps, and topographically confined glaciers that range over six orders of magnitude, between 10^{-4} and 100 mm yr^{-1}. Using a filtered dataset of contemporary erosion rates, we apply machine learning tools, using available environmental, glaciological, and geological datasets to assess the dominant controls on subgroups of nominal data categories. On a global scale, while glacial sliding velocity is an important control, we also discover equally strong or stronger correlations between other glaciological, environmental, and lithological parameters and glacial erosion rate, some of which have not been previously documented.

A REVIEW OF EARTH SCIENCE OUTREACH AND EDUCATION IN CANADA

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At the annual meeting of the Geological Association of Canada in Yellowknife in 2007, a group of more than thirty people participated in a session and two-day workshop that reviewed the state of Earth Science outreach in Canada. This ambitious program addressed better integration of geoscience outreach and education in Canada and sought to develop a framework for activity in geoscience outreach and education over the ensuing decade. A report was published in Geoscience Canada in 2007 (https://journals.lib.unb.ca/index.php/GC/article/view/10235/10618). The following year 2008 was designated as the International Year of Planet Earth (IYPE). In Canada, IYPE was a key opportunity which saw the publication and development of many geoscience outreach and education products over the ensuing six years. Now, more than a decade later, we review the results and plans outlined in the report and evaluate the impact of efforts made to improve the scope and reach of geoscience outreach from 2007 to the present. We examine the three major questions posed in the 2007 workshop. Have we increased the representation of Earth science in school curricula? Have we filled the gaps in Earth Science outreach products and services? Have we reorganized Earth science outreach so that we have been able to produce more funded and integrated outreach in Canada? There have been notable successes since 2007, but problems of organization and funding remain. Looking to the future, we will consider three factors integral to the present and future outreach and communication landscape in Canada: 1, funding, both to do and evaluate outreach; 2, technological advances; and 3, relevant developments in the field of science communication.

INFLUENCE OF SUBMARINE CHANNEL SINUOSITY ON GRAIN-SIZE SORTING OF CHANNEL AND LEVEE DEPOSITS

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Turbidity currents are one of the most important mechanisms for dispersal of sand in the deep marine environment. Spatial trends in grain size distribution within submarine fan deposits are controlled by turbidity current flow properties. Previous studies have focused on the relationship between fan deposits, sediment grain size, and suspension cloud concentration of parent flows. However, the effects of submarine channel elements, such as sinuosity, on turbidity current flow properties and on the characteristics of fan deposits remains understudied. This work uses an experimental approach to understand the influence of varying channel sinuosity on grain size distribution of levees and channel fill. Here, we present results from flume experiments conducted at the Queen's University Coastal Engineering Laboratory. Four submarine channels were built in a 4 m x 4 m x 1 m basin with sinuosity values of 1.0 (straight), 1.15 (low), 1.25 (medium) and 1.35 (high). Flow discharge, sediment concentration, and basin gradient were held constant. Turbidity currents consisted of two distinct sediment types: plastic melamine as a sand/coarse sediment proxy and ground walnut shell as a clay/fine sediment proxy. Samples were collected from channel fill and levee deposits for grain size analysis. An underwater laser scanner was used to obtain topographic scans of channels before and after each experiment. Preliminary results show that remixing of suspended sediments as turbidity currents move through channel bends favours transportation of fine-grained sediments down the channel. Coarse sediment is relatively less affected by this remixing and is deposited at bends due to reduction in flow velocity. As sinuosity increases, this trend becomes more pronounced. At high channel sinuosity, grain size analysis shows that fine-grained sediment almost entirely dominates deposits at distal parts of the channel as coarse grains are trapped at channel bends. The ratio of fine to coarse sediment at distal channel areas increases with increasing sinuosity. Laterally across channel bends (inner levee, channel fill and outer levee), inner levees appear to be relatively sediment starved, while coarse sediment dominates channel fill with the proportion of coarse sediment within the channel increasing from inner to outer banks. Turbidity currents overtop channel walls as they negotiate bends and deposit sediment overbank primarily in outer levees, which fine distally and become more pronounced as sinuosity increases. These early results suggest that increasing channel sinuosity favors turbidity current bypass of fine sediment at channel bends which is likely to result in finer and better sorted fan deposits.

THE USE OF SERPENTINIZED ULTRAMAFIC ROCKS OF THE BAIE VERTE OCEANIC TRACT (BVOT) IN NEWFOUNDLAND TO SEQUESTER AND MINERALIZE ATMOSPHERIC CO_2

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The world is constantly looking for solutions to the ever-growing climate crisis. Researchers have unanimously assented to the need for CO_2 sequestration as an effective way to reduce atmospheric CO_2 concentration and, consequently, mitigate climate change effects. This study focused on using highly weathered ultramafic rocks to trap atmospheric CO_2 and potentially use it to mineralize carbonate. Although studies have shown how fresh ultramafic rocks can sequester CO_2, the already-serpentinized ultramafic rocks of Baie Verte, Newfoundland, in their late stage of metamorphism, have not been studied for their CO_2 sequestration or mineralization potentials. Serpentinized rocks from the Baie Verte Oceanic Tract (BVOT), containing peridotite mostly with composition ranging from serpentinized mantle harzburgite to dunite, were crushed into two sample groups of distinct grain sizes, each of which was reacted with two different water types: deionized (DI) water and magnesium-rich water, and a known concentration of CO_2 in the LiCor flux chamber and CO_2 gas analyzer for four hours. Water-only experiments were also conducted in the same manner for the two types of water. After the 4-hour experiments, observations were made for the change in concentration of CO_2 in the system, changes in dissolved ions (Mg^{2+}) concentration, and change in total inorganic carbon (TIC). Results showed that CO_2 concentration in the system decreased in all experiments (water-rock reactions), with the most significant rate ($1.69 \times 10^{-7} \pm 1.40 \times 10^{-8}$ mol/minute) found in the Mg-rich water plus crushed rock (larger grain size) experiment. TIC, on the other hand, increased throughout the experiments, with the largest increase found in the DI water plus rocks with smaller grain size experiment, while the lowest increase was observed in the DI water-only experiment. Most of the experiments resulted in the dissolution of magnesium ions, with the highest rate of dissolution recorded in the Mg-rich water plus large grain-sized rocks experiment, while the least was from the DI water-only experiment. The change in CO_2 concentration results suggests that serpentinized ultramafic rocks in BVOT could sequester CO_2, while the TIC and dissolved ion analyses showed that the rocks could convert the sequestered CO_2 into more stable carbonates. This study can be taken further to study the stable isotope systematics of the potential carbonates that will form from rock-water reactions to ascertain the source of the sequestered CO_2.

BRITISH COLUMBIA'S GEOSCIENCE COMMUNICATION LANDSCAPE: SCIENCE COMMUNICATION MODELS IN PRACTICE

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With BC's wide range of museums, outreach programs, online resources, heritage sites, geotours, and more, geoscience communication practitioners (i.e. those involved in geoscience education, outreach, and communication) are well-positioned to create lasting social impact. Here we examine geoscience communication in BC through the lens of three science communication models (deficit, dialogue, participatory). The deficit model is driven by a perception that the public needs knowledge from scientists, while the dialogue model encourages a two-way dialogue between scientists and their audiences. The participatory model acknowledges the contributions of both the public and scientists and encourages the co-production of knowledge. By analyzing how practitioners communicate in light of these models, we can 1) characterize the forms of communication most commonly used; 2) provide a database from which to build on, identify gaps, and compare practitioners' goals with current practice; and 3) potentially propose new models for practice which are informed by theory and/or inform changes in practice to better meet goals. As practitioners engage with the public, examining how geoscience communication in practice compares with communication theories will provide insights to help guide future endeavours. We examine the websites of geoscience communication practitioners in BC and qualitatively code aspects of content related to their objectives and activities. A coding format of key terms and phrases related to each communication model, was applied to make it applicable to BC. In addition, interviews were conducted with several practitioners to verify the accuracy of our approach and identify inconsistencies between the coded data and practitioner goals. As part of the data analysis, the following questions were proposed. What science communication models are used when communicating with select target audiences? Do practitioners' mission statement objectives align with their activities? Is the messaging used reflective of practitioners' actual intentions? These and other key questions will be explored. Although deficit-style activities are most prevalent for general public audiences, dialogue-style activities (primarily hands-on experiments) are prominent when engaging with the K–12 education system, while participatory activities are scarce. When analyzing the stated objectives of activities for all target audiences, deficit objectives prevail over dialogue and participatory objectives. Preliminary results suggest that the notion of transferring knowledge is prominent in how and why we engage. Future research will guide the development of practices and activities which have been shown by science communication researchers to support increased engagement with audiences and support reaching practitioner goals.

GEOSCIENCE PROFESSIONAL DEVELOPMENT WORKSHOPS IN SASKATCHEWAN: A CASE STUDY WITH A FOCUS ON EVALUATION

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During a Mitacs internship with Mining Matters, a case study offering seven geoscience professional development (PD) workshops and a two-stage evaluation/

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engagement process with Saskatchewan educators was conducted. Geoscience PD opportunities across Canada have been championed by organizations such as EdGeo, Mining Matters, and MineralsEd. However, studies of attitudes towards geoscience education and comprehensive evaluations on the effectiveness of PDs in Canada are scarce. This research aimed to determine 1) educators' preparedness for and attitudes towards teaching geoscience; 2) the accessibility of geoscience resources; and 3) the value of guided geoscience PDs. Creating a platform where educators can share their insights will inform the geoscience education community's actions. Educators are a major contributor to students' success in society, and by supporting them, we are encouraging a cohort of young geo-literate citizens. Weaving Indigenous Ways of Knowing with geoscience was a focus of these workshops to highlight their commonalities and promote diversified perspectives. Relevant lesson plans selected from the Saskatchewan Mining Association's (SMA) "Mining Inquiry" and Mining Matters' "Deeper and Deeper" ensured that engaging materials were included in the workshop. Mining Matters engaged an Indigenous educator to modify geoscience lessons to include Cree references and relevant stories. In addition, a team of education experts and Indigenous elders collaborated to highlight Indigenous stories and knowledge while making connections to SMA's geoscience education lesson plans. Pre- and post-workshop surveys aimed to understand changes in perception/attitude, curiosity, content knowledge, and confidence surrounding geoscience education. Subsequently, focus group discussions expanded on these surveys by encouraging dialogue on the case study's overarching research goals. Interviews with education consultants were also conducted to better understand the process of creating relevant and engaging geoscience material. Preliminary research from pre-workshop surveys suggests that educators are unaware of and do not have access to geoscience resources to supplement classroom learning and do not feel confident teaching geoscience subjects. In classroom settings, textbooks were the most commonly used resource to teach geoscience. Educators also noted a lack of confidence surrounding Indigenous perspectives in geoscience and sought additional resources on this topic. Post-workshop survey results identified increased educator confidence, awareness of resources, and knowledge of Saskatchewan's mineral resources. Educators' direct feedback identified virtual mine tours, hands-on activities, and guest speakers featuring non-industry geoscientists as desirable future resources for geoscience education. Continued research will use these results to guide the actions of a second Mitacs internship focusing on youth geoscience workshops in Saskatchewan.

QUANTIFYING VARIABLE STRESS STATES IN METAMORPHIC ROCKS USING SUBGRAIN PIEZOMETRY

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The magnitude of tectonic stresses supported by continental crust range from 10s to 100s of MPa and are intrinsically linked to the metamorphic conditions (e.g. pressure, temperature, aH_2O) of the crust. Consequently, it is expected that the effective stress state of dynamically crystallizing crust will evolve throughout a rock's metamorphic history (i.e. during burial, heating, exhumation, and cooling). While the mineral assemblage and chemistry of a metamorphic rock can be used to determine its metamorphic history, quantifying the attendant stress imparted on a rock has been a more difficult challenge. Grain size piezometry is one technique that can be used to determine the magnitude of stress attained during the steady-state equilibrium between grain-size reduction and grain annealing or growth by diffusion. However, mineral microstructures in natural materials are often overprinted several times before reaching this equilibrium state, leaving an incomplete record of what may be a longer dynamic process with evolving stress states. Another major limitation of using grain size as a measure of stress is that it requires monominerallic rocks, which are themselves unsuitable for constraining the chemically derived metamorphic histories. A recently developed subgrain-size piezometer that was calibrated for electron backscattered diffraction (EBSD) data has been shown to reach steady-state deformation with less total strain, potentially record transient stresses not detected by traditional grain boundary piezometry and critically can be applied to most natural (polymineralic) lithologies. Our study is the first to attempt to quantify variable stress states in metamorphic rocks using this subgrain piezometer. To assess the variability of stress states recorded within an individual sample, we applied the subgrain piezometer to upper amphibolite-facies mylonitic schist from the Great Slave Lake shear zone in NWT that record a history of Barrovian metamorphism followed by ductile shear. Preliminary results indicate quartz subgrains within a single domain can record differences of up to 18 MPa. The cause of this variability is hypothesized to be due to the partitioning of strain in domains near more competent porphyroclasts, allowing the preservation of quartz subgrains in strain shadows that formed at higher metamorphic temperatures where the supporting stress was lower. Future research will focus on applying subgrain piezometry to feldspars and amphiboles with the aim of identifying how stress is partitioned between different phases of a polymineralic crust and to then link these stresses to the crust's metamorphic evolution using phase equilibria and thermobarometry.

MODELLING THE IMPACT OF DEEP, HYDRAULICALLY-ACTIVE FRACTURES IN POST-GLACIAL MARINE CLAY HILLSLOPES: IMPLICATIONS FOR GROUNDWATER FLOW SYSTEMS AND SLOPE STABILITY

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Groundwater flow plays an important role in regulating slope stability in the post-glacial marine clay deposits in Quebec (commonly referred to as marine clays). Because these deposits underlie most of the population and infrastructure of the province of Quebec, there is a practical interest in improving our understanding of the groundwater flow systems within them. Previous studies of slope stability in marine clay deposits assume simple 1-D or 2-D groundwater flow systems in a largely homogeneous medium. These conceptual models, developed in the late 1970s, have led to the common assumption that these clay deposits are intact below a fractured crust, which usually extends to depths of 3 to 5 m. However, recent work has shown that hydraulically active fractures can be present to depths of at least 15 m. This work uses parametric numerical simulations to explore the impact that deep, hydraulically active fractures could have on local hydrogeology and slope stability. The hydrological model 'Hydrogeosphere' was used to simulate the pore pressure distributions in slopes with discrete fractures, which were subsequently input into the slope stability model Slope/W. The model domain was composed of a 3 m fractured crust overlying a 36 m-thick clay formation which rests on a layer of till. The simulation scenarios considered different thicknesses of the underlying till unit, and different fracture apertures, depths, and spacing. In addition, for each scenario, two slope geometries were considered: one where downward flow was present in the slope face, and another where upward flow was present. Simulations with fractures are then compared to simulations without fractures and field data. The fracture scenarios better represent the hydraulic head variations observed in the field. Simulations without fractures were not able to recreate the sudden, large increases in pore pressure observed at depths 2–5 m below the extent of the fractured crust. These results suggest that deep, hydraulically active fractures play a significant role in local groundwater flow systems in marine clays deposits, and may eventually contribute to a better understanding of the mechanisms that trigger landslides.

QUANTIFYING EXCEEDANCES OF CHRONIC AND ACUTE CHLORIDE CONCENTRATION GUIDELINES WITH HIGH-FREQUENCY DATA IN NIAGARA ESCARPMENT STREAMS

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Chloride from winter road deicers has become ubiquitous in surface and shallow groundwaters in urban and urbanizing humid continental regions such as southern Ontario. Over-application of road salt in winter months can result in exceedance of the acute guideline, with accumulation in shallow groundwaters resulting in exceedance of the chronic guideline in summer months. The Niagara Escarpment is home to a variety of threatened and endangered species, including the Jefferson salamander and Lilliput mussels, making it particularly at risk from the impacts of chloride. Using high frequency (15-minute interval) monitoring of specific conductance (SpC) and bi-weekly grab samples analyzed by ion chromatography for chloride concentration ($[Cl^-]$), high frequency $[Cl^-]$ dynamics were estimated for the streams of

9 escarpment watersheds around Hamilton, Ontario for the period of March 2020–July 2021. The objectives of this study are to: (1) compare stream [Cl^-] dynamics across 9 watersheds and a gradient of urbanization, and (2) quantify the frequency and duration of exceedances of acute and chronic water quality guidelines for [Cl^-] in the salting and non-salting seasons in these watersheds. In 8 of 9 watersheds, winter snowmelt and rain-on-snow events resulted in [Cl^-] pulses that often exceeded the acute guideline (640 mg/L), whereas summer rain events temporarily diluted [Cl^-] below the chronic water quality guideline (120 mg/L). Six of 9 watersheds surpassed the chronic [Cl^-] guideline for > 90% of the study period. Of the 1–29 occurrences of the chronic guideline being exceeded for > 4 days, the durations ranged 4–176.5 days (average 12.1 days). Three of the 9 watersheds exceeded the acute guideline for > 5% of the study period, with 1–19 exceedances of the acute guideline for > 1 day ranging 1.1–24.8 days (average 5.5 days). While [Cl^-] and exceedance metrics generally increased with increasing impervious surface cover (ISC) in the selected watersheds, several watersheds failed to follow this pattern, potentially resulting from the balance between various surficial and subsurface pathways. This study shows the importance of groundwater in maintaining a supply of [Cl^-] to streams during the non-salting season, driving chronic exposures to aquatic life. This work further informs on the timing of stream [Cl^-] conditions, with implications for monitoring programs seeking to capture the true seasonal trends in contaminant concentrations. Moreover, this work will assist ecosystem managers in assessing vulnerabilities of aquatic species to road salt by identifying the timing and location of greatest risk from chronically high [Cl^-].

COMPARISON OF REGULATION AND DIRECTIVES ON NATURAL GAS EXTRACTION WELLS' SURFACE CASING VENT FLOW DETECTION RATES

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Due to economic and environmental impacts, governments often implement regulations to assess, reduce and prevent hazards posed by the natural gas industry. Surface casing venting has raised concerns because of methane emissions to the atmosphere and its impact on global warming. Similarly, H_2S and brines can flow out from the wells which can impact the health of nearby residents. The present study aims to study the influence of legislation on leakage detection at surface casing vents. The Province of British Columbia has delegated oil and gas regulatory responsibility to the British Columbia Oil and Gas Commission (BC OGC), which provides guidance and regulations on surface casing vent flows (SCVF). Despite the SCVF regulation implemented to reduce the risk of gas leakage, previous studies have shown that from 1919 up to 2016, 10.8% of the gas extraction wells in the region leaked at least once in their lifetime. However, leakage detection rates are dependent on the frequency and procedure used for testing wells, which are defined by regulations and guidelines provided by the BC OGC. Over time, BC legislation has evolved and the frequency of testing for SCVF has changed, primarily after two major changes in policy requirements in 1995 (wells were required to be tested for SCVF prior to abandonment) and 2010 (wells were required to be tested for SCVF regularly during their lifetime). Given newly released updated data by the BC OGC about SCVF testing, we updated the rate of wells that leaked at least once in their life up to 2020. We observe a rise of SCVF detection rates of up to 15.06% (leaky wells over drilled wells). Using the updated SCVF data, we study the influence of regulation on detection rates and find that between 2010 and 2020, there is an increase of 4.3% on leakage detection rates. Additionally, following a change in the regulation that happened in 2019, all SCVF testing results must be reported in British Columbia (prior to 2019, reporting was only required upon leakage discovery). As a result, the ratios of wells showing SCVF over wells that reported SCVF test results were calculated to be 76.1% in 2019, and 67.2% in 2020. When comparing other regions and studies (Alberta, Canada, and Pennsylvania, USA), positive correlations between legislation and compliance in SCVF detection rates have also been observed.

SPATIAL DISTRIBUTION AND RISK ASSESSMENT OF HEAVY METAL CONCENTRATIONS FROM AN AGRICULTURAL WATERSHED AREA OF ROCKY HILL, NORTHEASTERN USA

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Accumulation of trace metals in agricultural soils threatens the safety of the ecosystem, and human health through dietary consumption. This study examined the impact of land use activities on the chemical signature of trace elements within an agricultural watershed area of Rocky Hill, northeastern USA. A total of twenty-seven stream sediment samples, and corresponding stream water samples were collected, and analyzed for arsenic, and thirteen other chemical elements (Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn); and basic river sediment parameters such as particle size distribution, and organic matter contents. Using GIS maps with overlays of hydrology and land use activities, correlations among elements within the watershed were examined. Results showed positive correlation among elements, but there was no significant correlation with percent clay, silt, and organic matter contents. Calculations of element enrichment factors showed that a few locations are moderately to significantly enriched with respect to Mn, Pb, Cr, and Zn, suggesting impact of various anthropogenic activities. However, results of ecological risk assessment showed most elements pose little or no risk to aquatic organisms except for Zn. Overall, our results do not show a statistically significant effect of historical agricultural practices on trace element concentrations within the watershed area.

APPLICATIONS OF COSMOGENIC ^{14}C FOR THE NEW ^{14}C EXTRACTION LINE LABORATORY AT DALHOUSIE UNIVERSITY

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Reliable chronology of sediment landforms is required to establish surface ages as well as rates of a wide range of pedogenic and geologic processes. For instance, cosmogenic nuclide depth profile exposure dating provides a means of estimating the age of the upper metres of sediment by reducing uncertainty related to inheritance. However, uncertainty from other sources, such as muon production and surface erosion, remain largely unconstrained and together with other variables can contribute a significant uncertainty to cosmogenic nuclide exposure dates. We explore two novel applications of in situ cosmogenic Carbon-14 extracted from quartz with the new Dalhousie ^{14}C extraction line laboratory (DCELL): 1) improving constraints on surface erosion and 2) calculating post-depositional muogenic production of TCN in deep samples targeted for burial dating. The DCELL builds on recent innovations from other labs and introduces two additional features to improve process blank levels and reproducibility. DCELL is an automated, ultra-high vacuum, stainless steel extraction system, that uses induction heating to extract ^{14}C from quartz. A 10-kW induction furnace with a 10-tonne chiller is used to heat purified quartz sand in one or more platinum tubes within a sapphire combustion chamber. Heating is controlled with two system-integrated pyrometers with overlapping temperature ranges (200–1500°C and 800–2300°C) safely positioned 30 cm from the coil for an off-axis sensing with radius ~2 mm on the surface of the tubes. We anticipate improvements in repeatability from the automation, and a reduction in process blanks (order of magnitude) from the previous extraction line at Dalhousie University. We also expect to see reduced extraction time due to the faster heating with induction and reduced AMS counting uncertainty with the use of a CO_2 spike. These combined improvements will allow for more precise ^{14}C measurements. By measuring ^{14}C saturation concentrations in quartz sand from amalgamated sediment samples collected just below the soil mixing zone we have demonstrated a way to provide erosion-adjusted exposure ages for most sediment surfaces. Our next experiments will demonstrate the use of ^{14}C to establish muon production for the last 38 ka at depths > 10 m to adjust the concentrations of ^{10}Be and ^{26}Al for post-depositional exposure, so that the $^{26}Al/^{10}Be$ concentrations can provide more precise burial ages.

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BENEFITS OF MICROBIOLOGICAL MONITORING IN MINING: FOCUS ON As-CONTAMINATED GOLD MINES

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The microbiological research within the NSERC-TERRE-NET program helps elucidate linkages between the geochemistry and microbiology of mine systems. Microbial communities were investigated throughout the vertical profiles of tailings impoundments at two Canadian gold mines, for which remediation strategies are being developed, to mitigate As release and mobilization. Extensive acid mine drainage from mill tailings at the abandoned Long Lake Gold Mine (Ontario) has occurred during the past 100 years. Samples were collected from tailings sub-aerially deposited in an uncontained tailings area. Pore water from the oxidation zone near the surface was low pH (2.0–3.9) and contained ~400 mg L^{-1} As, while reduced conditions were detected at the tailings profile base. The mean relative abundance of S^0 and/or Fe^{2+} oxidizers was 8.1% of total reads (dominated by *Acidithiobacillus*). The inactive Giant Mine (Northwest Territories) is among the most challenging mine-site remediation projects in Canada. Flotation tailings mixed with roaster wastes stored in a tailings impoundment have low residual S (0.4 wt.%) and high As-bearing Fe oxide (~18 wt.%) contents. The tailings pore water was of circumneutral pH (~7.6) and contaminated with As (mean of 3.6 mg L^{-1}). Concerns include As mobilization via reductive dissolution of Fe^{3+} compounds in saturated tailings, and release of As through sulphide oxidation in the vadose zone. Mineral-oxidizers (dominated by *Thiobacillus*) accounted for 2.5% of total reads in unsaturated samples, indicating low sulphide oxidation rates. A low mean relative abundance of Fe^{3+} reducers was detected (with *Geobacter* accounting for 0.2% of total reads). However, most Fe^{2+} oxidizers (0.6%) and sulphate-reducers (0.5%) are also capable of Fe^{3+} reduction under anaerobic conditions. Fe and As concentrations in the tailings pore water increased with depth (up to 72 and 20 mg L^{-1}, respectively), which could indicate release of As by sulphide oxidation in the vadose zone and by reduction of oxidized phases below the water table. However, the occurrence of As in the tailings pore water is complex and it could have also been derived from residual mill process-water and/or water pumped from the underground workings. The extensive research within TERRE-NET has shown that microbiological data correlate well with geochemical (pH, dissolved metal concentration etc.), hydrological (water table level) and mineralogical data. Additionally, the extremely sensitive microbiological analyses can detect microenvironments of sulphide oxidation undetectable by other methods, showing a potential to serve as a novel tool for assessing and monitoring sulphide oxidation as well as the performance of remediation strategies.

METHODOLOGY DEVELOPMENT FOR INVESTIGATING BISULPHIDE SORPTION ONTO BENTONITE THROUGH LABORATORY BATCH EXPERIMENTS

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The Nuclear Waste Management Organization (NWMO) is planning to develop a deep geological repository (DGR) to safely isolate Canada's used nuclear fuel in a stable rock formation 500 m below ground surface. Within a DGR, the used nuclear fuel will be encapsulated in an engineered barrier system (EBS), which includes copper-coated used fuel containers (UFCs) surrounded by highly compacted bentonite (HCB). A potential concern towards the long-term EBS performance is the production of bisulphide (HS^-) by sulphate-reducing bacteria activity near the rock-bentonite interface. If produced, HS^- may diffuse through the bentonite and corrode the copper surface of the UFC. Although it is anticipated that sorption onto bentonite will reduce HS^- transport and minimize the risk of corrosion, the sorption phenomenon of HS^- onto bentonite has not been systematically investigated. This study addresses this knowledge gap through a set of batch experiments under various liquid to solid (L:S) ratios (50–1000); initial HS^- concentrations (1–5 ppm) and contact time (1–48 hours). All other key conditions, e.g. pH (9.5) and temperature (22 ± 2°C) were kept constant. This study required robust methodology development to build confidence in the experimental procedure and the results showed that among the selected L:S values, L:S= 100 was the minimum ratio suitable for determining the HS^- sorption capacity of bentonite. In addition, the sorption percentage of initial HS^- was found to increase with increasing contact time, which reached equilibrium at 24 hours under the experimental conditions. These findings provide critical information about how to conduct batch experiments to better understand the fundamental sorption mechanisms that may inhibit HS^- transport through bentonite. Altogether, this study supports the broader, ongoing effort to assess the long-term performance of EBS in Canada's DGR.

USING NUMERICAL SIMULATIONS TO SUPPORT THE INTERPRETATION OF THERMAL INFRARED REMOTE SURVEYS FOR MAPPING SUBMARINE GROUNDWATER DISCHARGE

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The Magdalen Islands in the Gulf of St. Lawrence are surrounded by salt water, and because of a lack of surface water, fresh groundwater is the only source of drinking water for its inhabitants. In addition, aquaculture is an important economic driver on which the archipelago's communities rely. Interest in studying submarine groundwater discharge (SGD) around the archipelago has recently increased due to its potentially significant effects on marine ecosystems, contaminant pathways, as well as on refinement of water budgets for the islands' groundwater resources. During the autumn of 2020, an experimental field campaign was conducted to locate potential SGD zones using infrared and photogrammetric surveys. Unmanned aerial thermal infrared surveys can detect SGD based on temperature contrasts at a given time in marine environments. Despite the apparent simplicity of the method, the interpretation of these surveys has proven challenging. The challenges in interpreting infrared surveys include unexplained sea surface temperature (SST) contrasts as well as the extent of the SGD. In order to support the analysis, numerical simulations were conducted with the Heatflow-Smoker model which simulates coupled density-dependent heat and mass transport. A 300 x 30 m vertical 2-D domain is used to represent a groundwater lens in a coastal area with saltwater intrusion and is informed by data collected during the field campaign. SST is computed from the 2-D hydrogeological model results, combined with an analytical sea surface thermal energy budget. A parametric study was performed to evaluate the impact of different variables, including bathymetry, coastal swamps, and physical parameters, on SGD and SST, under steady-state and transient tidal conditions. In light of the results, proving correlation between SGD and SST is possible but requires a rigorous interpretation framework to validate the presence of SGD, questioning the usefulness of this method for remote sites with little to no supportive field data.

NICKEL STABLE ISOTOPES AS TRACERS IN MINE-IMPACTED ENVIRONMENTS: NI ISOTOPE FRACTIONATION DURING PRECIPITATION OF NI SECONDARY MINERALS

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Metal stable isotope analysis provides an important contribution to the characterization of the biogeochemical cycling of metals and metalloids in the environment, as processes involved in the release, mobility and fate of metals can often be evaluated using changes in metal stable isotope signature. Due to the paucity of studies on Ni isotope fractionation associated with Ni mobility and attenuation in the environment, further research, aimed to fingerprint important biogeochemical processes involving Ni cycling in the environment, is needed to successfully apply Ni stable isotopes as tracers in environmental studies. Laboratory batch experiments were performed to investigate Ni isotope fractionation during the precipitation of three Ni secondary mineral phases (Ni hydroxide, Ni hydroxycarbonate, and Ni sulphide) in abiotic systems at ambient conditions. Ni isotope fractionation was measured for both the solid and liquid phases, whereas synchrotron-based powder X-ray diffraction (PXRD), and X-ray absorption spectroscopy (XAS) analyses were performed to

characterize the precipitates. The resulting data indicates preferential partition of light Ni isotopes into the solid phases, which results in similar Rayleigh trends characterizing all three investigated systems. The associated fractionation factors were ε = -0.40‰ ± 0.04‰, -0.50‰ ± 0.02‰, and -0.73‰ ± 0.08‰ relative to the hydroxide, carbonate and sulphide systems, respectively. Although this study cannot fully resolve the contribution of kinetic vs. equilibrium effects, the fractionation factors reported here are useful proxies for fractionation processes associated with rapid precipitation of Ni-bearing secondary minerals in Ni-contaminated environments, and offer a valid addition to the characterization of Ni isotope systematics.

TECTONIC SETTING AND EVOLUTION OF A TOURNAISIAN LACUSTRINE BASIN, NEW BRUNSWICK, CANADA

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Through the Tournaisian–Viséan interval from maritime Canada to Scotland a series of internal basins to Pangaea were the site of large lakes characterized by marked stratification with anaerobic deep water in which were deposited thick sequences of oil shale. The lower Tournaisian Albert Formation constitutes one of these oil shale-bearing lacustrine successions in New Brunswick, Canada. The 'Albert Lake' formed in a large dextral strike-slip zone between the Belleisle and Clover Hill faults in a right-hand transtensional step-over, and the Tournaisian–Viséan interval saw a transfer of right-lateral offset from the Belleisle to the Kennebecasis and Clover Hill faults. Initially a basin receiving fanglomerate deposits, largely from the southern side, prograding into playa-lake red beds, formed, evolving into a permanent lake in which a c. 1 km thick sequence including the oil-shale-bearing Frederick Brook Member (Albert Formation) was deposited. Two major deltaic sandstone units prograded into this stratified lake represented by the Dawson Settlement and Hiram Brook members (the latter forming the reservoir rocks to the Stoney Creek oil and gas and McCully gas fields). Soft-sediment structures mark subaqueous slope failure on every scale, from beds of metre-scale thickness slumping down slope to listric failures of 30–50 m thick sections. The largest listric failures visible in seismic reflection profiles affect much of the Albert Formation. Major slumps affecting the entire Albert section coincide with the deposition of the Hiram Brook delta, and the next unit above this, the Brookfield Formation, occupies a fault-bounded depression above the delta. Finally, as represented by the Gautreau Formation, the Albert Lake underwent complete desiccation producing a thick evaporite sequence including massive halite and Na-sulphates (glauberite, thenardite). A strong asymmetry to sediment provenance is apparent with the coarse-grained sedimentary rocks of the Memramcook and Kennebecasis formations largely derived from the southern side of the basin during deposition of the Albert Formation, and large deltas prograde from the same area. Only toward the end of the Albert Lake history did a major sediment influx from the north and northeast occur reflecting the geometry of fault movement during the Belleisle Fault to Clover Hill/Kennebecasis faults transfer. The entire basin underwent inversion during the late Tournaisian once transfer was complete and the area evolved from transtension into transpression.

GEOLOGY MATTERS — DEVELOPING THE NECESSARY FRAMEWORK FOR SITE-DESCRIPTIVE MODELLING AND ASSESSMENT OF SAFETY IN DEEP GEOLOGICAL REPOSITORIES

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The role of the geological setting in developing deep disposal concepts for long-lived nuclear waste is to provide long-term safety and security by isolating the waste from the human environment, maintain a stable chemical and physical environment to protect the waste from external phenomena, and contribute to the multi-barrier concept through features and processes that contain and prevent radionuclide migration. Site-specific geological conditions determine the nature of geological research and investigations required to assess the barrier capacity of the geosphere under consideration for hosting a deep geological repository. As the geological setting is the primary disposal environment, site-specific geological conditions must be assessed through comprehensive data gathering, analysis, and integration activities, and with the results documented in a descriptive geoscientific site model (DGSM) report. The DGSM is underpinned by a 3-D geological model which provides the basis for the development of integrated geomechanical, thermal, hydrogeochemical, hydrogeological, and, ultimately, transport models that together tell a robust and coherent story of why the geological setting is expected to be safe throughout the lifetime of the repository. The physical and chemical characteristics of the geological setting will impose a number of constraints on both the repository design and the approaches taken for assessment of long-term safety. Engineering designs and safety assessment scenarios must be developed to complement the expected geological conditions such that an adequate level of safety is provided by the combination of natural and engineered barriers. For example, natural and excavation-induced fractures will represent a primary migration pathway into, and out of, the deep subsurface in any geological setting. In addition, these fractures and the fluids within them may interact with components of the engineered barrier system. Furthermore, the chemistry of fluids within natural fractures provides insight into understanding hydrogeochemical stability over the million year time frame required for assessing the long-term performance of the repository. This contribution will provide examples of why and how the geological setting matters to both crystalline and sedimentary sites currently under investigation as part of Canada's plan for the disposal of high-level waste.

CHARACTERIZING THE FLUORITE ZONE FROM THE WHISKER VALLEY PROPERTY USING HYPERSPECTRAL IMAGING

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The newly discovered Fluorite Zone at the Whisker Valley Property on the Baie Verte Peninsula, Newfoundland is interpreted as representing an alkalic epithermal gold target similar in character to Cripple Creek Deposit in Colorado. Host rocks within this zone consist largely of felsic pyroclastic, tuffs and diatreme breccias of the Silurian Kings Point Caldera Complex. These rocks are typically brecciated with complex porphyry-like alteration patterns, with localized veins of chlorite and fluorite associated with gold, zinc and REE mineralization. The host rocks are generally very fine-grained in nature, which renders the accurate definition of alteration zones difficult using traditional means. Here, a hyperspectral imaging system consisting of VNIR-SWIR-MWIR-LWIR instruments covering the spectral range from 400–5000 nm and 8000–13000 nm was used to examine mineralogical patterns in approximately 1000 m of drill core from the Fluorite Zone. Within this zone, intervals of high white mica content are typically associated with higher quartz contents and generally correlate well with tuff layers. Over several intervals white mica alteration also correlates well with areas of pyrite mineralization. In addition, REE-bearing minerals within later fractures have been identified by hyperspectral mapping within the Fluorite Zone. Hyperspectral imaging is a viable tool for defining alteration patterns through characterization of mineralogy, and has the potential to vector towards mineralization in areas with complex alteration zones such as the Fluorite Zone.

TILL GEOCHEMICAL SIGNATURES OF THE BRUNSWICK HORIZON: INSIGHTS FROM GEOSPATIAL DATA ANALYTICS AND MACHINE LEARNING TECHNIQUES

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Volcanic-hosted massive sulphide (VMS) deposits in Canada are important sources of a range of commodities, including Zn, Cu, Pb, Ag, and Au. Given the glaciated landscape of Canada, till geochemical methods (bulk composition of till) have been important tools in the exploration for VMS deposits. These techniques have been applied to the Bathurst Camp with relative success. The Brunswick Horizon, the uppermost contact of the Nepisiguit Falls Formation with the overlying Flat Land-

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ing Brook Formation, is a prolific horizon hosting several significant VMS deposits, including Brunswick No. 12, Brunswick No. 6, Key Anacon and Gilmour South. The area has a complex glacial history with a dominant early eastward ice flow direction, and late north-northeast ice-flow direction. Till thickness is highly variable but generally does not exceed 2 m, and geochemical dispersion patterns are relatively short, ranging from 0.5 to 2 km. The underlying bedrock geology exerts substantial control on the distribution and dispersion patterns of elements in till. Regional till geochemical datasets were collected with a density of one sample per 2 km^2 and analyzed for multi-elements. Despite this coverage many deposits in the study area do not have directly correlative geochemical anomalies. Complex glacial stratigraphy and the presence of glaciomarine sediments with variable source areas limit the effectiveness of surface sampling in parts of the Curventon-Bathurst Valley. This study intends to apply geospatial data analytics, geostatistics, and machine learning techniques to till geochemical data to (i) assess how elements are transported from their sources; (ii) detect multi-element associations; and (iii) assess how these dispersion patterns can be used as vectors for mineral exploration. Dispersion patterns of elements in the till were compared with the lithogeochemical samples collected from drill core and bedrock exposures. A geospatial tool is proposed for quantifying the spatial relationship of single and multi-element geochemical associations with the Brunswick horizon. This tool was applied to the results of machine-learning-based multivariate techniques that help reveal the subtle associations among various elements. Finally, the outcome of these models was put into a predictive model for vectoring toward the mineralized horizons. This study has implications for VMS exploration in the Bathurst Camp and other VMS districts of Canada.

METAMORPHISM OF THE BUCHAN TYPE-AREA, NE SCOTLAND, AND ITS RELATION TO THE ADJACENT BARROVIAN DOMAIN

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The Buchan block of NE Scotland lies at the northeast end of the Grampian terrain and forms part of the Scottish Caledonides, the latter part of the Appalachian-Caledonian orogen. The Buchan block is the type-area of "Buchan-type" metamorphism, meaning low-pressure, high-temperature regional metamorphism characterized by andalusite-bearing mineral assemblages. In this study, the metamorphism of the Buchan block, and its relation to the kyanite-bearing Barrovian domain to its west, have been reassessed from consideration of mineral assemblages, microstructures, phase equilibrium modelling and monazite U–Pb geochronology. In the Buchan domain, zones of increasing metamorphic grade surround a central low-grade domain (biotite zone) and define a northward-opening, U-shaped metamorphic map pattern ascribed to post-metamorphic folding. The eastern and southern Buchan domain show the classic Buchan-type prograde sequence cordierite–andalusite–sillimanite–migmatite/gneiss, representing a metamorphic field gradient of gently increasing pressure between 2.5–3.0 kbar, ~550°C and 3.5–4.0 kbar, ~750°C. A lower pressure metamorphic field gradient (by less than ~0.5 kbar) is interpreted for the northeastern Buchan domain. The west Buchan domain shows a prograde sequence of staurolite + andalusite–sillimanite–gneiss/migmatite, representing a metamorphic field gradient higher by ~1 kbar or less than the classic sequence. Uniquely in the northwestern Buchan domain is a staurolite-cordierite-andalusite domain in which staurolite-bearing schist is interpreted to have been overprinted by cordierite + andalusite assemblages. Monazite U–Pb geochronology of schist and gneiss from the Buchan block, including the Cowhythe and Ellon gneisses, yields ages in the range 470 ± 5 Ma, supporting geological evidence that the gneiss units are metamorphosed Dalradian strata rather than older basement gneisses. The metamorphic ages are similar to the ages of mafic igneous intrusions in the Buchan block, even though many of the exposed intrusions post-date the regional metamorphic zones. The Buchan metamorphic zones are truncated to the west by the Portsoy-Duchray Hill lineament (PDHL), a ductile shear zone that juxtaposes the Buchan rocks against higher-pressure, lower-temperature (kyanite-bearing) Barrovian schists to the west. A 2–15 km wide corridor of andalusite pseudomorphed by kyanite occurs between the PDHL and the Keith shear zone to its west. Monazite geochronology of the Barrovian rocks west of Portsoy shows little evidence of the ca. 470 Ma signature of the Buchan block, instead yielding a dominant cluster of ages at ca. 450 Ma and a more poorly defined grouping at ca. 490 Ma.

A LONG WAY GONE: RECORD OF SEDIMENTARY RECYCLING FROM DETRITAL ZIRCON GEOCHRONOLOGY OF THE FURY AND HECLA GROUP (LATE MESOPROTEROZOIC, NUNAVUT, CANADA)

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Intracratonic basins that developed during supercontinent amalgamation are abundant in the Precambrian record but not fully understood. The Bylot basins of Arctic Canada and Greenland include the Fury and Hecla, Borden, Thule, and Hunting-Aston basins, which together record widespread sedimentation on northern Laurentia after assembly of supercontinent Columbia in the late Mesoproterozoic. Radiometric dating from the middle strata of the Fury and Hecla and Borden basins has constrained deposition to ~1090–1040 Ma. Detrital zircon geochronology from the Fury and Hecla basins provides new insight into the evolution and paleogeographic context of the Bylot basins. Seven samples spanning the Fury and Hecla Group were analyzed on the sensitive high resolution ion microprobe at the Geological Survey of Canada in Ottawa and record U–Pb age populations ranging from ~3350 to ~1695 Ma. Ages display a bimodal probability density distribution attributed to extensive zircon-growth events around ~2700 Ma (Rae cratonization) and ~1900 Ma (Snowbird and Trans-Hudson orogenesis, Taltson magmatism), respectively. Independent provenance studies suggest that Snowbird and Trans-Hudson topography was mostly levelled by ca. 1.1 Ga, such that the Fury and Hecla basins do not record unroofing and erosion of these orogens. Therefore, we test the hypothesis of sedimentary recycling into the Fury and Hecla basins (and other Bylot basins) from older supracrustal successions. The Amer Group, 600 km to the southwest, records a similar detrital-age distribution as the Fury and Hecla Group, and paleocurrent data support it as a possible source region. Compared to the Bylot Supergroup of the Borden Basin detrital-age record, the Fury and Hecla groups show similar age peaks but different distributions, notably lacking a younger Grenvillian age population. We posit that the Borden Basin received recycled sediment from the Piling Group 500 km to the southeast and the Elu Basin 900 km to the southwest. Different sediment pathways contributed to the Bylot basins despite their genetic link. This detrital geochronology dataset supplements recently proposed tectonostratigraphic divisions for the Bylot basins and helps to differentiate monotonous sandstone units based on changes in provenance. More broadly, our results further our understanding of the role of recycling in intracratonic basins developed during supercontinent amalgamation.

APPLICATION OF QUATERNARY GEOLOGY IN A REGION WITH HIGH POTENTIAL FOR UNDISCOVERED Zn, Pb AND Cu MINERALIZATION, SOUTHERN MACKENZIE REGION, NORTHWEST TERRITORIES

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As part of the Geological Survey of Canada's Geomapping for Energy and Minerals (GEM2) Program, Quaternary geology and mineralogical studies of till and stream sediments were undertaken in the region southwest of Great Slave Lake from 2017 to 2020. Multi-faceted research activities addressed the broad question, "Is there potential for additional carbonate-hosted sulphide deposits under the thick glacial overburden between Hay River, Kakisa Lake and Fort Providence?" Fieldwork involved surficial mapping and till and stream sediment heavy-mineral sampling in NTS map areas 85C, 85F, and 85G. No previous surficial mapping or surficial heavy mineral data existed for these areas. In addition to new field collections, the project benefited from additional samples donated by the Northwest Territories Geological Survey, collected as part of former Protected Area Strategy surveys. Recovered heavy minerals were subjected to trace element geochemical and isotopic analyses to elucidate potential mineralization source types, and eliminate known sources (i.e. Pine Point). Sulphide mineral grains (sphalerite, galena, chalcopyrite, arsenopyrite) recovered from the till and stream sediments were analyzed for chemistry and in-situ Pb and in situ and conventional S isotopes in order to assess potential deposit

sources. Sphalerite mineral chemistry (low Fe/Zn and Ge/Ga) and $\delta^{34}S$ signatures (-18.5 to +22.5‰) and galena mineral chemistry (high Ag/(Sb+Bi)) and $\delta^{34}S$ signatures, are indicative of deposition from low temperature fluids and are potentially derived from carbonate-hosted Zn-Pb mineralization. However, the Ge/Ga in sphalerite and Pb isotope signatures of galena, indicate that these grains are not derived from the neighbouring Pine Point deposits and instead represent unique, undiscovered sources of mineralization. Chalcopyrite grains have high Cd/Zn ratios and $\delta^{34}S$ values (-12.4 to +39.7‰) v that are also consistent with deposition from low temperature fluids and likely represent derivation from a sediment-hosted source (e.g. sediment-hosted Cu, Kipushi-type, or MVT(?) mineralization). Chalcopyrite is not found in any of the Pine Point deposits. Our integrated Quaternary research and heavy mineral geochemical and isotopic analyses indicate a strong potential for undiscovered Zn, Pb, and Cu mineralization occurring in bedrock, likely associated with major fault systems, concealed beneath Quaternary sediments in this region.

GEOCHEMICAL CONTROLS ON ACID GENERATION AND METAL(LOID) MOBILITY IN FROTH TREATMENT TAILINGS AT AN OIL SANDS MINE

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Froth treatment tailings (FTT) are produced during bitumen extraction at oil sands mining operations in northern Alberta, Canada. These tailings are characterized by elevated sulphide mineral content and past studies have reported that oxidative weathering can lead to acid-generation and metal(loid) release. Our research examines the geochemical evolution of a commercial scale sub-aerial FTT beach deposit located in an operational tailings facility. We collected continuous core samples extending up to ~50 m deep from six locations along a ~1.5 km transect of this deposit. Pore-water was extracted for chemical analysis at 0.25 m depth intervals over the upper 4.0 m, where localized evidence of oxidative weathering has been previously observed. Corresponding samples of tailings solids were collected for geochemical and mineralogical analyses. Acid generation and metal(loid) release was apparent within the vadose zone, which increased in thickness from 9 m along the transect. Pore waters in highly weathered areas of the vadose zone were characterized by low pH (1.9–4.7) and high dissolved Fe (3–15 g L^{-1}) and SO_4 (2–37 g L^{-1}) concentrations. Elevated concentrations of Al (0.8–39 mg L^{-1}), Zn (0.46–5.9 mg L^{-1}), Ni (0.3–3.5 mg L^{-1}), Co (0.002–3.0 mg L^{-1}), As (0.002–1.3 mg L^{-1}), and Cu (0.01–0.6 mg L^{-1}) and other dissolved metal(loid)s were also observed. Increases in pore water pH and decreases in metal(loid) concentrations, corresponding with increased depth, are attributed to acid neutralization and pH-dependent precipitation of secondary Fe(III) (oxyhydr)oxides including lepidocrocite [γ-FeOOH] and goethite [α-FeOOH]. Below the water table, pore waters are generally characterized by circum-neutral pH and relatively low concentrations of dissolved metal(loid)s. Sulphate reduction supported by residual hydrocarbons may also limit the transport of Fe, and SO_4 via subsequent sulphide precipitation. This research provides new insight into acid generation and metal(loid) mobility within oil sands FTT deposits that can inform mine closure and reclamation planning.

CHARACTERIZING ISLAND-WIDE VARIATION IN HYDROGEOLOGICAL SETTING ACROSS PRINCE EDWARD ISLAND

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Prince Edward Island (PEI) is the most groundwater-reliant among Canadian provinces; however, there is little information on the spatial variation in hydrogeological setting across the island. Several factors contribute to this scarcity of regional-scale mapping. The bedrock aquifer underlying PEI has the same general appearance throughout the island with interbedded sandstone and mudstone units often referred to as "red-beds". However, the lack of continuity for individual beds complicates correlation even on a local scale. Furthermore, there are two independent variants of shallow bedrock stratigraphy that prevent direct integration of data from different studies. The present study combines deep borehole logs, mapped dips of bedrock units, and archival offshore seismic data to produce a 3-D geologic model for the island to directly compare alternative stratigraphic variants. Simultaneously, data from over 20,000 water well logs were used to map groundwater elevations and sandstone fraction distribution in shallow bedrock across the island. Due to the high variability of the logged values and uncertainty regarding the quality of each individual log, the applied analysis involved aggregating data from many logs to determine regional trends in both mapped parameters. The developed model highlights structural differences between alternative stratigraphic variants and provides information about structural dip – an important factor influencing saltwater intrusions in coastal areas. The mapped groundwater elevations fit measured levels in provincial observation wells reasonably well and provide insights into the functioning of the bedrock aquifer. The well log analysis highlighted variability in bedrock lithology across the island and enabled the identification of a distinct cluster of elevated sandstone fractions around Malpeque Bay.

IGNEOUS ROCKS AT CLARKE HEAD, NOVA SCOTIA: NOT PERI-GONDWANAN BASEMENT GRANULITE?

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An important 20th century contribution by Brendan Murphy, together with Wes Gibbons and others, was the description and interpretation of 'metabasic granulite' at Clarke Head, near the Avalon-Meguma suture beneath the Bay of Fundy, as a sample of either Meguma or Avalonian lower crust, based principally on the presence of garnets. Uplift from the depths was related in some way to fault activity along the Meguma-Avalon terrane boundary. They wrote "[the] pyroxene- plagioclase-garnet metabasic granulite … is quite unlike anything else previously described from the Avalon Superterrane on either side of the Atlantic". The U–Pb zircon age of 370 ± 2 Ma was interpreted as the age of recrystallization and mylonitization of a granulite at 0.75–0.95 GPa (~25 km). Re-examination of the Clarke Head megabreccia shows that the 'metabasic granulite' is not the only igneous rock present in this largely dissolved salt wall. Brittly deformed gabbro is intruded by syenite. Diorite, with alternating bands richer in feldspar and in mafic minerals, preserves igneous contacts with a hornfelsed mudrock interpreted as Horton Group. A block of highly altered basalt is also present in the megabreccia. Furthermore, the deformation of the 'metabasic granulite' resembles mylonitized Late Devonian–Early Carboniferous gabbro elsewhere in the Cobequid Highlands. New whole-rock geochemical data demonstrate that the igneous rock assemblage at Clarke Head is very similar to hornblende gabbros in plutons along the Kirkhill–Rockland Brook master faults and other fault splays in the Late Devonian–Early Carboniferous Cobequid Shear Zone. It is only the garnets in the 'metabasic granulite' that are exceptional. These garnets have a pyrope content of about 24%, the feldspars are andesine, and there is minor hornblende and biotite, none of which are normally features of granulites. The Sm/Nd isotope systematics of the 'metabasic granulite' are similar to the Fountain Lake Group volcanic rocks. Elsewhere in the world, arc-related garnets of similar composition have been reported in andesites and interpreted to be from disintegration of comagmatic cumulate material at 0.8–1.0 GPa under hydrous conditions. We suggest a similar origin for the Clarke Head 'metabasic granulite' and propose a general tectono-magmatic model for the arc to backarc evolution of the gabbroic rocks of the Cobequid Highlands.

FAULT REACTIVATION AND HALOKINESIS: AN EXAMPLE FROM THE PENOBSCOT 3-D SEISMIC VOLUME, OFFSHORE NOVA SCOTIA, CANADA

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Polyphase deformation on passive margins, including fault reactivation, has been documented globally. These processes form complex structures that can be integral to petroleum systems and can provide essential constraints on the kinematic and structural evolution of rifts and passive margins. Inversion structures can also be used as a global marker for far-field stress changes. Despite the importance of reactivated faults, their identification, extent, kinematic controls, and knowledge of interaction within populations are often poorly constrained. As such, there is need for

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detailed investigations of such structures, including their relationship with halokinesis, which can lead to complex and sometimes misleading structural observations. We present a new structural interpretation of the Penobscot 3-D seismic reflection survey, and associated relay ramp, imaged offshore of Nova Scotia, Canada, down to ~3.5 s twt, constrained by two exploration wells. The relay ramp comprises two dominant faults that dip approximately SSE and are associated with smaller antithetic and synthetic faults. The wider fault population is dominated by ~ENE-WSW striking normal faults that dip both NNW and SSE. The two major normal faults display evidence for reverse deformation in their lower portions (below ~2.5 s twt), which manifests as anticlinal folding and reverse offsets. However, in their upper portions the faults display normal offset. Smaller faults tend to affect the uppermost strata and do not show evidence of reactivation. Analysis of fault throw demonstrates that movement on the two main faults was coupled during both the reverse and normal deformation intervals. Through our structural analysis and previous regional interpretations of widespread salt kinesis, we determine that the observed style of deformation likely occurred due to normal (extensional) reactivation of reverse faults that had initially formed due to halokinesis of underlying salt. The timing of salt movement broadly corresponds to documented times of kinematic reorganization on many Atlantic margins, and thus salt kinesis may have been in response to this. The kinematic dichotomy with depth along the two dominant faults is important to document as this style of polyphase reactivation may go unrecognized where seismic data does not image the full depth of a structure. Therefore, reactivation may be more widespread than previously thought if only uppermost parts of structures have been imaged. The interpretation of salt as an important contributor to kinematic reactivation of faults is crucial as it likely provides a mechanism to explain inversion at many other locations globally.

NUMERICAL MODELLING OF A RIVER TALIK SYSTEM FOR SUSTAINABLE WATER SUPPLY

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A 3-D numerical model has been developed to understand the dynamics of a river talik below the Kuuguluk River in a continuous permafrost environment near Salluit (Nunavik, Quebec). The talik is located within fractured bedrock and is being used as a source of drinking water for the local community; however, the system behaviour under pumping and climate change is not well understood. This study evaluates the limits of sustainable pumping from the river talik and explores the effects of different climate change scenarios. The 3-D talik-aquifer system is simulated using the HEATFLOW/SMOKER code which solves a fully coupled system of density-dependent groundwater flow and advective-dispersive transport of thermal energy, and accounts for the effects of freeze-thaw, latent heat, and ice-induced relative permeability changes. Hydraulic conductivity, fluid density, heat capacity and thermal conductivity are temperature dependent. A Picard iteration scheme with an efficient matrix solver is used to solve the non-linear system. A 3-D geological model of the Salluit Valley was first built with GoCAD using topography, Quaternary deposit maps, bedrock outcrops, drilling and geophysical investigations. A 3-D structured finite element grid of deformed brick elements was used to resolve the hydrostratigraphy. Correlation functions between observed seasonal variations in air and ground surface temperatures for three ground surface classes are used to impose ground-surface boundary temperatures over time on the top model boundary. Numerical simulations representing current and future conditions including the pumping well were carried out following a 100-year spin-up temperature-equilibration period. The performance of the numerical model was evaluated by comparing the measured profiles of the river talik extent to the model results. Consistent with a previous modelling study further downgradient in the Salluit Valley, the simulated 3-D talik follows the path of the river and is closely correlated to the river meanders. We discuss the modelling approach used to simulate the river-talik system and present initial results of the flow system and temperature field under the influence of pumping. The outcome of this study will help to ensure the sustainable management of this and similar river-talik systems for northern communities in permafrost environments.

INVESTIGATION OF THE TEMPORAL VARIATIONS OF GEOCHEMICAL PARAMETERS OF GROUNDWATER MEASURED IN SITU AND IN THE LABORATORY DURING THE HIGH-FLOW PURGE OF A WELL

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Groundwater sampling generally implies standardized protocols. According to a protocol generally standardized at the scale of southern Québec, more than 3,000 groundwater samples were sampled in the framework of the "Groundwater Knowledge Acquisition Program" (Programme d'acquisition de connaissances sur les eaux souterraines; PACES) of the Ministère de l'Environnement et de la Lutte contre les Changements Climatiques (MELCC) of Québec. The protocol includes a high-flow purge and monitoring of in situ parameters (temperature, pH, dissolved oxygen, redox potential, and conductivity) prior to sampling. According to the cited protocol, the purge is considered complete after stabilization of the in-situ parameters. However, it is rare that stabilization is perfectly achieved. To understand the geochemical processes happening during the purge, sampling was done every 5 minutes in 3 individual wells during a 75-minutes purge (15 samples per well). To assess natural inter-annual variations, samples were also taken over a 3 year period (2019, 2020 and 2021). The 3 wells are located in three distinct hydrogeological contexts, in the region of Lanaudière (2 wells) and in the region of eastern Mauricie (1 well). The chemical composition in terms of major, minor, trace (rare earth elements and heavy metals), and isotopic elements (^{18}O, ^{2}H, and ^{13}C) of groundwater was obtained using high-resolution analytical methods in accredited laboratories. The preliminary results indicate that the purge influences differently the temporal evolution of specific chemical parameters and that a stabilization of the parameters in situ does not necessarily mean the stability of groundwater chemistry. The specific parameters that do not reach apparent stability are however related to the hydrogeological context (e.g. Ca^{2+}, Ba^{2+}, Sr^{2+}, Mg^{2+}, K^{+}). The water's isotopic signatures obtained at different periods suggests different recharge water temperatures (spring snowmelt and fall rains in summer), which allow making links with inter-annual hydrochemical variations in terms of major, minor and trace elements, and to draw conclusions about the water regime of the investigated contexts. The negative correlation of ^{13}C concentrations with iron and manganese concentrations suggests the influence of organic carbon on the mobility of these metals. An important effect of pumping is the increase in the mobility of redox ions (such as uranium, iron and manganese). Observations are reinforced by very distinct rare earth element patterns from well to well.

THE IMPORTANCE OF MULTI-PROXY ANALYSIS IN PROVENANCE STUDIES: AN EXAMPLE OF DETRITAL ZIRCON LASER ABLATION SPLIT-STREAM U-Pb-Hf DATA FROM THE SEDIMENTARY ROCKS IN THE CONNECTICUT VALLEY – GASPÉ BELT IN FINGERPRINTING LAURENTIAN AND GONDWANAN SOURCES

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In the Northern Appalachian orogen, the accretion of Neoproterozoic terranes with Gondwanan affinity to Laurentia during the Ordovician to Silurian remains debated, as well as the areal extent of such terranes. Determining the nature of erosional sources that contributed to the infilling of Ordovician–Devonian sedimentary basins is one of the key tools that can identify newly arrived crustal blocks and help understanding of the chronology of their arrival. In order to constrain sediment provenances, we generated new laser-ablation split-stream U–Pb and Lu–Hf isotopic data from detrital zircon grains from Ordovician to Devonian sedimentary rocks in the Gaspé Peninsula. The split-stream technique was essential in our context, with complex and small zircons, the U–Pb and Hf systems needed to be collected simultaneously (i.e. to ensure they were collected from the same growth domains). We sampled throughout the stratigraphy of the Connecticut Valley–

Gaspé trough (CVGT), a major Late Ordovician to Devonian post-Taconian sedimentary basin. The formation of the CVGT is associated with a late Silurian to Early Devonian crustal extension event, which was almost coeval to, or immediately followed, the Salinic orogeny. The CVGT was regionally deformed during the Middle Devonian Acadian orogeny, interpreted as marking the final accretion of the peri-Gondwanan Avalon terrane. Detrital zircon U–Pb ages show typical Laurentian and Appalachian age sources, characterized by abundant Mesoproterozoic ages (Grenvillian) throughout the succession. However, Ordovician samples demonstrate late Paleoproterozoic sources while Devonian samples contain some Ediacaran grains and show an increase in the proportion of Ordovician, Silurian and Devonian ages toward the top of the succession. Although εHf values are generally consistent with Grenvillian or Appalachians sources, the Upper Ordovician Garin Formation is characterized by Ordovician zircons with a primitive Hf signature suggesting a different source, potentially from the Pennobscot arc or the basement of peri-Gondwana terranes which must have been nearby at the time. These results suggest a strong influence of the erosion of Laurentian (cratonic, Grenvillian, and Appalachian) sources during the formation of the CVGT from Ordovician to Silurian time and highlight the proximity of peri-Gondwanan terranes in the Gaspé-Peninsula area by the Late Ordovician. The influence of this Gondwanan component would have been missed if only U–Pb data had been collected, highlighting the importance of multi-elemental (or multi-mineral) analysis, when possible, in provenance studies.

PRECAMBRIAN GOLD "FOOTPRINTS": CANADIAN MALARTIC AND BEYOND

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Gold exploration in greenfield settings, at depth or in poorly exposed areas, is challenging. Solutions to assist future deposit discoveries include recognizing both crustal-scale sources and pathways for mineralizing fluids as well as increasing the size of the targets. To this end, the NSERC-CMIC Mineral Exploration Footprints program (2013-2018) developed a comprehensive model of the metasomatic halo of the Canadian Malartic deposit (26 Moz Au), located south of the crustal break between the Abitibi and Pontiac subprovinces. Our work aimed at characterizing the distal signature of such a major ore system, identifying exploration criteria, and developing new exploration methodologies by integrating multidisciplinary datasets. This approach revealed various field- and laboratory- based parameters that could lead to a more efficient targeting of similar deposits. In particular, structural and petrophysical properties to outline fluid pathways and traps, and hyperspectral imaging to measure mineral chemistry and document hydrothermal alteration, are valuable tools to characterize gold systems. Current research initiatives, in the western Superior Province at the intrusion-hosted Hammond Reef deposit (5.6 Moz Au) and Guiana Shield at the intrusion-related Toroparu deposit (8.4 Moz Au, 6 Moz Ag, 396 Mlb Cu), build upon these findings to refine exploration vectors and expand their applications in various Precambrian gold settings.

NUMERICAL MODELING INVESTIGATIONS OF HYDROLOGIC REGIME SHIFTS DURING PERMAFROST TRANSITION PERIODS (WOLF CREEK CATCHMENT, YUKON)

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Permafrost is warming and thawing on a global scale due to anthropogenic climate change. Regions which currently have continuous or discontinuous permafrost coverage are expected to experience a significant decrease in permafrost extent and thickness. The influence of groundwater on permafrost thawing and talik formation has recently been investigated, but such studies have generally been conducted for small, two-dimensional hillslopes. For this study, a FEFLOW groundwater model of the Wolf Creek catchment in the Yukon Territory was constructed. Wolf Creek is a 200 km^2 catchment that comprises both high-elevation alpine areas and low-elevation forested areas, with the current permafrost distribution in the catchment varying significantly according to elevation and aspect. Groundwater flow, aquifer-surface water interactions, and heat transport are modelled with FEFLOW, while phase change mechanics are simulated using the FEFLOW plug-in piFreeze. Surface boundary conditions are implemented using data from the multi-decadal measurements for the catchment, including atmospheric measurements and soil temperature records. The model will be used to investigate what happens during periods of permafrost transitions, and what role groundwater-surface water interactions play in these transitions. Additionally, due to the topographical and ecological variations of the catchment, the catchment will be used in a "space-for-time" approach, as areas currently classified as low-elevation forested biomes will expand and comprise an increasing portion of the catchment. Similarly, areas currently considered as barren and alpine may experience the formation of vegetation cover and altered permafrost dynamics. The model will also be used to simulate what happens during periods of permafrost formation during future cooling climates as such transitions are of international interest in the context of nuclear waste storage.

PRISMA HYPERSPECTRAL DATA EVALUATION FOR MINERAL IDENTIFICATION

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The hyperspectral remote sensing imagery has been developed as a potential tool for mapping new mineral resources. Excellent spectral resolution can be used to find the spectral signature of target materials which is required to discriminate different minerals. Specific minerals can be identified via their peculiar absorption bands. Absorption depth, position, and asymmetry are directly related to the chemistry of the earth materials and are crucial in surface mineral mapping. Due to the low spatial resolution of space-borne hyperspectral imagery, each pixel might be a mixture of various materials that might be present on the ground. The development of satellite-borne hyperspectral sensors started with EO-1 Hyperion launched in 2001 and was the main space-borne hyperspectral data for more than one decade. In 2019, the Italian Space Agency launched PRecursore IperSpettrale della Missione Applicatava (PRISMA) with different levels of radiometric, geometric, and atmospheric corrections. It has a 30 km x 30 km SWATH with a total acquisition capacity of 1800 km in a continuous strip, 12 nm spectral resolution for the VNIR and SWIR bands (400–2500 nm). This study tries to evaluate (atmospherically corrected) D2 level PRISMA data for hydrothermal mineral identification for further mapping. Investigation of different spectral signatures of various hydrothermal minerals from PRISMA hyperspectral imagery has been focused on in this research. Dimensionality reduction and spectral unmixing/end-member extraction algorithms were performed to initially extract the spectral characteristics of different minerals in the scene.

CONSTRAINING THE DUCTILE DEFORMATION MECHANISMS OF GARNET ACROSS PRESSURE-TEMPERATURE SPACE

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Garnet is a common mineral at elevated pressures and how it deforms plays an important role in the strength of lower crustal shear zones, subduction thrusts, and the mantle. Strong shape preferred orientations in elongate garnets at elevated temperatures and pressures attests to garnet's ability to deform through ductile mechanisms; however, how individual garnets deformed is frequently ambiguous or disputed. Garnet microstructures from the Morin shear zone and the Sulu ultra-high pressure terrane are revisited using fine-scale electron backscattered diffraction and wavelength dispersive spectroscopy mapping. The dominant deformation mechanism at each site is re-interpreted, and we show that garnet deformed through dissolution-precipitation creep at Sulu and through dislocation-assisted diffusion creep at Morin. These observations are integrated into a compilation of ductile deformation microstructures for garnet which reveals domains where dissolution-precipitation creep, recovery-accommodated dislocation creep (through subgrain rotation dynamic recrystallization), and dislocation-assisted diffusion creep dominate in P-T space. Garnet may deform through ductile deformation at temperatures as low as ~500°C and deforms under low differential stresses in both eclogite and granulite facies conditions. The efficacy of deformation indicates that 1) garnet may not be the strongest phase in these environments; and 2) that at elevated temperatures, inclusion barometry may be affected by garnet's inability to maintain high differential stress.

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GROWTH RATES AND AGES IN THE DEEP-SEA BAMBOO CORALS *ACANELLA ARBUSCULA* AND *KERATOISIS* SP. FROM THE NORTHWEST ATLANTIC AND EASTERN CANADIAN ARCTIC

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Deep-sea corals often have high longevities and slow growth rates, and can provide habitat for invertebrates and fish, including commercially fished species. However, they are currently threatened by anthropogenic activities such as bottom-contact fishing, as suggested by the common presence of deep-sea corals in fishing bycatch. The deep-sea bamboo corals *Acanella arbuscula* and *Keratoisis flexibilus* are conspicuous components of mud-bottom habitats in the Northwest Atlantic. Little is known about their growth rates and longevity, which are important indicators for how quickly the species may recover from anthropogenic disturbances. To address this lack of knowledge, colonies of *A. arbuscula* and *K. flexibilus* were collected using a remotely operated vehicle aboard the CCGS *Amundsen* in 2021. *A. arbuscula* colonies were collected on the SE Baffin Slope (Davis Strait) at ~1300 m depth and *K. flexibilus* colonies were collected at Disko Fan (SE Baffin Bay) at ~900 m depth. Additional colonies of *A. arbuscula* previously collected were used to compare geographic and bathymetric variation in growth rates and ages, particularly focusing on colonies from the SW Grand Banks, Northern Labrador Sea, and Davis Strait. Longevity and growth rates were determined from growth ring counts at the proteinaceous nodes of their skeletons. To validate growth ring periodicity and longevity estimates, laser-ablation bomb-^{14}C analyses will be conducted at the proteinaceous nodes of the coral skeletons. Both species exhibited major and minor growth banding, with *A. arbuscula* having 3–12 and *K. flexibilus* having 3–9 minor growth rings per major ring. Based on relationships of major and minor rings with size metrics, major rings were determined to represent annual banding in both species. Growth ring counts in *A. arbuscula* indicate ages of 9–29 years, radial growth rates of 0.025–0.16 mm·year^{-1}, and linear growth rates of 1.9–16.1 mm·year^{-1}. A weak relationship exists between depth, and growth rate and age. Radial growth rates were fastest, yet colonies were youngest in Davis Strait, while growth rates were slowest, yet colonies were oldest in the SW Grand Banks. Growth ring counts in *K. flexibilus* indicate ages of 13–40 years, radial growth rates of 0.037–0.143 mm·year^{-1}, and linear growth rates of 6.8–41.6 mm·year^{-1}. *K. flexibilus* growth rates and ages will be compared to *Keratoisis grayi*, as *K. grayi* colonies have been observed primarily in the SW Grand Banks attached to hard substrate, while *K. flexibilus* from Disko Fan form dense thickets on mud bottoms.

PALEOMAGNETISM FROM THE EDIACARAN OUARZAZATE GROUP, MOROCCO

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The first evidence for widespread metazoan life and appearance of complex biological strategies is found in fossils from the Ediacaran Period (635–539 Ma). These biological advances coincided with dramatic geochemical and environmental perturbations of the Earth system that are not well understood. Paleogeography has important implications for nutrient cycling, climate, and the proliferation of life on Earth. A sparsity of reliable paleomagnetic evidence from the Mid Ediacaran to the Early Cambrian has long presented problems when reconstructing paleogeography. Paleomagnetic poles from this period suggest rapid movement of continents and are at odds with our current understanding of plate tectonics. True polar wander, where the solid Earth rotates uniformly about an equatorial axis, has been invoked to account for discrepancies in the paleomagnetic record. Alternatively, a weak and rapidly reversing magnetic field has been invoked. To investigate these discrepancies, we sampled the Ouarzazate Group from the West African Craton (WAC) in order to constrain its paleogeography and characterize the magnetic field. High-precision magnetostratigraphy and geochronology can assess geomagnetic reversal rates. In context with reliable preexisting paleomagnetic data from the WAC and other cratons, this approach will allow us to achieve our overarching goal: reconstructing paleogeography across the Ediacaran–Cambrian transition and understanding the circumstances that led to the appearance of the Ediacara biota and the Cambrian explosion of animal diversity. This presentation will discuss preliminary paleomagnetic results from the Ouarzazate Group and their paleogeographic and geodynamic implications.

RECENT ADVANCES IN OUR UNDERSTANDING OF VMS DEPOSITS

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Volcanogenic massive sulphide (VMS) are important contributors of metal to the Canadian and global economy and have been studied both on land and via their seafloor massive sulphide (SMS) cousins on the seafloor. Despite extensive studies, new advances continue to occur. New insights have come from integrated studies of deposit geodynamic settings and their secular evolution, the importance of crustal architecture and substrate in metal budgets and abundances in deposits, emplacement mechanisms and the processes related to subseafloor sulphide accumulation (i.e. replacement), roles of basin redox and biotic controls on deposit genesis, mechanism of metal incorporation and metal residence as deduced from microanalytical methods, rates of mineralization formation and basin development due to advances in geochronology, and the importance of magmatic fluids/volatiles on the metal budget in some deposits. In the coming decades the utilization of integrated field, geochemical, geochronological, and microanalytical work, coupled with comparative studies with SMS, will be important for answering questions that are still incompletely or poorly understood regarding the setting, style, genesis and exploration for onland VMS deposits. These questions and suggested directions for research and development will be discussed in this presentation.

INVESTIGATING THE HYDROTHERMAL ALTERATION OF THE POCOLOGAN-KENNEBECASIS SHEAR ZONE, CANADIAN APPALACHIANS, USING WHOLE ROCK GEOCHEMISTRY AND MOLAR ELEMENT RATIO ANALYSIS

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The dextral strike-slip Pocologan-Kennebecasis shear zone (PKSZ) hosts polymetallic mineral occurrences (Au-Fe-Ag) indicating that the region may be prospective for magmatic-hydrothermal mineralization similar to the Cobequid Highlands of Nova Scotia. The felsic orthogneiss that hosts the PKSZ is characterized by three distinct mineral assemblages: (A) zoisite, no muscovite; (B) zoisite and muscovite; (C) muscovite and potassium feldspar. Herein, we test whether these mineral assemblages are indicative of primary lithological variation or hydrothermal alteration using major and trace element geochemistry, and we quantify the age of deformation and alteration of the PKSZ using in-situ apatite U–Pb petrochronology. Exploratory analysis of whole rock compositions indicates that, with respect to Zr, no major or rare earth elements (REE) except Eu and Hf were conserved in specimens with mineral assemblages B and C. Thin section observations and mobile element ratios indicate that the PKSZ records a successive enrichment in K+Al+Si leading to sericitization of plagioclase, followed by the albitization of plagioclase (+Na) and the formation of potassium feldspar; Fe and Mg were also depleted through this process. Additionally, the REE compositions of the most altered specimens (assemblage C) are characterized by a negative Eu anomaly that is absent in specimens with mineral assemblage B. Apatite grains from three specimens representing assemblages B and C were imaged with backscattered electron methods prior to laser ablation U–Pb geochronology. The grains are 50 to 200 μm in diameter with euhedral to xenomorphic cores surrounded by foliation-parallel overgrowths. The apatite analyses define discordant U–Pb spreads, with lower intercept ages ranging from 377 +44/-45 Ma to 313 +20/-21 Ma for the most altered specimens, and 341 +15/-16 Ma for the least altered specimen. Whereas the apatite REE signatures from the most altered specimens have a negative Eu anomaly, only the youngest analyses from the least altered specimen have a negative Eu anomaly. Such results indicate that the apatite negative Eu anomaly may reflect the bulk rock relative enrichment in REE with respect to the least mobile Eu. The geochemical and geochronological results indicate that the PKSZ records a protracted deformation and alteration history. The

alterations can be tracked with whole rock geochemistry, and can potentially be dated with apatite petrochronology. Finally, these alterations are collocated with Au-Fe-Ag occurrences, indicating that the potential of the Canadian Appalachians for IOCG mineralization may extend beyond the Cobequid Highlands of Nova Scotia into the syn-kinematic structures of southern New Brunswick.

FROM CORES TO CODE: IGCP 725'S PLAN TO BRIDGE THE GAPS BETWEEN GEOLOGY, PROCESS, AND NUMERICAL MODELLING TO IMPROVE FORECASTS OF COASTAL CHANGE

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Coastal communities are prone to a range of geohazards, including sea-level rise, storms, subsidence, and tsunamis. They can result in major changes to our coastlines, causing loss of life, damage to infrastructure, economic hardship, and degradation of coastal ecosystems. A key scientific goal is improving the ability to forecast system response to coastal change across spatial and temporal scales, thereby enabling effective decision-making about how best to manage the coastal zone and reduce risk. Accurate forecasts of coastal change are best achieved by combining geological field and laboratory data with predictive numerical models. However, coastal geologists and numerical modellers often approach the issue in different, and not always complementary, ways. To overcome this key issue, IGCP Project 725, a 5-year initiative starting in 2021, aims to bring together scientists from coastal geosciences and numerical modelling to improve the predictive capacity of numerical models to fore- and hind-cast coastal change. Project 725 builds on previous IGCP projects by continuing to encourage early-career researchers and those from developing countries to participate and contribute their expertise in an ever-more societally relevant field of science. This project has three main objectives: 1) bring together scientists from cognate sub-disciplines of geoscience (e.g. geomorphologists, sedimentologists, stratigraphers, geoarchaeologists, and geochemists) and modelling (e.g. process, sediment transport, morphodynamic, inundation, and coastal erosion); 2) produce a 'best practice' guide for how geoscientists can effectively use and integrate models into their investigations in a range of coastal settings, over a range of timescales (past and future), and for different applications; and 3) develop guidelines for effective communication of evidence- and science-based coastal policy. In this presentation, we discuss how we intend to address these project objectives through a series of print reports, publications, special issues, online workshops, presentations, and discussion panels, as well as in-person meetings and field trips.

FRACTURE FILL MINERALOGY AND CHEMISTRY FROM THE OBERON GOLD DEPOSIT, NORTHERN TERRITORY, AUSTRALIA

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With an ever growing population and an increase in technology, the demand on mineral commodities has risen and the exploration of new ore deposits is crucial to provide for future generations. However, the discovery of new ore deposits provides a challenge as many of the deposits are undercover and at depths previously underexplored. New geochemical exploration techniques need to be developed to detect the dispersion of mobile ions associated with ore deposits against background concentrations. Fractures provide open permeable pathways for elements to migrate along and can facilitate element dispersion from ore deposits into the surrounding environment. Classification of the mineralogy and chemistry of fracture fill above ore deposits and understanding how elements migrate along these pathways could be important for future exploration. The Oberon gold deposit is located in the Northern Territory, Australia, near the Newmont Tanami Operations about 550 km northwest of Alice Springs. The deposit is hosted in a sequence of metasedimentary rocks that have been folded to form a doubly plunging anticline, which is intersected by multiple igneous intrusions. Abundant gold deposits exist within the region but exploration remains a challenge, as many deposits are undercover. The Oberon gold deposit lies under cover, yet shows elevated Au and As anomalies at surface. Fracture samples were collected from six drill holes surrounding the deposit to understand if fractures can record the migration of elements from the ore deposit through fracture networks to the surface. Fracture samples were collected from a wide variety of depths and proximal and distal to the observed surface anomalies. Preliminary field data show a wide variety of fracture colours exist surrounding the Oberon gold deposit. The eight main fracture colours include: 1) orange; 2) purple; 3) white; 4) red; 5) green; 6) black; 7) brown; and 8) multi-coloured. The variation in colours suggests changes in mineralogy and chemistry upwards through the overburden above the deposit. In addition, some samples show a mixture of colours, possibly recording multiple fluid flow occurrences. Fracture fill mineralogy and chemistry data from energy dispersive spectroscopy (EDS) analysis with a scanning electron microscope (SEM), visible, near-infrared and shortwave-infrared (VNIR-SWIR) spectroscopy, and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) will be presented to show the applicability of fractures as a tool for mineral exploration within the region.

A TOOL FOR THE EXPLORATION OF UNDERCOVER ORE DEPOSITS: LASER ABLATION ICP-MS METHOD FOR THE IN-SITU MEASUREMENT OF ELEMENT CONTENTS AND Pb ISOTOPE RATIOS ON FRACTURE COATINGS IN DRILL CORES

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Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) for in-situ measurement of element concentrations and isotope ratios in geological samples is a powerful tool that has allowed for increased analytical sensitivity and spatial resolution. Several recent studies have demonstrated the use of fracture coatings in mineral exploration but require laborious removal and acid digestion of fracture coatings. With this in mind, element contents and Pb isotope ratios in fracture coatings were measured for samples from the McArthur River unconformity-hosted uranium deposit, Athabasca Basin, Canada using image mapping LA-ICP-MS to establish an in-situ method for analyzing the chemistry of fracture coatings. Classifying the chemical composition of fracture coatings above ore deposits is a useful proxy for mineral exploration, as fractures provide permeable fluid pathways for element dispersion from ore deposits into the surrounding rocks and overburden. The development of an in-situ method of analyzing the chemical composition of fracture coating, allows for the study of fracture coatings to be applied to a wide range of geological environments and deposit types, especially where fracture coatings are insufficient for acid digestion methods. High resolution compositional maps of mounted fracture coatings from backscattered electron (BSE) imaging show varying topography and mineralogy on fracture coatings including Mn and Fe oxide, clay, silicate, and carbonate minerals. Areas of interest (~500 by 500 ìm) were targeted in a cell spaced grid pattern using a 50 ìm spot, with 200 ìm spacing between spots and 100 ìm between lines using an ESI-NWR Eximer 193 nm ArF Laser Ablation System interfaced to a quadrupole ICP-MS. Rasterized maps generated in Iolite™ effectively demonstrate the chemical distribution of element contents and Pb isotope ratios on the fracture coatings allow for the chemical mapping of minerals. Sample spacing, depth of laser penetration and reproducibility were varied in this study to develop optimum parameters for in-situ fracture coating analysis to overcome sample surface topography and more rapid sample acquisition time without loss of spatial resolution and analytical sensitivity. Bulk geochemical values can be calculated using an integration of 2-D image data and are compared to different fracture coating acid digestion methods (i.e. aqua regia, weak acid leach) and the implications to exploration programs are discussed. This is the first application using LA-ICP-MS for measuring element concentrations and Pb isotope ratios in-situ on fracture coatings and demonstrates its importance as a new geochemical tool to the mining industry for future mineral exploration.

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VARIABILITY IN SEDIMENT PROVENANCE IN THE NEOPROTEROZOIC WINDERMERE SUPERGROUP, SOUTHERN CANADIAN CORDILLERA: MULTI-ISOTOPE AND TRACE ELEMENT PERSPECTIVES

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Interest in the Neoproterozoic Era (1000–542 Ma) has grown steadily over the past few decades as it represents a pivotal time of change in a number of Earth systems. These significant events involve three potentially global glaciations following a 1.5 billion-year-long interglacial period, a transition to a more oxic atmosphere that may have stimulated the evolution of metazoan life, and, of particular interest to this study, the assembly and breakup of the supercontinent Rodinia. Events surrounding the origin of the passive margin forming the western edge of the ancestral North American continent (Laurentia) are an important constraint on the breakup of Rodinia and set the stage for the Phanerozoic evolution of western Laurentia. One of the prime areas to study the history and the breakup of Rodinia is the Neoproterozoic Windermere Supergroup (WSG), located in the southern Canadian Cordillera. The WSG represents a 7–9 km-thick continental rift-to-drift succession associated with the breakup of Rodinia and subsequent development of a passive margin and deposition of mostly siliciclastic-rich deep-marine strata. This study focuses on a 2.5 km thick succession of basin-floor to base-of-slope deposits exposed in the Castle Creek study area in British Columbia. Detrital zircon geochronology of deep-water WSG strata show a consistent bimodal distribution of Paleoproterozoic (~1.8 Ga) and Archean (> 2.5 Ga) U–Pb dates suggesting a long-standing and stable continental drainage system with an eastward-lying cratonic sediment source. However, a recent high-resolution geochronology study yielded discordant detrital zircon ages ca. 2.4–2.0 Ga in continental slope deposits of Isaac Formation, suggesting a major, but only temporary change in the drainage basin. New field stratigraphic data, combined with Sr and Nd isotope geochemical studies and analysis of trace elements by ICP-MS, were conducted on strata of the WSG in order to investigate this marked change in sediment provenance and better understand the complex drainage patterns along the northwestern passive margin of Neoproterozoic Laurentia.

ASSESSMENT OF THE OCCURRENCE AND GEOCHEMICAL CONTROLS OF Mn CONCENTRATIONS IN GROUNDWATER OF ALBERTA, CANADA

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Reliance on groundwater resources to supply clean drinking water to rural and urban communities is increasing considerably around the world. Thus, groundwater systems need to be monitored for elevated concentrations of natural and anthropogenically derived contaminants to ensure that water quality for human consumption meets applicable health guidelines. Manganese (Mn) contamination of drinking water sources is a rising concern due to possible neurotoxicity for animals and humans and especially in children. The objective of this ongoing study is to investigate the occurrence of Mn in groundwater in the province of Alberta (Canada) and to explore the geochemical processes that result in elevated Mn concentrations in aquifers. To achieve this objective, we evaluated water quality data for groundwater from domestic and monitoring wells while considering information on well completions and geological formations in which the wells are screened. Preliminary results from more than 10,000 groundwater samples collected between 1960 and 2020 with measured Mn concentrations indicate that Mn is ubiquitous in groundwater throughout the province. A total of 2580 or 23% of the groundwater samples were associated with elevated Mn concentrations above the Health Canada maximum acceptable concentration (MAC) of 0.12 mg/L. Groundwater samples with elevated Mn concentrations were predominantly associated with calcium-bicarbonate water and derived from shallow wells (10 m below ground surface). Ongoing research will further explore the dependence of the occurrence of elevated Mn concentrations in groundwater on redox conditions and other chemical variables to constrain the dominant sources and sinks of dissolved Mn in groundwater systems of Alberta. This study will help to improve the scientific knowledge of the geochemical processes controlling Mn in groundwater and to ensure safe water quality for the population that depends on groundwater for their drinking water supplies.

MAPPING TECTONIC STRESS AND FOREARC STRUCTURE AT SUBDUCTION ZONES USING EARTHQUAKE FOCAL MECHANISMS

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Although earthquake focal mechanisms (perhaps more than any other data source) have contributed substantially to our understanding of modern tectonic stress regimes, they have rarely been used to systematically map stresses across broad regions, and stress variations with depth are almost never considered. This study presents 3-D grids of tectonic stress tensors using pre-existing focal mechanism catalogs from several subduction zones, including Cascadia, Japan, Mexico, and northern Chile. We bin data into 25 x 25 x 10 km cells (north, east, vertical), with 50% overlap. The resulting maps and cross-section views of stress can be used to infer a degree of coupling on the plate interface, from homogeneous stress across locked areas of plate-interface to 90° stress tensor rotations across freely slipping areas. Similarly, by dividing the focal mechanisms catalog in northern Japan into those before and those > 6 months after the 2011 Mw 9.1 Tohoku-Oki earthquake, we are able to produce detailed 3-D maps of stress rotation, which approaches 90° in the areas of highest slip. These results could inform future geodynamic rupture models of megathrust earthquakes in order to more accurately estimate slip, shaking, and seismic hazard. Whereas some regions, such as northern Cascadia, have nearly homogeneous stress within the continental forearc, other regions, such as southern Cascadia and southern Japan, appear to have rheological discontinuities at ~20 km depth; this depth roughly coincides with the previously documented Conrad discontinuity in seismic velocity. This observation may help us unravel the lithologic composition of the different forearcs and how that composition influences subduction zone behaviour and seismic hazard.

METALLOGENESIS AND EXPLORATION POTENTIAL OF REE-Th-U MINERALIZATION IN THE ALCES LAKE AREA, CANADA AND WEST AZOV AREA, UKRAINE

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The importance and need for rare metals are increasing rapidly nowadays for the economic development of countries as more and more green technologies are coming on stream and being used. Rare earth elements are considered a strategic critical raw material (critical metals), thus identification and documentation of the key characteristics/parameters of their metallogenetic history and tectonic environment would give new mineral prospectivity and targeting methods for identifying new high-grade mineralization areas of interest. In this research, the authors are carrying out a study of selected REE-Th-U mineralized occurrences of the Canadian (Alces Lake, SK) and Ukrainian (Dibrovo, West Azov area) Shields. The main objective is to study the lithological, petrological and geochemical data from both areas in order to identify parameters responsible for the genesis of this high-grade REE-Th-U mineralization. Mineralization of both study areas, i.e. Alces Lake within the Beaverlodge Domain (Canada) and West Azov region within the Azov Block (Ukraine), has a complex genesis, related to Paleoproterozoic tectonic events (the main one circa 2.0–1.9 Ga) that highly deformed and metamorphosed the meta-sedimentary (and meta-igneous) Archean/Paleoproterozoic rocks. As a result, abundant granitic and pegmatitic sheets were produced throughout the Beaverlodge Domain and the Azov Block. Mineralization of both Precambrian areas occurs at or near the unconformity surface between the Archean basement rocks and the Paleoproterozoic metamorphosed meta-sedimentary/meta-igneous rocks. In this current study, we conducted various mineralogical, petrological, and geochemical analyses of outcrop and core samples in order to understand the complex processes responsible for the genesis of the critical metals and to identify the key mineralization characteristics/parame-

ters for targeting and evaluating economically the REE-Th-U complexes (i.e. similarities and/or differences) of the Canadian and Ukrainian Shield areas. Within the Alces Lake area the high-grade mineralization is found within monazite-rich granitic to residual melt/cumulate pegmatites, enriched in REE, Th, U, Ga, and Zr, which are associated with biotite-rich (± sulphides) paragneiss. In the Dibrovo area, economic grade mineralization is localized in metasomatically altered microcline metasedimentary quartzites, and to a lesser extent in dynamo-metasomatically altered pegmatites, which penetrate the quartzites. Samples taken from both areas are strongly enriched in LREE and relatively depleted in HREE with significant negative Eu anomalies. The geochemical data, coupled with the micro to macroscopic sample observations, confirm the metasedimentary source rock of Dibrovo mineralization and indicate a possible metasedimentary source (± mantle contribution) for the Alces Lake REE mineralization.

INVESTIGATIONS OF THE SOURCE OF SULPHUR AND CHLORINE IN THE SIBERIAN TRAPS

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Emplacement of the Siberian Traps large igneous provinces (STILP) (~252.28 ± 0.011 Ma) appears to have triggered the end-Permian extinction ~251.941 ± 0.371 Ma where 95% of life on Earth disappeared. Volatiles released during the eruption caused significant environmental degradation that contributed to the end-Permian mass extinction, though the rate of the outgassing is unknown. The volatile source for the magmas has been suggested to be due to assimilation of sedimentary units including evaporites with gypsum and anhydrite and coal. Sulphur (S) and chlorine (Cl) assimilation is estimated to contribute 6300–7800 Gt S and ~3400–8700 Gt Cl. The objective of this research is to quantify the S and Cl diffusion and to analyze their interactions with the basaltic magma. Laboratory experiments are being performed to simulate the assimilation during STILP magmatism using a dyke composition from the Central Atlantic Magmatic Province and crystals of gypsum and anhydrite. Later experiments will use a meymechitic melt composition modeled on those of the STILP. Preliminary results for dissolution of a ~2.5 mm diameter by 1 mm long gypsum cylinder in the basalt demonstrate the transport of S and H_2O over a distance of 2 mm in only 30 minutes at 6 kbar and 1250°C, leading to estimated diffusivities of both volatiles on the order of 10^{-9} m^2 s^{-1}; however, exact diffusivities could not be extracted because the enriched water concentration in the melt, due to gypsum dissolution, resulted in extensive quench-crystal growth. Nevertheless, these diffusivities are approximately two orders of magnitude greater than the diffusion of sulphur in the anhydrous basalt. Initial results for the anhydrite crystals (0.5–2 mm in length) added to the basalt show complete dissolution. An estimated total of ~15,530 ppm S was added to the basalt through the anhydrite. Understanding the rate at which assimilation of evaporite minerals by basaltic magma occurs will allow construction of a model that can predict the rate of volatile uptake within a magmatic system. Specifically, the model will assist in determining the rate of S and Cl assimilation in basaltic magmas for varying dyke sizes. In addition to the STILP's impact on the biosphere, because the STILP is associated with one of the largest Ni-Cu-Pd deposits, understanding the diffusivity of S could help us understand how efficiently S can be added to magmas to generate sulphide ore deposits.

VIABILITY OF IN SITU CARBON DIOXIDE SEQUESTRATION IN MANTLE PERIDOTITE OF APPALACHIAN OPHIOLITES

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On Earth, carbon sequestration in geologic units plays an important role in the carbon cycle; removing CO_2 from the atmosphere for long-term storage in various rock reservoirs. Stabilization of atmospheric CO_2 at a level that does not lead to an increase in global temperature requires capture of carbon dioxide through natural or engineered sequestration. Various methods for carbon dioxide removal are gaining increasing attention as a potential mitigation technology to stabilize the atmospheric concentration of CO_2. Geological carbon sequestration is one of several approaches for removing CO_2 from the atmosphere and ensuring its long-term storage in the subsurface. The efficacy of these geological carbon reservoirs, however, depends on the storage capacity, retention time, reservoir stability, cap rock impermeability, and mobility of CO_2 to prevent leakage. A viable solution for long-term carbon storage involves the engineered chemical reaction of CO_2 with silicate minerals in ultramafic rocks. Mantle peridotite, tectonically exposed in ophiolite offers the greatest potential for in situ carbon mineralization. A prominent belt of ophiolite suites is present across the Appalachian orogen in Newfoundland and occurs as discontinuous massifs exposed in a series of structurally emplaced allochthons. The Bay of Islands complex, in western Newfoundland, is the largest and most complete ophiolite suite in North America, comprises four major massifs, and contains the best-preserved mantle peridotites in the world. Other ophiolite sequences in western Newfoundland include the Little Port, Betts Cove, Advocate, St Anthony, and Annieopsquotch complexes. Ophiolites exposed in eastern Newfoundland include the Gander River, Pipestone Pond, Coy Pond, and Great Bend complexes. Ultramafic rocks in ophiolites are low in silica and have high concentrations of calcium, magnesium, and iron-rich olivine and pyroxene, making them a source of alkalinity with the highest capacity for secure CO_2 storage. Mineral carbonation has a distinct advantage over other sequestration methods because it utilizes the natural process of serpentinization to convert atmospheric CO_2 into stable carbonate minerals. Ophiolite sequences may offer an important, hitherto neglected, repository in the global carbon cycle as carbonate minerals are geologically stable, therefore ensuring permanent sequestration of CO_2 in solid phases for thousands of millennia.

KINEMATICS AND DEFORMATION CHRONOLOGY IN THE ELLSWORTH BELT, MAINE

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The Cambrian Ellsworth belt is one of several fault-bounded blocks exposed along the southeastern coast of Maine that formed within the peri-Gondwanan realm of the Appalachian orogen. The Ellsworth belt remains an inadequately documented yet highly significant part of Ganderia as it is interpreted to record Ganderia's departure from the Columbia segment of Amazonia prior to 500 Ma. Despite its prominence in Ganderia, understanding of fundamental aspects of the Ellsworth belt such as its geometry, kinematics, relative timing of deformation structures, and accretionary history with respect to Paleozoic continental elements is poorly constrained. The Ellsworth belt comprises a structurally complex supracrustal assemblage that includes polydeformed quartz–feldspar– chlorite–mica schists (Ellsworth Schist) and Miaolingian bimodal volcanic rocks of marine origin. The deformed Lamoine Granite is a 1500 m long, east–west striking sill that was emplaced within the Ellsworth Schist at 492 ± 1.7 Ma, approximately 16 million years after deposition of the protolith of the Ellsworth Schist. This is the first unequivocal evidence of Furongian magmatism in the Ellsworth belt. Emplacement of the Lamoine Granite was succeeded by a regional shortening event leading to the development of the main S2 fabric of the Ellsworth Schist, which is also present within the Lamoine Granite. Regional shortening of the Ellsworth belt was a tectonometamorphic event that formed under greenschist facies conditions in the mid-crust. Kinematic indicators support progressive horizontal shortening and crustal thickening attributed to thrust faulting. Abundant microfractures along fold hinges and deformed extensional quartz veins associated with the S2 foliation are consistent with a brittle strain pattern of deformation under conditions of low deviatoric stress at a relatively high structural level in the lithosphere. A maximum age of 492 Ma for regional metamorphism indicates that an earlier thermal event produced an older S1 fabric present in the Ellsworth Schist interpreted as a gravity-driven compaction foliation of hot volcanogenic sediment. Polarities of structures, degree of metamorphism, and style of plutonism of the Ellsworth belt resemble Paleozoic rocks and structures in Atlantic Canada. The Cambrian age of the Lamoine Granite permits correlation with the Cameron Road Granite in the Annidale belt of New Brunswick where subduction-related magmas intruded the Penobscot arc–back-arc and were subsequently deformed during the Penobscot Orogeny.

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DEGRADATION OF THE HERBICIDE METOLACHLOR IN A FRACTURED BEDROCK AQUIFER: INSIGHTS FROM COMPOUND-SPECIFIC STABLE ISOTOPE ANALYSIS

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Pesticides are increasingly detected in groundwater worldwide and pose a major threat to ecosystems and public health. Despite their ubiquity, little is known about the long-term fate of such compounds at the field scale due to the difficulty in demonstrating their in situ degradation. Compound-specific isotope analysis (CSIA) is a promising tool to address this issue. During the transformation of organic contaminants, molecules with light isotopes (e.g. ^{12}C, ^{35}Cl) are usually degraded at a different rate than those with heavy isotopes (e.g. ^{13}C, ^{37}Cl), creating a fractionation in the undegraded molecules and providing direct evidence of the compound transformation. This approach has been limited for a long time to legacy contaminants, but recent analytical progresses have made the application of CSIA to pesticides realistic at typical environmental concentrations (i.e. sub-µg/L range). This study focuses on a metolachlor (halogenated organic herbicide) plume discovered in 1992 in a fractured dolostone aquifer in Ontario, Canada. Sequestration of mass in the matrix led to the present-day conditions in which back-diffusion from the rock matrix into groundwater moving in the fracture network results in a persistent low concentration plume. However, data indicate that metolachlor concentrations have been recently decreasing. The goal of this study was to assess whether this observed decrease of concentrations could be associated to metolachlor degradation in the aquifer. Several multi-level systems have been sampled and groundwater was analyzed for hydrochemistry and multi-elements CSIA (carbon, chlorine) was also conducted for metolachlor. CSIA demonstrated metolachlor degradation, indicating that biotransformation contributes to the observed mitigation. Data also indicate that different transformation pathways may be responsible for metolachlor degradation in this aquifer, although this aspect should be further explored in process-specific studies. A large fractionation was observed for chlorine compared to carbon isotopes. Chlorine therefore proved to be a particularly sensitive indicator of metolachlor degradation and a highly relevant parameter to include in future studies.

DISMANTLE TO REBUILD - SYSTEMIC RACISM AND DECENTERING WHITENESS: THE ROLE OF THE EARTH SCIENTIST

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The proportion of white women and women and men of colour who pursue earth sciences has only shifted slightly. Essentially, the pipeline leading to engineering education and to the engineering profession is still largely filled with white privilege. We must also challenge engineering and science educators to think critically about course curricula and outcomes – recalibrating, based on expectations about daily lives and anticipating that students are experiencing subtle and overt racism throughout each day. How to rebuild? How to decentre? For me, it's turning to my Indigenous heritage – rebuilding my true self. Together, we will make a difference, and the centre of earth sciences will be rebuilt to become a true reflection of all communities; to be of great service to society; to make the world a better place.

MONITORING IN-SITU THERMAL TREATMENT PROGRESS TO PREDICT POST-TREATMENT GROUNDWATER QUALITY

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Manufactured gas plants (MGPs) were prevalent throughout North America to satisfy the demand for gas lighting in the early 1800s to 1950s. A by-product of manufactured gas is coal tar, a semi-volatile dense non-aqueous phase liquid (DNAPL) composed of hundreds of compounds with varying properties, including polycyclic aromatic hydrocarbons (PAHs). Historic waste disposal practices led to releases of coal tar and impacts to soil and groundwater, where it can pose serious health and environmental risks. Former MGPs are typically located near urban centres and waterfronts, on valuable land that is highly sought after for redevelopment if soil and groundwater quality standards can be met. In-situ thermal treatment (ISTT) is often used to treat coal tar-contaminated sites when stringent remediation objectives must be met over short timeframes. However, the high energy demand of many ISTT technologies leads to higher costs and a larger carbon footprint. These costs are increased if heating continues longer than necessary. Therefore, there is a need to establish approaches to accurately track the progress of ISTT at coal tar-contaminated sites to lower its energy demand and promote sustainable remediation. This study outlines an approach to track ISTT progress and support shutdown decisions based on both mass removal and groundwater quality (concentration) objectives. An analytical model was developed to predict PAH removal and subsequent groundwater concentrations after ISTT of coal tar and was compared to a laboratory experiment. Experiments were conducted in a 1 L stainless-steel cylinder packed with sand, water, and a synthetic coal tar of known composition. Conductive heat was applied to the cylinder, producing water and PAH vapour which escaped via a recovery line. PAH recovery was monitored by collection and sampling of condensate during DNAPL-water co-boiling and DNAPL heating. PAHs were predominantly removed between 260°C and 450°C, with early-stage condensate composed of higher volatility PAHs and later-stage condensate composed of lower volatility PAHs. Modelling and experimental results showed that tracking intermediate-volatility PAHs (e.g. fluorene) could provide information over a wider range of temperatures during heating and could be used to infer PAH groundwater concentrations that would result from different levels of treatment. It is expected that the results of this study could be used by practitioners to support shutdown decisions by monitoring PAH removal when reduced groundwater concentrations are the treatment objective.

MINERALOGY AND PETROLOGY OF THE GOOD HOPE CARBONATITE COMPLEX, MARATHON, ONTARIO

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The Good Hope carbonatite is located northwest of Marathon, Ontario (49°02'N, 86°43'W). It occurs along the northwest margin of the Prairie Lake complex. Due to extensive glacial overburden, the Good Hope carbonatite has very limited outcrop. Most thin sections examined were cut from drill core for optical petrography, SEM-BSE imagery, and quantitative EDS. The objectives of this research are to characterize the carbonate and other mineralogy of the Good Hope carbonatite, use mineral compositions and textural associations to discuss the petrogenesis, and compare and contrast the mineralogy of the Good Hope and Prairie Lake carbonatites to assess potential relationships. The major rock-forming minerals in the Good Hope carbonatite are ferroan dolomite, calcite, and apatite. The apatite occurs predominantly as elongated aggregates and clasts that define heterogeneous banding within the carbonatite. The groundmass is composed of either ferroan dolomite or calcite with significant variation in the modal mineralogy at the thin section scale. The minor minerals include dolomite, orthoclase, quartz, chlorite, magnetite, barite, biotite–phlogopite, magnesio-arfvedsonite, aegirine, pyrochlore, albite, and fluorite. The accessory minerals include pyrite, synchysite-(Ce), rutile, siderite, strontianite, thorite, parisite-(Ce), bastnaesite-(Ce), burbankite, and zircon. Syenite clasts, on the scale of centimetres to tens of centimetres in size are incorporated as xenoliths and disaggregated xenoliths that commonly exhibit a reaction rind of biotite – phlogopite ± magnesio-arfvedsonite in contact with the carbonatite. The apatite occurs as euhedral-to-subhedral, very fine-to-medium-, randomly-oriented grains. The pyrochlore is almost exclusively associated with the apatite aggregates and clasts. Apatite is typically the first phase to crystallize from a carbonatitic magma, and the close association with pyrochlore suggests they accumulated together and were redistributed by a later pulse of magma. The ferroan dolomite and calcite are typically anhedral, ranging from 100–6000 µm in size with variation occurring on a millimetre-to-centimetre-scale. The calcite and ferroan dolomite variably contain inclusions of REE-fluorocarbonates, burbankite, strontianite, barite, quartz, magnetite, and fluorite. In addition to occurring as inclusions, the REE-fluorocarbonates also occur as fine-to-medium-grained syntaxial intergrowths, intergrown with thorite or strontianite. Veins and veinlets of quartz, fluorite, chlorite, calcite, and ferroan dolomite crosscut the groundmass and the apatite clasts, providing evidence for late-stage hydrothermal processes. This sequence of emplacement: syenite; magmatic

apatite + pyrochlore; magmatic calcite- and ferroan dolomite-carbonatite; magmatic-hydrothermal ferroan dolomite; late-stage hydrothermal calcite + quartz + chlorite + fluorite + REE-fluorocarbonate minerals is similar to observations at other alkaline rock – carbonatite complexes.

WALVIS RIDGE HOTSPOT TRACK EXPLORED DURING IODP EXPEDITION 391

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International Ocean Discovery Program Expedition 391 explored the geodynamic significance of the Walvis Ridge (WR) hotspot track, and its genetic link with the African large low shear-velocity province. WR is located in the South Atlantic Ocean and extends from the Mid-Atlantic Ridge to the Namibian coast in Africa. WR is the longest known geochemically zoned hotspot, and the start of its zonation coincides with splitting of the track in three separate seamount chains, which started at ~70 Ma and resulted in distinct isotopic compositions and a unique trifurcate morphology. Moreover, the expected hotspot age progression is disrupted by the presence of Valdivia Bank, an oceanic plateau part of WR that may have formed around a microplate. Expedition 391 had three main objectives: (1) to investigate the isotopic zonation of the ridge and its potential ties with the African large low shear-velocity province via a transect across the ridges; (2) to document the age progression of the chain and test models of ridge-hotspot interaction; (3) to constrain paleolatitude changes of the hotspot track to allow testing of models of hotspot motion and true polar wander. Five holes have been drilled at four sites (U1575, U1576, U1577, U1578), with recovery ranging from 49 to 79% of sedimentary and igneous rocks. The deepest hole reached a depth of 486.4 m below the seafloor, penetrating 302.1 m of igneous basement.

EDIACARAN THROUGH EARLY PALEOZOIC EVOLUTION OF GONDWANAN UNITS IN THE IBERIAN MASSIF

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The Iberian Massif consists of various tectonostratigraphic terranes accreted to one another during the Variscan collision of Gondwana and Laurussia. These include: 1) units that occupied the northern margin of Gondwana prior to the Variscan orogeny (Cantabrian, West Asturian-Leonese, Central Iberian, lower allochthons of the Galicia-Trás-os-Montes (GTMZ), and Ossa Morena (OMZ) zones, from inner to outer margin, respectively); 2) oceanic affinity units (Intermediate allochthons in GTMZ, internal allochthons in OMZ, Pulo do Lobo Zone); and 3) exotic units thought to belong to Laurussia (upper allochthons in GTMZ, South Portuguese Zone).Breakup of the Neoproterozoic supercontinent Rodinia ca. 750 Ma ago produced significant global plate reorganizations, among which the amalgamation of Pannotia/Gondwana culminating near the Precambrian-Cambrian boundary is particularly relevant in our case. The future Iberian Massif was then part of the northern active margin of Gondwana, under which subduction of the surrounding Mirovoi Ocean gave rise to the Cadomian Arc and orogeny during the Ediacaran. Subduction until ca. 535 Ma is documented in the OMZ but it was replaced by extensional deformation at ca. 530 Ma. Oblique collision of a mid-ocean ridge with the outboard trench is held responsible for this abrupt change in geodynamic scenario and the progressive transformation of the previous active margin into a largely transcurrent one, similar to the San Andreas system in western North America. A combination of slab break-off and continued motion of the Gondwanan upper plate over the ridge-trench collision zone is envisaged as a likely scenario for generation of a slab window and subsequent propagation of rifting processes towards more inboard parts of the margin, in a manner similar to the presently ongoing opening of the Gulf of California. Rift development started in OMZ ca. 530 Ma ago, reaching the innermost West Asturian-Leonese and Cantabrian zones later in the Cambrian. By ca. 490 Ma, a breakup unconformity marks the rift-drift transition in the OMZ, i.e. close to the rift axis. This is taken as evidence of opening of a brand-new oceanic tract (Rheic Ocean) and eventual drift-away of a ribbon of the previous Gondwanan margin (Avalonia sensu lato). The break-up unconformity propagated inwards reaching the innermost Iberian Massif zones in Early Ordovician time. Break-up was succeeded by a rapid transgression (thermal subsidence) that established relatively stable passive margin conditions throughout the Gondwanan continental shelf facing the Rheic Ocean, which prevailed until the onset of the Variscan collision in Devonian times.

QUANTIFYING TOPOGRAPHIC RELIEF EVOLUTION IN THE ALPS WITH MUON-PALEOTOPOMETRY?

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Understanding topographic relief evolution and its continuous change(s), over hundreds of thousands to million-year timescales, remains challenging. Modern approaches usually combine numerical modelling of terrestrial cosmogenic nuclide exposure ages on strath terraces, exhumation histories based on thermochronology, drainage basin evolution, and basin stratigraphy. However, even when combined, these methods are unable to precisely characterize changes in the rate of relief evolution over million-year timescales, which is needed to differentiate climate from tectonics over multiple glacial cycles and longer timescales. Muon-paleotopometry is a new approach that tackles the methodological gap of determining relief generation. Muon-paleotopometry utilizes the spatial pattern of concentrations of multiple stable and radioactive terrestrial cosmogenic nuclides measured along a near- horizontal underground transect to quantify the change in crustal shielding of cosmic radiation. It provides paleotopographical variation above the sample datum over an isotope-specific monitoring duration as a function of the nuclides' half-lives and erosion rates. Early proof-of-concept investigations at Dalhousie provided encouraging results to allow for a large-scale relief investigation of the European Alps. For centuries, the Alpine relief evolution has been studied to evaluate if the Alpine exhumation patterns are the result of Pleistocene incision, or mantle driven rock uplift. Here we present the project concept of applying the muon-paleotopometry method along a near horizontal transect in the Gotthard Base Tunnel (Switzerland) to quantify the Alps' relief evolution and potentially resolve the scientific dispute. Samples have already been obtained and are being processed. Will muon-paleotopometry provide an answer to this decade-long debate?

CHANGES IN THE SEA-SURFACE CHARACTERISTICS ON THE SE GRAND BANKS AND NEWFOUNDLAND BASIN DURING THE LAST 145,000 YEARS: A STUDY BASED ON THE SEDIMENTOLOGICAL AND PALEONTOLOGICAL PROXIES

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Dramatic changes in temperature and salinity, and freshwater input occur due to the interaction of the cold and fresh equatorward-flowing Labrador Current and the warm and salty North Atlantic Current (NAC) on the southeastern Grand Banks of the northwest Atlantic Ocean. As a result, the seasonal stratification of the upper water masses and the biological productivity are intensified. Such changes must have been more dramatic during glacial times due to the penetration of the Polar and Arctic fronts and southward migration of the Gulf Stream/NAC. However, the extent to which such change impacted the sea-surface characteristics in the Newfoundland Basin is poorly known. Here, we report changes in the sea-surface characteristics using two piston cores (Hu2011031-032 and Hu9007-08) collected from the SE Grand Banks and Milne seamounts during the last glacial cycle. Heinrich layers H1, H2, H4, and H5 and H11 within the marine isotope stage (MIS) 3 and at the penultimate deglaciation were identified by ice-rafted detritus (IRD), *Neogloboquadrina pachyderma* peaks and lighter oxygen isotopes. Rapid turnover of foraminiferal species with distinct depth habitats and ecological niches in the mixed layer and thermocline suggest an interplay between the polar and subpolar water masses during Heinrich and non-Heinrich periods. Only two North Atlantic-wide cooling events, C24 and C21, in which the latter event linked to the minor IRD event during the MIS 5 in Hu90-08, compared to the eight events in the eastern subpolar gyre. Millennial-scale *N. pachyderma* variability in the western subpolar gyre appears to be absent in the eastern subpolar gyre during the MIS3 suggesting the occasional presence of salty and warm water by NAC inflow, implying a different climate state

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between the western and eastern subpolar gyre. Although *T. quinqueloba* data are fragmentary, there are differences between the western and eastern subpolar gyre and the differences within the western subpolar gyre during MIS 5 that might imply a variable influence by the subpolar water. This finding suggests that influence by the NAC outweighs the impact of cold and fresh polar water in the northern northwest Atlantic during MIS 5.

IDENTIFYING BASEMENT SOURCES FOR TUNGSTEN-ASSOCIATED GRANITE PLUTONS IN THE MACKENZIE MOUNTAINS, CANADA

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The Mackenzie Mountains, spanning the southern Yukon–Northwest Territories border, host significant tungsten mineralization, including: 10.8 Mt at 1.2% WO_3 at Cantung (combined historic and current estimates), 44.9 Mt at 0.85% WO_3 at Mactung and 0.75 Mt at 1.2% WO_3 at Lened. This mineralization is associated with a narrow belt of small, crustally derived mid-Cretaceous granite plutons belonging to the Tungsten plutonic suite. A pre-enriched supracrustal melt source is one of the major controls proposed for tungsten metallogeny; however, possible source rocks for the associated granitic magmas are unknown due to a lack of exhumed basement in the Mackenzie Mountains. This study endeavours to determine the lithological source(s) for tungsten and related magmas in the Cordilleran basement. Inherited cores in zircons from the Cantung, Mactung and Lened areas are being used to characterize the U–Pb age and Lu–Hf composition of the melt and metal source rock(s). Cores are identified by SEM–CL mapping and analyzed in a laser ablation split stream (LASS) ICP-MS system where the Lu–Hf and U–Pb isotopic compositions are simultaneously determined in-situ. Preliminary results for the Cantung area demonstrate that inherited cores are Mesoproterozoic to Neoarchean in age and have Hf isotopic compositions reflecting sourcing from multiple isotopic reservoirs in the crust. These observations are consistent with the derivation of granitic magmas by melting of supracrustal basement containing detrital zircons derived from multiple terrains. Comparing the zircon core age data with existing regional detrital zircon datasets will further constrain the fingerprint of ancient crustal basement that contributes to plutons associated with tungsten mineralization. The prospective source rock(s) identified by detrital zircon age populations will be confirmed via additional LASS analysis of detrital zircons from selected units, and their capacity for pre-enrichment in tungsten will be assessed based on mineral and rock chemistry. Our results will provide information on the age and composition of Cordilleran basement and will contribute to the global framework for the generation of world-class tungsten provinces.

COUPLED δ^{56}Fe AND δ^{18}O SIGNATURES OF THE PALEOPROTEROZOIC FRERE FORMATION, WESTERN AUSTRALIA, AND IMPLICATIONS FOR BASIN SCALE CIRCULATION

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The Paleoproterozoic Frere Formation (ca. 1.89 Ga) is a ~300-m-thick sedimentary succession of five stacked, Fe- and silicate-rich upwards-shallowing cycles. Collectively, these cycles, or parasequences, record a marine transgression punctuated by higher frequency fluctuations in relative sea level. Parasequences are composed of magnetite-rich chemical mudstone or magnetite-bearing, hummocky cross-stratified sandstone that grades stratigraphically upwards into hematite-rich chemical mudstone and cross-stratified granular iron formation. Such shallowing records the progradation of intertidal and tidal channel deposits over shallow subtidal and more distal storm-generated lithofacies. Deposition in an oxygen-stratified water column is supported by the occurrence of deeper, anoxic magnetite and Fe-chlorite-rich mudstones beneath shallower, suboxic hematitic grainstones. Collectively, lithofacies associations suggest iron formation precipitation and accumulation occurred on an unrimmed continental shelf associated with coastal upwelling of hydrothermally derived Fe. The Fe isotopic variability of 36 whole rock samples (–0.54‰ ≤ δ^{56}Fe ≤ +1.54‰) and 12 individual magnetite (–0.09‰ ≤ δ^{56}Fe ≤ +2.06‰) from suboxic and anoxic lithofacies are interpreted to have been controlled by equilibrium and kinetic isotopic fractionation processes. The decreasing trend of δ^{56}Fe values of magnetites in stacked parasequences is thought to reflect progressive deepening and impingement of anoxic seawater on the shelf during transgression. This substantiates the utility of δ^{56}Fe as a robust chemical tracer for oceanographic circulation processes in the Precambrian ocean. Wide variations of δ^{18}O values of magnetite (–0.6‰ ≤ δ^{18}O ≤ +2.8‰, n = 12) and quartz (+8.8‰ ≤ δ^{18}O ≤ +20.1‰, n = 11) and $\Delta^{18}O_{quartz\text{-}magnetite}$ (+9.1‰ ≤ $\Delta^{18}O_{quartz\text{-}magnetite}$ ≤ +18.7‰, n = 5) values indicate that pristine δ^{18}O values of minerals were overprinted by diagenesis. The δ^{18}O values of fluids calculated at 200°C in equilibrium with quartz (–3.0‰ to +8.3‰) and magnetite (+8.0‰ to +12.7 ‰) suggest closed system diagenesis involving fluids with heterogeneous δ^{18}O values. These pore fluids may have evolved from waters possessing δ^{18}O values of ~0‰ and therefore were similar in oxygen isotopic composition to modern seawater. This coupled isotopic investigation demonstrates that despite low-grade metamorphism, δ^{56}Fe values from magnetite in iron formation can preserve a primary depositional signal that records oceanographic circulation processes. Such novel use of Fe isotope data to understand water mass movements may provide a new tool for interpreting the basin-scale processes of Fe accumulation.

CONSTRAINTS ON GOLD ENDOWMENT AT THE AUGMITTO-BOUZAN SEGMENT (ABITIBI SUBPROVINCE, QUEBEC) OROGENIC GOLD DEPOSIT, FROM STABLE ISOTOPES (O, C, H) AND 3-D FLUID FLOW MODELLING

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The Augmitto-Bouzan segment (Rouyn-Noranda) is an orogenic gold deposit that covers a 12 km stretch of the Cadillac Larder-Lake Deformation Zone (CLLDZ). It is characterized by irregularly distributed gold mineralization across the property. The segment is subdivided into six major zones (from west to east): Augmitto, Cinderella, Lac Gamble, and Astoria, forming the gold endowed sectors, as well as East-Bay and Bouzan, which constitute the less endowed sectors. This project aims to compare the spatial variation of fluid flow between those gold endowed and less endowed portions of the deposit. Representative quartz ± carbonate ± tourmaline veins and associated host rocks have been sampled throughout the property for stable isotope analyses. A 3-D numerical model (hydrogeosphere) of the Augmitto-Bouzan segment has also been created to simulate reactive transport of oxygen isotopes and to compare fluid flow behaviour between sectors. Temperature-dependent fluid-rock isotope fractionation was included assuming a linear vertical temperature gradient across the modeled CLLDZ domain. The isotopic composition of vein quartz ($\delta^{18}O_{VSMOW}$: 11.8–16.1‰), tourmaline ($\delta^{18}O_{VSMOW}$: 8.5–11.9‰; δD_{VSMOW}: -18 to -59 ‰) and carbonate ($\delta^{18}O_{VSMOW}$: 11.3–21.9 ‰; $\delta^{13}C_{PDB}$: -6.5 to -0.5 ‰) does not display systematic variations along the segment, thus showing that the whole region has been affected by the same hydrothermal system. The isotopic composition of water suggests fluid mixing between two main end-members; a deep-seated metamorphic fluid ($\delta^{18}O_{VSMOW}$ > 10 ‰; δD_{VSMOW} ~-30 ‰, T > 500°C) and an upper crustal fluid ($\delta^{18}O_{VSMOW}$ < 3 ‰; δD_{VSMOW} > -10 ‰, T < 250°C). Quartz-tourmaline equilibrium defines a strong vertical gradient (30°C per 100 m) with preferential zones of high temperature in the Augmitto-Cinderella and Astoria areas that could record the progressive infiltration of the hotter deep crustal metamorphic fluid and mixing with the cooler resident upper crustal fluid. Spatially, gold endowed sectors are in close association with areas dominated by infiltration of deep-seated metamorphic fluid, whereas less endowed sectors are dominated by the upper crustal fluid. This implies that most of the gold is transported by the deep-seated metamorphic fluid rather than the upper crustal fluid. Modelling of 3-D fluid flow and reactive oxygen transport shows that infiltration of the deep-seated fluid originated from the rock packages at depth, at the base of the model, whereas the fluid drain was limited to the trace of the CLLDZ towards the surface. The higher temperature zones require higher permeability, and their spatial association with gold ore shoots suggests these were structurally permeable zones for the infiltration of deep-seated metamorphic fluids.

GEOTHERMAL RESOURCES FOR ENERGY TRANSITION: PAST, PRESENT AND FUTURE OF IGCP GROUP 636

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IGCP Group 636 on geothermal energy began its activities in 2016 under the young research program, unifying researchers of the Americas and Europe helping to unlock geothermal resources. UNESCO support to Group 636 was renewed in 2020 for another five years under the regular program, expanding our network around the globe. Today IGCP Group 636 is led by researchers of Canada, Colombia, Argentina, Chile and Italy and includes the participation of more than twenty institutions from 18 countries spread over five continents. Our main objective is to advance methodologies and techniques to characterize and model geothermal reservoirs, ensuring sustainable exploitation and social acceptability of this form of renewable energy. Collective goals are to increase understanding of geothermal reservoirs, promote knowledge related to geothermal heat pump systems and to conduct outreach activities with communities. This initiative facilitated the mobility of more than twenty-five students from the Bachelor to PhD levels, travelling among participating countries to conduct internships in multicultural environments, participate to the group meetings, and learn from natural geological laboratories. Field-based research to focus group meetings have taken place at Nevado del Ruiz volcano in Colombia, remote northern Indigenous communities of Nunavik in Canada and Campi Flegrei Caldera in Italy, just to cite a few examples. The most recent achievements of IGCP Group 636 are a public opinion survey about deep geothermal energy in several participating countries, as well as a review of recent drilling projects targeting unconventional geothermal resources associated with supercritical fluids, enhanced geothermal systems and hot sedimentary aquifers of Italy, the UK and Canada, respectively. A future goal is to trigger geothermal exploration drilling projects in developing countries, bridging northern and southern hemispheres, expanding the use of unconventional resources with new technologies and taking actions to foster a global energy transition.

METAMORPHIC ARCHITECTURE AND EVOLUTION OF THE NEOARCHEAN QUETICO SEDIMENTARY SUBPROVINCE, SUPERIOR PROVINCE

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The ca. 2.7 Ga Quetico subprovince (QS) is a 1200 km long, east-striking metasedimentary belt in the central Superior Province that has historically been viewed as an accretionary prism that formed during the subduction-driven convergence of the Wawa and Wabigoon terranes. This model has since been strongly contested in the face of a plume-driven geodynamic model, which predicts that such sedimentary basins were initially extensional. The final assembly of the Superior craton obliterated many early features of the QS but preserved metamorphic assemblages, which can be powerful indicators of geodynamic environments. Pelitic protoliths of the QS record a continuous, across-strike metamorphic progression from greenschist to granulite facies, but the metamorphic history, gradients, and styles are poorly constrained. A series of N-S field mapping transects document mineralogical changes and textural-structural relationships to better characterize and quantify P-T-time conditions of metamorphism in the QS. The transects cross eight metamorphic zones and display an inward, broadly symmetrical configuration. These zones include, from lowest to highest grade, (1) chlorite-sericite; (2) biotite; (3) garnet; (4) staurolite-andalusite; (5) cordierite; (6) sillimanite; (7) melt; and (8) orthopyroxene. All isograds are generally parallel, regionally extensive, and not controlled or displaced by faults, including those separating subprovinces. Preliminary results from field mapping and petrography show that most andalusite and cordierite have an internally rotated S1/S2 foliation, are elongate parallel to F3 fold axes, are overprinted by an S3 foliation, and are cross-cut by randomly oriented chlorite, garnet, staurolite, and sillimanite, which appear late- to post-S3. Preliminary pseudosection models predict equilibrium conditions of 2–4 kbar and 500–600°C for cordierite assemblages and 5–7 kbar and 450–600°C for garnet-staurolite assemblages. Two distinct metamorphic events in the QS are inferred from these results: a low-P/high-T event (M1) producing cordierite-andalusite assemblages during D1/D2 deformation and a medium P/T event (M2) producing garnet-staurolite-(sillimanite) assemblages spanning late-D3 to D4 deformation. This first-order interpretation contrasts with previous studies inferring early high-P conditions in QS from the presence of kyanite, which has not been identified in this study. The metamorphic style and evolution thus appear more compatible with a plume-driven tectonic model where sedimentation was preceded by the establishment of a high thermal gradient, consistent with extension and lithospheric thinning over a rising plume and was followed by convergence and crustal thickening due to the imbrication of crustal blocks away from the plume head.

CHEMOSTRATIGRAPHY OF LATE ORDOVICIAN TO EARLY DEVONIAN BASINAL STRATA HOSTING THE PRAIRIE CREEK Zn-Pb-Ag DEPOSIT, MACKENZIE MOUNTAINS, NORTHWEST TERRITORIES

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The Prairie Creek Zn-Pb-Ag deposit contains vein and stratabound mineralization hosted in Late Ordovician to Early Devonian basinal strata deposited primarily in the Selwyn Basin. Characterization of the background lithogeochemistry of host strata provides important supporting information for the interpretation of regional geochemical anomalies and the identification of cryptic alteration halos around mineralization. Furthermore, lithogeochemistry is an indicator of paleodepositional redox conditions, which played a role in the formation of stratabound Zn-Pb mineralization in other districts and could have implications for exploration strategies at Prairie Creek. To characterize the background lithogeochemistry of host strata at Prairie Creek, an 1800 m drill hole that intersects an unaltered section of host strata ~2 km from the main Prairie Creek deposit was sampled every ~15 m and analyzed for bulk multielement geochemistry and total organic carbon (TOC). The Upper Whittaker, Road River, Cadillac, and Arnica formations (oldest to youngest) have distinctive major element geochemistry. The terrigenous input profile (TIP) shows the contribution from a terrigenous detrital source is more prominent in the Cadillac (7.57 ± 2.45 wt.%) and Road River (5.58 ± 3.18 wt.%) than in the Upper Whittaker (0.89 ± 0.54 wt.%) and Arnica (0.84 ± 1.07 wt.%). Non-detrital Si shows the contribution of biogenic Si is highest in the Upper Whittaker (6.74 ± 7.74 wt.%) and Arnica (3.58 ± 5.59) and lower in the Cadillac (2.55 ± 2.93 wt.%) and Road River (0.88 ± 1.39 wt.%). Molar Ca and Mg have a 1:1 ratio in most samples, which is consistent with the presence of dolomite. Excess Ca, presumably in calcite, is common in the majority of Road River samples and a quarter of the Cadillac samples. The Cadillac Formation is the least carbonate-rich. Geochemical proxies indicate that all formations were deposited under primarily suboxic to anoxic conditions. The upper Cadillac Formation shows the strongest evidence for anoxia (68 ± 42 ppm non-detrital Mo) and has the highest concentrations of TOC (2.90 ± 0.79 wt.%). Evidence for euxinia is absent or rare in all formations except for in the upper Cadillac where it is moderately common (half of samples contain > 4 ppm non-detrital Mo/U). The Upper Whittaker, which hosts stratabound Zn-Pb mineralization, was deposited under the least reducing conditions with almost all samples containing 0.4 wt.% (indicating fully oxic conditions).

FEELING RELIEVED: A ROADMAP FOR CREATING BATHROOM-POSITIVE FIELDWORK CULTURE

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Fieldwork takes place in a wide variety of settings outside the standard classroom or office environment. Whether it's a day trip in an urban setting or a lengthier excursion in a remote wilderness area, fieldwork typically poses some level of disruption to participants' bathroom habits. Bathroom behaviours directly impact the physical and emotional wellbeing of field workers, with negative outcomes due to disruptions ranging from minor discomforts to serious physical health problems (e.g. dehydra-

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tion and urinary tract infections caused by restricting water intake and urination, constipation caused by restricting defecation) and emotional distress (e.g. anxiety about maintaining personal privacy). Bathroom behaviour is also a matter of field safety; for example, the desire for privacy can lead to isolation from the group without clear communication, which can increase the risk of unexpected encounters with dangerous wildlife or heavy machinery. Despite these hazards, bathroom matters receive relatively little attention within the typical field health-and-safety framework. Furthermore, bathroom-related concerns or problems distract from workers' abilities to fully engage in fieldwork, and may even discourage participation entirely. In this talk we will provide a roadmap for creating a bathroom-positive fieldwork culture along with practical tips for improving personal comfort. The most important practice is clear communication. Expectations for professional conduct regarding bathroom behaviour should be laid out in advance of any excursion and revisited in the field. Bathroom-related information should be integrated with other key information regarding logistics, gear lists, and health and safety. Consider supplementing first aid kits with bathroom-specific items including toilet paper, disposable urine directors, menstrual hygiene products, ibuprofen, and hand sanitizer, and make sure participants know these items are available. Health and safety training should include information about bathroom-related health hazards such as urinary tract infections, kidney stones, constipation, yeast infections, and toxic shock syndrome. In addition, we will provide an overview of resources describing best practices for going to the bathroom in the field and specialized field gear designed to make taking care of business in the bush more convenient. This talk is for everyone, whether you are looking to take control of your own field experience, want to improve field bathroom culture for others, or have never given a second thought to going to the bathroom in the field.

MOBILITY OF METALS AND LIGANDS DURING PROGRADE METAMORPHISM OF NEOARCHEAN CLASTIC BASINS: INSIGHT FROM THE PONTIAC AND QUETICO SUBPROVINCES

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It is broadly accepted that the fluids involved in orogenic gold deposits result from metamorphic devolatilization of crustal rocks during prograde metamorphism. The breakdown of hydrous mineral phases leads to the liberation of fluids, particularly at the transition between greenschists and amphibolite facies. This boundary is commonly marked by temperature-dependent breakdown reactions of chlorite and pyrite, which are responsible for the release of substantial volumes of fluid, metals, and sulphur. Several phase equilibrium modelling and geochemical studies have shown release and mobility of key elements (e.g. S, Au, As, and Sb) from metasedimentary rocks during prograde metamorphism, indicating that they may represent a viable source of metals and ligands for orogenic gold deposits. Although metasedimentary rocks are generally recognized as source of metals in Phanerozoic deposits, they have been mostly discarded in Archean greenstone belts, given their low abundance. However, in the Superior Province, highly metamorphosed metasedimentary belts (up to granulite facies) occur adjacent to, and are commonly overthrust by moderately metamorphosed greenstone belts (up to lower amphibolite facies). This tectonometamorphic setting suggests that the devolatilization of the metasedimentary belts may have sourced significant volumes of metals and ligands to the overlying greenstone units. To address this hypothesis, this study focuses on the Pontiac and Quetico subprovinces, two metasedimentary belts in the Superior Province adjacent and overthrust by the Abitibi and Wabigoon greenstone belts, respectively. We report whole-rock geochemistry analyses of base metals and trace elements, and ultra-low-detection-limit analyses of Au acquired by pressed powder pellet (PPP) - LA-ICP-MS from a suite of metasedimentary and subordinate interlayered mafic volcanic rocks. A total of 143 samples without alteration or veins were selected from three areas with contrasting gold endowment. The samples are representative of the protolith variety and cover a broad range of metamorphic conditions (from chlorite to sillimanite zones). Monitoring of element mobility in these metasedimentary belts throughout prograde metamorphism provides insights to evaluate the potential of the Pontiac and Quetico subprovinces as viable sources of metals and ligands for orogenic gold deposits in the Superior Province.

GEOCHEMICAL REANALYSIS OF ARCHIVED REGIONAL LAKE SEDIMENT SAMPLES FROM THE HOPEDALE BLOCK, LABRADOR

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The north coast of Labrador is composed of bedrock lithologies hosting multiple polymetallic deposits and showings of differing geochemical affinities including critical metals (e.g. Voisey's Bay (Ni) and Strange Lake (Zr-Y-HREE)). However, the full mineral potential of the region is difficult to ascertain, in part due to a thick cover of glacial sediment that masks the underlying bedrock. Previous reanalysis of archived lake sediments samples in Labrador by the Geological Survey of Canada (GSC) during the Geo-Mapping for Energy and Minerals (GEM II) program (2014–2018) yielded important insights into the mineral prospectivity of the Core Zone. To build on this previous work, an additional 3162 lake sediment samples from eastern Labrador were submitted for reanalysis using aqua regia dissolution followed by inductively coupled plasma-mass spectrometry. Samples were originally collected from National Topographic System (NTS) map sheets 13I, 13J, 13K, 13N, and 13O at an average density of ~1 sample per 14 km^2 over an area of 45,000 km^2. Reanalysis of these regional lake sediment samples will determine a total of 65 elements that were not available following the original sample collection and analysis (ca. the 1970s and 1980s). Analytical results will augment a large geochemical atlas of previously reanalyzed samples from Québec and Labrador, creating the largest contiguous regional lake sediment geochemical coverage in Canada. These new re-analyzed data will be used to assess the potential for the Hopedale region to host a multitude of critical metals and provide data that will be vital to future regional- to property-scale mineral exploration targeting in this highly prospective region.

EFFECTS OF RETROGRESSION AND REHYDRATION ON META-MAFIC ROCK DEFORMATION DURING SUBDUCTION INFANCY: EVIDENCE FROM THE SUB-OPHIOLITE METAMORPHIC ROCKS OF MONT ALBERT (GASPÉ PENINSULA, QUÉBEC, CANADA)

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The first few million years of subduction (i.e. subduction infancy) involve rapid changes in thermal structure as a new plate boundary shear zone develops. Previous work on metamorphosed oceanic crustal rocks exposed beneath ophiolites – i.e. metamorphic soles – demonstrates that they record deformation and metamorphism associated with subduction infancy and that infancy is characterized by cooling. Cooling impacts metamorphic phase stability and fluid content, and therefore strain-localization processes. However, it remains unclear how these factors affect operative deformation mechanisms in meta-mafic rocks. Here, we combine petrological and microstructural analyses on the Mont Albert metamorphic sole (Québec, Canada) to assess how cooling affects metamorphism and deformation mechanisms in key strain-accommodating phases in young subduction zones. The Mont Albert metamorphic sole is part of an Ordovician ophiolite complex that comprises a structurally higher high-temperature (HT) unit and structurally lower low-temperature (LT) unit that are distinguished by metamorphic grade and deformation style. The HT unit is in direct tectonic contact with sheared, serpentinized peridotites of the hanging-wall; it records the earliest stages of deformation and metamorphism during subduction infancy and comprises coarse-grained amphibolite to granulite facies rocks. At the micro-scale, HT rocks comprise lenses of garnet and pyroxene surrounded by layers where pyroxene is overgrown and replaced by hornblende, recording a (re)hydration reaction near the peak temperature of metamorphism. Zoning in garnets, amphiboles, and feldspars suggests that prograde granulite facies fabrics are overprinted and retrogressed (i.e. re-hydrated) under amphibolite facies conditions, which we interpret to have occurred during cooling of the subduction interface. Electron backscatter diffraction analyses of granulites and amphibolites demonstrate that their well-developed foliations are characterized by crystallographic preferred orientations (CPOs) in pyroxene and hornblende, respectively. In amphibolites, hornblende porphyroblasts exhibit clear subgrain development, core-

and-mantle structures, and finely recrystallized strain-free grains. We interpret that both rock types exhibit dynamic recrystallization accommodated by dislocation creep. This implies that the HT sole accommodated strain during and after peak temperatures of metamorphism, but in different minerals, reflecting the changes in temperature and fluid content during subduction interface cooling. Our results suggest that strong granulites may be progressively weakened by rehydration (amphibolitization) and subsequent grain size reduction, facilitating continued deformation in the sole as the interface cooled. This study highlights that the strength of infant subduction shear zones is controlled by complex coupled metamorphic and deformation processes.

MIDDLE TO LATE PERMIAN RECORD OF EARLY ARC MAGMATISM AND CRUSTAL REORGANIZATION IN WESTERN LAURENTIA

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Early Cordilleran arc development along the southwestern margin of Laurentia in Permian time is recorded in plutonic rocks and in coeval sedimentary strata deposited adjacent to the nascent arc and in the distal backarc basin. Earliest arc rocks are preserved in southeastern California, USA, and Sonora, Mexico, but no confirmed exposures exist between these two areas, and the relation between the two, including their allochthoneity or original juxtaposition, is uncertain. Previous work has demonstrated that in the western parts of the early arc, different crustal provinces were juxtaposed, yielding geochemical variation in magmatic rocks, but the timing of this juxtaposition is uncertain. Igneous and detrital zircon geochronology, coupled with trace element geochemistry and Hf-isotopic analysis, provides insight into how the early arc was segmented and when different crustal provinces were juxtaposed along the margin. We delineate three provinces based on ages and geochemistry of zircon from Permian to Triassic plutonic rocks. In northwestern Sonora, early arc rocks are ca. 270 Ma and zircons have highly evolved εHf values, as do ca. 250–230 Ma plutons of the central Mojave and Transverse Ranges of California. Plutonic rocks of the El Paso terrane in the northern Mojave Desert are 275–230 Ma and have dominantly juvenile isotopic signatures. Combined age-εHf isotope signatures of these early arc provinces allows tracking of the dispersal of the arc in Permian–Triassic time into backarc (Moenkopi Fm and equivalents) and forearc/intra-arc (Monos Fm of Sonora, Mexico, and Holland Camp strata of southern California) basins. Zircon grains from back-arc successions have spatially variable signatures. Those from the northwesternmost exposures (marine Inyo Mountains) appear derived from the juvenile, northern Mojave arc. Those from the southeasternmost exposures (marine Buckskin Fm) appear derived from the Sonora arc segment. The terrestrial Moenkopi Fm of the Colorado Plateau has a mixed provenance. Zircon from intra-arc Holland Camp strata have complex age spectra and isotopic signatures, recording adjacent arc and additional, uncertain sources. We use these observations to infer that the Cordilleran arc developed simultaneously across different crustal blocks in separated segments. Crustal blocks were juxtaposed prior to arc development and sedimentation. Although arc segments were dispersed, detritus from all segments moved along-shore into disconnected marine basins where substantial source mixing occurred in some areas, and very little in others. Terrestrial successions received volcanic detritus from both segments.

FOX CREEK PROJECT ON CUMULATIVE EFFECTS: AN UPDATE FROM THE GROUNDWATER PERSPECTIVE

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A project on the assessment of cumulative effects in the Fox Creek area (west-central Alberta) was initiated in 2019. This area was selected because it has been one of the most active regions for hydrocarbon production in Canada for the past 50 years. The regional aquifer in this area is the Paskapoo Formation, a complex succession of interbedded mudstone and siltstone with sandstone channels. In 2020, nine monitoring wells were drilled and geophysically logged (depths 35–90 m). Groundwater from these monitoring wells, screened in shaley intervals in an attempt to sample more geochemically evolved water, as well as 13 water wells belonging to oil and gas operators screened in sandstone intervals, were sampled in the summer of 2021 for chemical analysis. Permeability testing was performed in the monitoring wells using slug tests and in the surficial sediments using Guelph permeameters. Soil moisture and temperature are monitored at three depths, while water is sampled from lysimeters and rain collectors on a monthly basis at five locations in the study area, each instrumented at vegetated and non-vegetated (i.e. affected by human activities) sites. A 3-D flow model of the 700 km^2 watershed integrating bedrock and unconsolidated sediments was developed in FEFLOW. The results thus far show that shallow groundwater quality does not appear to have been affected by several decades of oil and gas activities, which is positive news. Only a few wells contained small concentrations of microbial methane. Groundwater throughout the study area is predominantly of the $CaHCO_3$ type, corresponding to relatively young water. This suggests that groundwater circulates well both in the sandstone channels and along bedding-parallel fractures in the fine-grained matrix. The median hydraulic conductivity (K) for our monitoring wells is 4 x 10^{-6} m/s, while that for unconsolidated sediments is lower (~10^{-7} m/s). Physical properties (V_p, V_s, density, resistivity) obtained from borehole logging show highly variable values, confirming the heterogeneity of the Paskapoo Formation. However, log interpretation is affected by wall roughness, as this formation is soft. Initial soil moisture and temperature values in the vadose zone were found to be quite different between the vegetated and unvegetated sites, indicating differences in the various water budget components. The 3-D model helped define different K-value zones for the upper Paskapoo Formation and confirm the recharge rate previously estimated from other methods. These various data feed each other to eventually provide a global understanding of the water flow dynamics in this area, to help evaluate environmental cumulative effects.

NUTRIENT TRANSPORT AND GROUNDWATER-SURFACE WATER INTERACTIONS UNDER TEMPERATE CLIMATE CONDITIONS IN AN AGRICULTURALLY-INTENSE GREAT LAKES CLAY PLAIN WATERSHED

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Water quality within the Great Lakes Basin (GLB) continues to be a concern due to nutrient and sediment loss from agricultural land, despite increasing nutrient management and rural stormwater management efforts. This topic has been widely studied within the GLB; however, there remains insufficient evidence to support necessary changes to management practices to reduce further water quality and economic degradation. Intensified changes in agricultural practices and climate have resulted in continual and complex algal blooms and contaminated drinking water systems. An often overlooked piece of the nutrient transport puzzle is nutrient-laden groundwater discharge to surface water features. Furthermore, it is understood that significant nutrient loadings from agricultural land to receiving water bodies are more likely to occur during the non-growing season (October–March). Therefore, rural water management studies that focus on year-round monitoring of both groundwater and surface water are necessary to identify hydrologic vulnerabilities (i.e. elevated groundwater levels during rain on snow winter events) that result in unsuccessful management efforts. The Upper Parkhill watershed is a small headwater catchment to Lake Huron within southwestern Ontario. Land use is predominantly agricultural, consisting of low permeability soils. The watershed features an integrated climate and water monitoring station that was established by the Ontario Ministry of the Environment, Conservation and Parks. The objective of the project is to identity climate indicators for vulnerable moments of groundwater-surface water interactions and nutrient transport through year-round extensive watershed monitoring. From 2020–2021, monthly and event-based samples were collected for nutrients (phosphorus and nitrogen), sediment and stable isotopes of water ($\delta^{18}O$ and δ^2H) from groundwater and surface water locations. There are six surface water sites in the watershed that are monitored for quality and flow (including a tile drainage outlet);

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and eight wells and nine drive-point piezometers from which groundwater elevation and quality are monitored. Six suction lysimeters are used to monitor pore water quality in the unsaturated zone. An additional 12 surface water locations are sampled on an event-basis. Preliminary results indicate surface water and groundwater nutrient concentrations can become elevated in response to variations in seasonal and event-based climate conditions. Nutrients are elevated in all water compartments; 86% of surface water and 94% of tile samples exceeded the provincial water quality objective (0.03 mg/L) for total phosphorus. Methods developed in this study are relevant to policy makers, researchers and landowners for understanding current and future climate impacts on watershed health.

TOWARDS AN IRON FORMATION BASED DEEP TIME Ph PROXY

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Marine pH over the course of the Cenozoic may be accessed based on an empirical sedimentary proxy: foraminiferal boron isotope composition. Yet, the application of a sedimentary proxy for marine pH over large swaths of Earth's history, the Archean to Proterozoic, remains elusive. As a result, estimates for marine pH in deep time are based on geochemical models grounded in our understanding of earth systems, or through extrapolation from carbon dioxide values derived from terrestrial paleosols. To address this gap, we describe a novel method for estimating Archean to Proterozoic marine pH values based on the trace element composition of iron formations. Using a surface complexation model for trace metal adsorption to hydrous ferric oxides (HFO), the precursor minerals to iron formations, we predict the trace metal distribution on HFO particles over a range of atmospheric carbon dioxide values, and by extension pH conditions. The surface complexation model employs a Monte Carlo approach, drawing from 5000 random uniform distributions of each input trace metal concentration to generate a database of trace metals adsorbed to HFO. Using the iron formation record, trace metal ratios (e.g. La/Lu, Zn/Fe) are applied to filter the results of the surface complexation model. In doing so, we identify model runs that reproduce the range of trace metal ratios observed in the physical iron formation record and the corresponding pH range. When compared to previous, model-based efforts to reconstruct Proterozoic marine pH, we find the lower range to median of our surface complexation model runs conform reasonably well. Elevated pH estimates using this approach present a challenge but may be attributed to the effects of metabolic activities expected to generate alkalinity and which may accompany iron formation diagenesis, such as dissimilatory iron reduction. Results, therefore, suggest that this approach is capable of constraining the minimum paleomarine pH values required to account for the trace metal inventory of iron formations. While this approach remains in development, its refinement may present a novel way for empirically assessing paleomarine pH over the course of the Archean to Paleoproterozoic, a critical transition period in Earth's dynamic history.

PROVENANCE AND GEOCHRONOLOGY OF LOMONOSOV RIDGE: A CONTRIBUTION TO THE GEOLOGY AND TECTONIC HISTORY OF THE ARCTIC OCEAN FROM DREDGED ROCK SAMPLES

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The Lomonosov Ridge is understood to be a microcontinental fragment separated from the Barents Shelf during the early Cenozoic; however, the geological affinity of the Lomonosov Ridge bedrock remains uncertain. Over 650 kg of rock samples were collected from a dredge site on a flank of the Lomonosov Ridge at water depths ranging from 2.2 to 3.5 km. The dredge samples are primarily greenschist-facies rocks, including metasandstone and metasiltstone. We define lithologies and lithofacies to categorize the rocks and attempt to better understand their provenance and depositional settings. A total of 96 rock samples were cut to view sedimentary structures, define lithofacies and interpret depositional environments. Lithofacies analysis resulted in the definition of two lithofacies associations: one indicates a tidal delta setting with fluvial input and the other indicates a tidal flat setting. Heavy mineral separation was completed at a specific gravity of 2.9, which yielded a limited number of tourmaline, amphibole, and orthopyroxene grains which were further analyzed using scanning electron microscope and electron microprobe. A sensitive high-resolution ion microprobe (SHRIMP) was used for U–Pb isotope analysis of 719 detrital zircon grains from 10 rock samples. U–Pb detrital zircon ages show an age range of early Neoproterozoic to Paleoproterozoic, with peaks at 1.1 and 1.6 Ga, and a few Archean grains, and a maximum depositional age of 950 Ma. The detrital zircon U–Pb ages were compared with sedimentary and metasedimentary rocks from elsewhere in the Arctic using multidimensional scaling analysis to find analogous rocks and to propose a potential provenance. The rocks are interpreted to have been deposited as sediment shed off predominantly granitic terranes in Baltica into a rift basin associated with the breakup of Rodinia.

SUBTERRANEAN ESTUARIES ARE DYNAMIC SYSTEMS: WHAT DOES THIS MEAN FOR POLLUTANT INPUTS TO COASTAL WATERS?

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Predicting pollutant inputs from groundwater to coastal waters is complex, as the magnitude and timing of pollutant inputs are controlled by the specific pollutant sources, groundwater flow paths, and by geochemical processes occurring along these flow paths including within subterranean estuaries. Subterranean estuaries are spatially heterogeneous and dynamic systems, with multiple hydrologic forces acting on the systems across a wide spectrum of timescales from decadal and seasonal timescales to high frequency sub-second wave action. This presentation will examine recent advances in our understanding of subterranean estuaries as dynamic systems and what this means for the way in which we conceptualize these systems, conduct field investigations, interpret field data, and predict pollutant inputs to coastal waters via submarine groundwater discharge. The presentation will focus on three examples: i) impact of tides and waves on flows and salt transport in subterranean estuaries and submarine groundwater discharge; ii) impact of tides and waves on terrestrial nitrogen inputs to coastal waters; and iii) potential hot moments of release of arsenic to coastal waters in response to storm events and in response to longer term climate-driven changes. While the presentation will cover examples that focus on the impact of tides, waves and storms on groundwater pollutant inputs to coastal waters, the findings will be generalized across multiple timescales.

SUBDUCTION EROSION IN PERI-GONDWANAN ARCS: WHOLE ROCK ISOTOPIC GEOCHEMISTRY AND U–Pb GEOCHRONOLOGY OF ARC-RELATED MAGMAS (SW IBERIAN MASSIF)

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The Gondwanan margin around the West African Craton experienced subduction and accretion during Proterozoic–Cambrian times. The pre-Paleozoic basement is formed by thick sequences of metasedimentary rocks derived in part from cratonic areas, plus juvenile supplies from the magmatic activity of the so-called Avalonian-Cadomian magmatic arc (ca. 750–500 Ma). Sections of this margin appear dismembered and were incorporated in Late Paleozoic times to the innermost sections of the Variscan Orogen. In the southern branch of this orogen, the basement of the Ossa-Morena complex (OMC, Iberian massif) contains a Neoproterozoic to Early Cambrian metasedimentary series, traditionally referred to as Serie Negra Group. A precise age for the base of the Serie Negra Group is unknown, but intrusions of (meta)mafic rocks constitute the oldest magmatic episode of arc building preserved (ca. pre-600 Ma) in this section. Neoproterozoic magmatism also includes calc-alkaline granitic bodies, which are more abundant to the north of the OMC. The upper unit involved in the tectonostratigraphy of the Mérida massif (northern OMC) is referred to as the Upper Schist-Metagranitoid unit, which comprises mafic to felsic

metaigneous rocks intruding a metasedimentary series belonging to the Serie Negra group. The magmatic evolution investigated in the Mérida massif suggests that subduction erosion mechanisms played a role in the dynamics and petrogenesis of arc magmatism. Low subduction angles favored high rates of tectonic erosion and lead to the generation of more silicic magmas with adakitic characteristics and with crustal isotopic signature (Nd-Sr). On the other hand, roll-back episodes with an increase in the subduction angle would decrease the sediment rate from the tectonic recycling of the arc itself, thus generating typical calc-alkaline arc magmas with great influence from the metasomatized/modified mantle wedge. Inheritance of igneous zircon grains in the arc-related granitoid rocks studied in Mérida spans from ca. 645–625 Ma, without interruptions, until at least ca. 540–534 Ma, which suggests tectonic recycling remained as an ongoing process for at least the same time. Whole-rock geochemical and isotopic Nd-Sr analyses combined with U–Pb laser ablation zircon ages of five metaigneous complexes showed, that the main magmatic events happened in a well-preserved arc crustal section of the Cadomian peri-Gondwanan arc in the SW Iberian Massif. This small section contains an excellent record of the cyclicity of petrogenetic and geodynamic processes in this ancient active margin.

A DECADE OF TRACING INPUTS OF WASTEWATER-AFFECTED GROUNDWATER TO SURFACE WATERS WITH ARTIFICIAL SWEETENERS

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Over the past decade, artificial sweeteners (AS) have been increasingly used by researchers as a tracer to investigate wastewater inputs to surface water and groundwater environments. Many AS occur in ionic form, including acesulphame, cyclamate, saccharin and sucralose, allowing them to travel well through groundwater systems. Therefore, their detection in groundwater discharging to a surface water body or in the surface water body itself can indicate wastewater inputs from sources such as sewage lagoons, leaky sewers, and septic systems, through this subsurface pathway. With those AS may come wastewater-sourced nutrients, with implications for eutrophication and harmful algal blooms, and various hazardous chemicals (e.g. pharmaceuticals), with implications for human and ecological health. This area of study has been a key focus of our research group over the past decade and continuing today. This presentation will demonstrate a range of applications of this suite of AS for assessing wastewater contaminant exposure and inputs to surface water systems, and distinguishing input pathways (e.g. groundwater vs. direct inputs or overland flow). Cases will include specific groundwater plume studies to subwatershed-scale assessments, in both rural and urban settings.

POLYMETALLIC IRON-OXIDE MINERALIZATION AND ALKALI-CALCIC METASOMATISM OF THE NONACHO BASIN, NORTHWEST TERRITORIES, CANADA

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The Nonacho basin is a fault-bound Paleoproterozoic basin located southeast of Great Slave Lake along the western margin of the Rae craton of the Western Churchill province. The basin hosts numerous hydrothermal polymetallic (Cu-Pb-Zn-Ag-U-Th-Mo) occurrences spatially associated with Fe-oxide mineralization (magnetite, hematite) and extensive alkali alteration (i.e. albitization and potassic alteration). Iron-oxide mineralization is widespread throughout the entire basin, occurring in various rock types including: (i) gneiss and granitoid rocks of the Archean–Paleoproterozoic basement; (ii) Paleoproterozoic basinal sedimentary rocks; and (iii) Paleoproterozoic alkaline intrusive rocks (e.g. the 1830 Ma Sparrow dykes, the 1813 Ma Thekulthili stock, and the undated red dykes) that crosscut the basin. These younger alkaline magmatic rocks contain primary igneous magnetite (type-I magnetite), and is considered in this study, as a heat engine and possible fluid/metal source for the hydrothermal polymetallic mineralization and alteration of the Nonacho Basin. All lithologies are variably replaced by hydrothermal alkali-calcic alteration along regional structures. The style and paragenesis of overprinting alteration assemblages are evaluated using a combination of field observations and μ-XRF (micro-beam X-ray fluorescence) elemental distribution maps. The types of alteration identified include early high temperature (HT) sodic alteration (albite), which is overprinted by HT iron-calcic alteration (type-II magnetite and amphibole), HT potassic-iron alteration (type-III magnetite and K-feldspar) variably enriched in Au, Cu and Ba, and low-temperature potassic-iron alteration (hematite and sericite) that is commonly associated with Ba-rich U minerals. The association of Fe-oxides with i) widespread alkali-calcic alteration and polymetallic mineral occurrences along regional structures, and ii) alkaline magmatism, is similar to mineralization styles of world-class iron oxide-copper gold (IOCG) and affiliated hydrothermal ore deposits.

OXYGENIC PHOTOSYNTHESIS IN ANCIENT CYANOBACTERIA AND THE IMPLICATIONS FOR THE GREAT OXIDATION EVENT

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It has been estimated that oxygen-producing cyanobacteria evolved sometime around 3.6 to 3.0 billion years ago (Ga). However, a major source of uncertainty remains in explaining the time lag between their evolution and the oxygenation of Earth's atmosphere, the so-called Great Oxidation Event (GOE) ca. 2.5 Ga. This apparent paradox has been explained by nutrient (e.g. phosphate) limitation keeping primary production low but even in the modern oligotrophic oceans cyanobacterial oxygen production rates are non-negligible. The veracity of nutrient limitation can be questioned if the earliest cyanobacteria were benthic and grew at the sediment-water interface where nutrients would accumulate, and where the mats themselves would concentrate nutrients. Here we examine net oxygen production rates in modern cyanobacterial mats to demonstrate that Archean biomats, even though they were severely limited in their distribution to photosynthetically effective water depths, could have oxygenated Archean oceans in far less time than would account for the delay between the evolution of oxygenic photosynthesis and the oxygenation of Earth's atmosphere. This result clearly highlights that if cyanobacteria were in the marine realm in large quantities, they would have oxygenated the Earth very quickly. The most parsimonious explanation is that marine cyanobacterial mats were not abundant during the Archean, and thus marine stromatolites from that time either represent cyanobacterial mats that were selectively preserved, or they are lithified remnants of anoxygenic species. Despite our findings calling into question the origins of marine cyanobacteria, our hypothesis is congruent with phylogenetic and geochemical evidence for cyanobacteria having evolved earlier on land in the form of soil crusts and freshwater mats, thus generating weathering signals from these localized oxygen oases. In summary, the GOE represents the evolution of photosynthetic cyanobacteria within a marine habit and the break-even point where O_2 production in the ocean overtakes methane production, allowing for oxygenation of the Earth's atmosphere.

CHARACTERIZING GROUNDWATER-SURFACE WATER INTERACTIONS IN REMOTE, DISCONTINUOUS PERMAFROST TERRAIN

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Hydrologic monitoring within Canada's northern landscape is of value to the energy sector in advance of oil and gas development and can also elucidate gradual environmental change as a result of climate warming. However, hydrologic monitoring studies in these regions are complex and expensive to undertake due mainly to limited access, lack of infrastructure and presence of variable permafrost conditions. This is particularly true for the subsurface/groundwater component of the hydrologic cycle. Recent research completed within the Central Mackenzie Valley (Bogg Creek watershed) combined remote sensing techniques with portable field monitoring methods and geochemical/isotope tracing to map regions of groundwater discharge and improve the understanding of groundwater-surface water interaction within discontinuous permafrost terrain. Orbit-based optical imagery provided evidence of recurring icings within the study area suggesting locations of groundwater

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discharge. Low elevation infra-red camera surveys, conducted during late summer, identified temperature anomalies indicative of cold groundwater discharge. Terrestrial investigations using portable, manual equipment confirmed groundwater discharging conditions with evidence of upward groundwater flow in the shallow subsurface. A range of geochemical and isotopic signatures suggested the existence of several different groundwater sources including water from the shallow active zone and from deeper bedrock aquifers. Surface water and groundwater collected along the length of Bogg Creek illustrated variability in groundwater–surface water interaction and provided evidence of suprapermafrost and subpermafrost groundwater exchange. Combining information from remote sensing systems and focused terrestrial monitoring using portable sampling techniques provides a methodology for characterizing aspects of groundwater flow and groundwater-surface water interaction that could be applicable throughout discontinuous permafrost regions in Canada and elsewhere.

CANADA'S INITIAL INVOLVEMENT WITH DEEP OCEAN DRILLING – ORPHAN KNOLL - SERENDIPITY AND HUTZPAH

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Canada was not a member of the Deep Sea Drilling Project (DSDP) when it began its first hole in 1968. The presenter was a Dalhousie graduate student still floundering without a thesis topic defined, and a disallusioned advisor. Updates on the DSDP successes came by mail in monthly issues of "Geotimes". I was in a three-person office, one of whom was a contract undergrad, David Monahan. His task was to construct an oblique view of the east coast bathymetry from Florida north to Newfoundland using a pantograph to transform available contoured bathymetry maps into elevated views. Canada had not yet published bathymetry of the northern Grand Banks. David was provided GEBCO Sheet #27 of tracks of raw soundings north of 45°N. All the tracks ran NE-SW and so did David's hand-drawn contours. I assured him that these did not reflect the true ocean-floor and I volunteered to edit/recontour the bathymetry. Out of this emerged a broad, 7500 km^2, topographic feature, 1100–1200 m high, located 550 km northeast of the Avalon Peninsula. Its minimum depth was 1725 m dropping to 4000 m northeastward. We had a quite unknown feature. I hypothesized that it was a continental fragment that was abandoned as the Labrador Sea opened ~60 Ma ago; I dubbed it "Orphan Knoll". I wrote a hand-written letter to the DSDP to suggest a future drilling site. I was told that Doc Ewing liked the idea, searched-out magnetometer data from the Charcot to convince himself that the feature was not a huge basaltic platform, and Orphan Knoll was added to 1970 Leg 12: Boston–Lisbon. I attended the AGU in Washington where DSDP Chief Scientist, Mel Peterson, reported on DSDP's initial drillholes. After his talk I went up and asked: "Can I get on board Leg 12?" Peterson was having trouble with "the Canadians". Shell Oil had just been issued its first deep-water Exploration Permits off Shelburne and it did not want the DSDP drillship, which did not use blowout preventors, to drill an open hole on the abyssal seafloor mounds that were thought to be expressions of actively rising salt structures. I volunteered to go to Ottawa to defend the DSDP site and Peterson agreed. I ended up in a Deputy Minister's office. I lost the diapir hole but Orphan Knoll passed muster. The last core on Site 111 gave us 0.5 m of non-marine Bajocian sandstone and I was on hand to help log a continental core.

CONSOLIDATING DIGITAL GEOLOGIC DATA INTO VIRTUAL REALITY FIELD EXPERIENCES FOR TEACHING GEOSCIENCE

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Greater accessibility to digital data collection technologies, coupled with the need for remote learning during the Covid-19 pandemic, has amplified the demand for and accumulation of digital geologic data. Designing and effectively using the vast amount of data to our advantage for teaching remains a significant challenge. Digital content is often displayed as individual models on websites such as Sketchfab, photos at different perspectives, and occasionally incorporated into video game like experiences. The utilization of virtual reality (VR) in the classroom has been constrained by time, tight budgets, previously prohibitive costs, and missing skills for VR design and development. The advantages inherit to VR lead it to be a powerful teaching tool. Sites located anywhere in the physical world can be visited instantly once digitized, and at a lower cost. It could also increase accessibility to field experiences, particularly in high-enrollment introductory classes where the logistics of field trips create a significant challenge. The leading advantage of this format is the sense of immersion experienced by the user. The now lower costs of standalone VR headsets for immersive (VR) gives us the opportunity to aggregate 3-D models and other digital content into cohesive and realistic simulations of, for example, geologic field work. Presenting such simulations as immersive VR experiences allows us to get a feel for field work in an environment that is naturally self-paced and exhibits one-on-one type instructions while the user completes the simulation's content checkpoints. Here we present an immersive VR demo of a geologic excursion with three types of interactions to illustrate possibilities for geoscience teaching. Each activity is structured to encourage the user to observe, record, then interpret the materials being taught. The first activity consists of investigating rock samples, classifying these and sorting them by placing them into corresponding rock type bins. The second task introduces the user to the use of a compass and measuring the orientation of glacial striation. The third activity illustrates an outcrop investigation with the task of finding geologic features on the 3-D outcrop model which are accompanied by short descriptions. Just as interactive video games incorporate completion of tasks, the simulation includes immediate feedback in form of alerts such as "well done" or "try again", with possible explanations. This framework can easily be expanded into larger scale simulations for singular field sites or conglomerates of location segments depending on desired learning outcomes.

WHEN THE ROCKS START TALKING: GEOSCIENCE EDUCATION AT STONEHAMMER GEOPARK

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A wise woman once told me that the rocks have a story to tell, you just need to listen. I've since discovered that it's also very important to know the language they are speaking. When studying any new discipline, it is critical to first learn the language of that field. This author postulates that because many students are not exposed to the language or nature of geology until well into post-secondary studies it can appear daunting and inaccessible to them. Just like travelling to a foreign country with no knowledge of the local language, being thrust into a university geology course without any prior exposure to the scientific language behind it can be intimidating and uncomfortable. At Stonehammer UNESCO Global Geopark, we strive to remove this barrier to learning through engaging multidisciplinary programming that allows participants to discover the geological heritage of the region through several different access points. Rather than opening the same well-worn door to geoscience education wider, we strive to create different doors that appeal to a wider variety of learners. This holistic approach explores concepts throughout the geopark that link to curricula across all topics and grade levels. The familiar content acts as a gateway, leading to opportunities to delve deeper into and foster greater understanding of specific geoscience topics. This enhances geoscience literacy and creates excitement for all that the field as to offer.

VISUALIZING THE SUBSURFACE GEOLOGY OF SOUTHERN ONTARIO: FROM VIRTUAL TO TACTILE MODELS

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For many it is difficult to engage with, interact with, visualize, and comprehend subsurface geology. Traditionally, subsurface stratigraphy has been delivered as graphic logs, fence diagrams, and structural and isopach surfaces that commonly require advanced geological knowledge and 2-D-3-D visualization skills of the viewer. Digital modelling techniques have enabled the design of fully interactive 3-D models that provide advanced opportunities for data integration, analysis, and visualization.

For many people, and certainly individuals outside of the geological modelling community, engaging with and learning from digital 3-D models remains challenging as information overload, recognizing data limitations and spatial sense are a continual challenge. Over the past few years digital 3-D lithostratigraphic and hydrostratigraphic models of southern Ontario's subsurface have been developed in Seequent LeapFrog, accessible through a freely available viewer. Nevertheless, the relatively large number of geologic layers and lack of supplemental information restricts interaction and understanding of the model. To encourage the broadest possible public engagement and communication of salient details of the models, a number of derivative initiatives have been initiated that involve the design of 2-D computer animations, augmented (AR) and virtual reality (VR), and 3-D prints of the models. Each approach uses storylines that guide the viewer through southern Ontario's geology and geomorphology. An integrated approach connecting digital, tactile and field learning is proposed to better support and encourage use of geological datasets and derived 3-D models. Animations provide guided storylines to initiate learning, in conjunction with AR models that offer interactive 360° experiences with the 3-D digital model (i.e. scale, rotate and move layers relative to geologic time) and connect to field sites, boreholes and rock samples. Custom-designed applications for immersive AR and VR experiences with headsets which offer up-to 6 degrees of freedom allow for deeper exploration of the model, interaction with the data and connection, which help motivate, engage, and excite learners. AR implementations are being tagged to the 3-D-printed physical model, which provides tactile connection and simplification that may be important for many users, particularly individuals that are not part of the digital gaming community. The Covid-19 pandemic has expanded our appreciation of new opportunities and value of digital products and virtual tools, while at the same time highlighting the enormous challenges, learning curve, and potential limitations in communicating geological information and knowledge about subsurface geology important for everyday life.

RADON IN ALBERTA GROUNDWATER

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Exposure to ^{222}Rn (radon) in indoor air is the leading cause of lung cancer among non-smokers globally and about 14% of houses in Alberta have indoor radon concentrations that exceed Health Canada's guideline (www.evictradon.com). Geogenic radon is produced in some geologic formations as part of the uranium-238 radioactive decay chain. Many efforts have focused on mapping radon exposure potential based on surficial materials and near-surface bedrock, but few have integrated the potential role of groundwater, either due to degassing of domestic well water or subsurface free-phase gas emissions. Additionally, groundwater wells are often screened in bedrock formations and may alter radon migration pathways allowing interactions between indoor environments and deeper geological settings. Existing literature rarely examines groundwater radon in the context of other geochemical parameters or major gas species. Therefore, the objectives of this study are to evaluate Alberta groundwater as a radon source for indoor air, determine if groundwater radon concentrations are correlated with specific aquifers or geochemical parameters, and to consider subsurface radon migration pathways. Between 2019 and 2021, 40 monitoring wells in Alberta's Groundwater Observation Well Network with known screen depth and aquifer formation were sampled for dissolved radon, along with geochemical and field parameters (including pressure of total dissolved gas (PTDG)). Groundwater radon concentrations ranged from 0.16 to 75.1 Bq/L (median = 9.2 Bq/L) across the province and did not tend to occur in any specific geographical area. Radon concentrations exhibited few correlations with geochemical, field, or well parameters, or aquifer types. Increased radon concentrations did not tend to occur in samples of any particular water type nor were they related to the evolution of groundwater. The only notable relationships were an anti-correlation between dissolved radon and both methane concentrations and PTDG. Between the four aquifer types (bedrock, surficial, channel, and till as defined by the Alberta Geological Society), no significant differences in radon concentrations were observed, but within the water samples from bedrock formations, Paskapoo aquifers had significantly higher radon contents than other bedrock aquifers. These results suggest that 1) the concentrations observed are not high enough to account for indoor air radon concentrations being derived from groundwater usage; 2) the increased radon content in groundwater is not related to increased rock-water interactions; and 3) that gas charged environments (high PTDG and methane, as observed in non-Paskapoo bedrock samples) have low radon, perhaps due to free phase gas stripping by bubble formation and escape.

LONG-TERM CHANGES IN GROUNDWATER LEVELS IN CANADA'S MOUNTAIN REGIONS

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Mountain groundwater systems play a significant role in global water supply through their contributions to mountain streamflow and central valley aquifers, providing substantial water resources to lowland populations. Rising temperatures in mountain regions due to climate change are projected to increase evapotranspiration and alter snow and ice melt timing and quantity. These factors, along with changes in precipitation, may impact groundwater recharge rates and, in turn, have the potential to impact vital groundwater contributions to mountain streamflow. Recent numerical modelling work suggests that mountain groundwater resources are vulnerable to climate change and groundwater storage may decline in some mountain ranges. However, there is a lack of field evidence in the literature for these trends, especially at regional to global scales. Since many previous studies of mountain groundwater systems have been local in scale, we also lack an understanding of the broad hydrologic and geographic characteristics that influence the vulnerability of different mountain groundwater systems to climate change. This research aims to quantify trends in mountain groundwater storage and expand our understanding of what makes mountain groundwater resources more or less vulnerable to climate change. This will be accomplished through analysis of a large dataset of long-term groundwater levels compiled from provincial observation networks for mountain regions in Canada. These data will be filtered based on record length, data gaps, and proximity to surface water bodies. Trend analysis will be conducted on groundwater level data using the seasonal Mann-Kendall statistical test to identify areas with declining groundwater storage. Next, the relationship between trends in groundwater storage and mountain watershed characteristics (e.g. topography, geology, climate, etc.) will be explored and used to determine the main factors influencing mountain groundwater vulnerability. This research will expand our understanding of a critically important water resource beyond the local scale and identify risk factors that can be easily identified by water managers to promote sustainable water resource management in mountain environments.

GEOCHEMISTRY OF DEVONIAN OPHIOLITES FROM NW IBERIAN MASSIF: THE RECORD OF AN EPHEMERAL OCEANIC BASIN

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The section of the Variscan Orogen represented in the Iberian Massif preserves several ophiolitic sequences from which the Devonian cases have been the most controversial. Initially considered the remnants of the Rheic Ocean, formed during its closure by intraoceanic subduction, after more detailed studies they were reinterpreted as an ephemeral oceanic basin that opened at the most external margin of Gondwana after its collision with Laurussia. The representatives of these Devonian ophiolites, located at the allochthonous complexes of northwestern Iberia, Careón, Purrido and Moeche, occupy an intermediate position within the allochthonous nappes. The Careón Ophiolite located southeast of the Órdenes Complex, consists of three tectonic slices including ultramafic and gabbroic sections. Diabase dykes intruding both sections, together with the absence of volcanic members, differentiates this ophiolite from the typical "Penrose" assemblage. Purrido and Moeche ophiolites outcrop to the west and to the east of the Cabo Ortegal complex. Unlike Careón, these ophiolites are mostly constituted by amphibolites (Purrido Ophiolite) and mylonitic greenschists with some alternations of ultramafic rocks and mica schists (Moeche Ophiolite). The chronology of the three units has been dated at ca.

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400 Ma by the U–Pb method but there is also evidence for a zircon source of ca. 1160 Ma recorded in a sample of Purrido Ophiolite, which agrees with the old/crustal εHf signature of the zircons from mylonitic greenschists of the Moeche Unit. These facts were key to discard the origin of this oceanic basin as result of intraoceanic subduction. A global review of the geochemical data available from the most representative mafic lithologies of these ophiolites provides a picture of the different sections of the same oceanic basin. A progressive change of the chemical composition can be noticed from the ophiolite stacked in the highest position (Careón) to the lowest (Moeche). This fact is reflected in different diagrams such as Th/Yb vs. Nb/Yb, which monitors subduction/crustal input. While the greenschist samples from the Moeche Ophiolite plot within the MORB array, Purrido amphibolites drift toward higher Th/Yb ratios and Careón samples plot above the MORB array, indicating a stronger input from the subduction zone. The interpretation of these data indicate that each of the Devonian ophiolites might represent a different part of a developed suprasubduction basin where the Careón Ophiolite was located closest to the trench in the northeast position, and the Purrido and Moeche ophiolites were the sections progressively farther to the south and less influenced by the subduction activity.

THE PALEOPROTEROZOIC AUCOIN OROGENIC GOLD PROSPECT HOPEDALE BLOCK, LABRADOR: IMPLICATIONS ON MINERALIZATION AND HOST ROCKS

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The Aucoin gold prospect, located 70 km west of Hopedale in the Archean Hopedale Block, North Atlantic Craton (NAC), Labrador, occurs near the southern extremity of the Torngat Orogen and the inferred boundary between the Hopedale and Saglek blocks. Geological, lithogeochemical and U–Pb SHRIMP zircon geochronological data indicate that the Aucoin prospect host rocks comprise four types, three of which were previously unrecognized in the region and form the Aucoin Intrusive Suite. The suite is constrained, based on U–Pb SHRIMP zircon geochronology on the earliest phase, to have intruded at ≤ 2567 ± 4 Ma and includes massive to weakly foliated: 1) earliest, alkali and LREE-enriched hornblende-clinopyroxene syenite; 2) contemporaneous, sinuous, non-chilled dykes of clinopyroxene-hornblende monzodiorite with E-MORB-like chemistry, and; 3) a ≤ 50 m thick, irregular sill of hornblende-porphyritic, alkali monzogabbro or essexite. Altered and quartz-veined, northwest-trending tholeiite dykes of the ca. 2235 Ma Kikkertavak swarm form the fourth altered rock type. All intruded Mesoarchean Maggo gneiss, Weekes amphibolite and Kaniriktok intrusions of the Hopedale block. Aucoin suite mafic rocks represent low-degree partial melts of an enriched garnet-bearing asthenospheric source; whereas syenite likely represents contemporaneous, strongly fractionated melts that assimilated lower crust. Emplacement of the Aucoin suite was contemporaneous with granulite facies metamorphism and small volume granites in the region, an interval interpreted to record late Archean reworking (transtension?) along the Saglek-Hopedale boundary zone after amalgamation of the NAC. Mineralization consists of anastomosing, discontinuous, northeast- and northwest-trending quartz veins (typically $^{40}Ar/^{39}Ar$ plateau age of 1873 ± 6 Ma), overlapping with early orogenesis in the Torngat Orogen and collision of the southeast Churchill Core Zone with NAC (ca. 1870–1850 Ma). This interval is a global, auriferous metallogenetic window and highlights the potential for comparable mineralization along the Torngat orogenic front in Labrador.

BACK-ARC BASIN FORMATION AT THE LAST STAGES OF THE PALEO-ASIAN OCEAN EVOLUTION, CENTRAL ASIAN OROGENIC BELT: A NEW TECTONIC FRAMEWORK BASED ON EVIDENCE FROM THE LIUYUAN COMPLEX AND SURROUNDING UNITS, NW CHINA

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The mafic Permian Liuyuan Complex has been at the centre of the debate regarding the final stages of the evolution of the Central Asian Orogenic Belt (CAOB) and, by implication, the Paleo-Asian Ocean. The internal stratigraphy and tectonic setting of the Liuyuan Complex were previously poorly understood. Two contrasting interpretations existed concerning its origin: 1) a fore-arc ophiolite, or 2) a large continental rift. A combined field, geochemical and geochronological study suggests the Liuyuan Complex represents a back-arc basin ophiolite and a more complex Permian tectonic history for the southern end of the CAOB than previously thought. We propose a new tectonic model for the final stages of the CAOB between the southern margin of Composite Siberia in the north and the Baidunzi terrane in the south. We interpret the Liuyuan Complex to have formed between 290 and 282 Ma as a back-arc basin dominated by suprasubduction zone tholeiitic basalt associated with the extensional calc-alkaline Ganquan arc system, active between 295 and 282 Ma. Arc extension and back-arc basin formation was likely caused by slab roll back causing the arc to migrate southwards. Back-arc basin extension and arc magmatism ceased by 282 Ma, caused by the collision of the Baidunzi terrane with the southern, leading edge of the Ganquan arc system, which terminated northwards subduction beneath the Gangquan arc system and forced the subduction zone to step-back into the remaining, trailing wide oceanic back-arc basin. The new subduction zone switched the remaining part of the back-arc Liuyuan Complex into a new arc to fore-arc setting, such that it became the basement for ca. 280–269 Ma arc magmatism, recorded by dacite and plagiogranite intrusions in the Liuyuan Complex, and rhyolite beds interlayered with marine sedimentary rocks on the southern edge of Composite Siberia farther inboard. This tectonic model provides a new framework for the Permian evolution of the southern CAOB and the Paleo-Asian Ocean.

STABILITY OF SECONDARY MINERALS AND ARSENIC MOBILIZATION IN MINING-IMPACTED LONG LAKE SEDIMENT

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The Long Lake Gold Mine (1908–1939) near Sudbury, Ontario, produced sulphide-bearing tailings that were discharged directly to shallow wetland areas without containment, and oxidation of sulphide minerals (mainly pyrite and arsenopyrite) has resulted in elevated aqueous arsenic (As) concentrations downstream in Luke Creek and Long Lake. Over time, erosion and transport of tailings-derived solids, and their deposition in the lake, formed a sediment delta at the mouth of the creek. In the 1970s, the Ontario government attempted to stabilize the surface by covering it with sand (~0.3 m thick) and the sand cover now contains cemented crusts formed by the precipitation of secondary minerals. The geochemical and mineralogical properties of the tailings, the sand layer, and the sediment in the delta are being investigated to understand the stability of secondary minerals that exert control on the mobility of sulphide-oxidation products, including As. Vertical cores were collected from the tailings and the sediment delta. The cores were dried anaerobically, and polished thin sections were prepared for examination by SEM-EDS, EPMA and (S)TEM-EDS. High concentrations of solid-phase As (1.41 wt.%), Fe (7.62 wt.%), and S (2.88 wt.%) in the sand indicate upward transport of sulphide-oxidation products from the underlying tailings. SEM-EDS and EPMA analyses of the secondary minerals in the tailings and the sand layer indicate that the dominant phases consist of two principal chemical compositions: Fe-As-O and Fe-S-O-K/Na, indicating the presence of ferric-arsenate (FA) and K/Na-jarosite, respectively. The sediment from the delta in Long Lake (maximum thickness of 1.5 m) contains fragments of cemented crusts derived from the tailings and sand cover. SEM images from fragments collected near the sediment-water interface in the delta display morphologies suggestive of partial dissolution, and (S)TEM-EDS analyses indicate that the As:Fe ratios are low relative to the FA crusts in the tailings and sand cover. The FA minerals are destabilized by reducing conditions in the sediment and the As appears to be selectively reduced and mobilized, leaving residual Fe-oxyhydroxides, but some of the Fe (III) has recrystallized to form Fe-oxyhydroxide spherules. At depths of 1.6 to 2.0 m in the sediment, reductive dissolution of tailings-derived FA, jarosite and Fe-oxyhydroxide minerals has resulted in precipitation of As-sulphide (orpiment) and framboidal pyrite. These phases have relatively low solubility, so the diagenetic reduction/precipitation processes leading to their formation may have implications for design of remedial action.

AGE, PETROLOGICAL, AND CHEMICAL SIMILARITIES BETWEEN THE SOISSON INTRUSIONS AND THE GABBROIC-TROCTOLITIC INTRUSIONS OF THE NAIN PLUTONIC SUITE, AND IMPLICATIONS FOR NI-CU-CO MINERALIZATION WITHIN THE SOUTHEASTERN CHURCHILL PROVINCE

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The Soisson intrusions are kilometre-scale, well-preserved olivine-bearing gabbroic intrusions occurring over a ~180-km NW-SE strike length area within the western Core Zone, an amalgamation of several Mesoarchean to Paleoproterozoic crustal blocks resulting from the collision between the Superior and North Atlantic cratons within the southeastern Churchill Province. These intrusions are mainly composed of massive to subophitic olivine gabbro, gabbro, gabbronorite, and minor norite with cumulus plagioclase, olivine, and locally clino- and orthopyroxene, enclosed by clinopyroxene oikocrysts (± orthopyroxene and olivine) with plagioclase chadacrysts. A thin serpentinized peridotite unit was also recognized in one of these intrusions, the Papavoine intrusion, but was not characterized in the course of this study. Two of the Soisson intrusions, roughly 80 km apart, yielded U–Pb baddeleyite crystallization ages of 1312.4 ± 1.3 Ma and 1311.4 ± 1.3 Ma. In addition to their coeval ages, comparable petrographic, geochemical, and mineralogical characteristics suggest that all of these gabbroic intrusions are co-genetic and form the Soisson Intrusive Suite. The Soisson intrusions formed from basaltic parental magmas with low MgO (~6–7 wt.%) and high Fe-Ti contents. Overall, they exhibit similar fractionation at the regional-scale and incorporated variable amounts of upper crustal materials (e.g. graphitic paragneiss) during emplacement, as indicated by field (e.g. xenoliths, hybrid zones) and geochemical (e.g. high HILE/MILE, depletion in Nb ± Ta) evidence. Furthermore, these gabbroic intrusions contain Ni-Cu-Co showings with subeconomic concentrations in Ni, Cu, and Co. Among the Soisson intrusions, the Papavoine intrusion may be the most prospective intrusion as a Ni, Cu, and Co exploration target. This intrusion is composed of the most primitive rocks of the intrusive suite, exhibits the highest magmatic sulphide accumulations along the contacts with the country rocks, and shows significant Ni and Cu abundance (up to 1.2% and 0.5%, respectively). Moreover, the Soisson intrusive suite shares many petrological, geochemical, and mineral chemistry similarities with the troctolite and olivine gabbro cumulates of the Voisey's Bay and Mushuau intrusions of the Nain Plutonic Suite (NPS). They are contemporary with the younger gabbroic-troctolitic intrusion phase of the NPS (e.g. Mushuau intrusion: 1317–1313 Ma versus Voisey's Bay: 1334–1330 Ma) and appear to have been emplaced through crustal-scale faults within zones of crustal anisotropy. These similarities suggest that the Soisson Intrusive Suite and the gabbroic-troctolitic intrusions of the NPS were formed by similar petrological processes, prospective for Ni-Cu-Co mineralization, but also open questions about their potential genetic link and magmatic connectivity at depth.

SOLID CARBON: A DEEP-SEA CO_2 MINERALIZATION DEMONSTRATION PROJECT FACILITATED BY IODP DATA AND SAMPLES

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The basaltic oceanic crust offers immense capacity to durably and safely store anthropogenic CO_2. Its estimated capacity (250,000 Gt CO_2) is more than sufficient to lock away all past and future anthropogenic CO_2 emissions. Moreover, recent field-scale CO_2 injection operations by CarbFix in Iceland and the US Wallula project have demonstrated that CO_2 injected into basalts will mineralize (turn into carbonate rock) over relatively short timescales, thus making it a highly durable form of carbon capture and sequestration (CCS), and extremely safe if done away from populous areas and without pathways to freshwater aquifers or the atmosphere. Thus, building on decades of work demonstrating the efficacy of CCS on land and in offshore sediments, Solid Carbon has proposed that gigaton-per-year scale CCS in the basaltic oceanic crust is possible. To demonstrate the feasibility of this proposal, Solid Carbon is currently planning an offshore sequestration test in the NE Pacific Cascadia Basin. We aim to carry out the Cascadia Basin demonstration experiment by 2025, using IODP as a platform. The target area for the injection is that of ODP Leg 168 and IODP Expeditions 301 and 327, which provided the most detailed structural and hydrogeological data for oceanic crust globally. This previous research has shown that the ocean crust is porous, permeable, and the overlying sediments act as a cap rock sealing the crustal reservoir below. Our current research includes laboratory experiments to examine the reactivity of IODP-recovered basalt cores, and reactive transport modeling to explore the fate of CO_2 injected into the Cascadia Basin aquifer. Initial results show that Gt-scale CO_2 sequestration in ocean crust is indeed possible, however the mineralization time would be considerably longer when injecting supercritical CO_2 compared to already dissolved CO_2 as done by CarbFix, though at the cost of large injection fluid volumes. Other research focuses on optimized scientific monitoring, including OSMO-fluid-sampling in monitoring holes and using reactive and conservative tracers to track carbon. Old structural data from the early ODP and IODP campaigns are reanalyzed to model induced seismicity, backing up the safety of this region. Other aspects of the Solid Carbon project include the long-term aspects of implementing this solution commercially over the next decades, such as the CO_2 capture itself in a marine environment, generation of sustainable energy in the deep ocean, as well as evaluating the regulatory framework and developing a potential business case for this climate solution.

TRENDS IN AQUEOUS MERCURY SPECIATION AND BIOAVAILABILITY IN PRAIRIE POTHOLE REGION WETLANDS OF SASKATCHEWAN

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The Prairie Pothole Region (PPR) of North America consists of numerous wetland complexes that are susceptible to mercury (Hg) inputs. In Saskatchewan, the biogeochemistry and hydrogeology of these wetlands varies fundamentally due to inconsistencies in surficial Quaternary lithology and changing land use, posing significant challenges in understanding Hg cycling. Methylmercury (MeHg), a neurotoxin that may lead to the bioaccumulation of Hg in higher trophic levels of food webs, is a product of Hg cycling in aquatic environments such as the PPR wetland complex. Both dissolved organic carbon (DOC) and sulphate, primarily introduced through the oxidation of pyrite in glacial tills in the region, fuel microbial sulphate reduction and methanogenesis, resulting in increased Hg methylation rates. As such, understanding the biogeochemical cycling of wetlands that prove sensitive to Hg inputs and methylation is critical for safeguarding of the environment. Previous studies have identified the PPR wetland complexes as biologically productive sites, with biotic Hg methylation associated with seasonal changes in water chemistry and widespread anoxia. Mercury is known to primarily exist in complexes with biogenic and organic materials in the water column; however, in anoxic freshwater, Hg is more often complexed by sulphur species in the sediment-water interface. Here, we utilize open-source aqueous geochemical modeling software to examine the influence of sulphur cycling and redox conditions on Hg speciation in the St. Denis National Wildlife Area (SDNWA) wetlands within the PPR. Surface and groundwater chemistry datasets obtained from the Global Institute of Water Security and previous studies conducted at the SDNWA are used to develop models for Hg speciation in ponds with differing major ion water chemistry types (calcium sulphate versus calcium bicarbonate type) and MeHg concentrations. The results indicate that Hg speciation in these wetlands could vary with concentrations of surface water sulphate. Seasonal precipitation and wetland permanence is expected to influence water column redox conditions and, by extension, the dominant Hg species, and bioavailability of Hg. Overall, we suggest that sulphur and DOC-complexes may exhibit fundamental controls on Hg bioavailability and the production of MeHg within SDNWA wetlands and, more broadly, the PPR. These results may also be used to provide insights in global geochemical Hg cycling in wetlands with overall sulphidic systems.

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LIDAR-ASSISTED ENVIRONMENTAL RISK ASSESSMENT OF SINKHOLES IN THE CUMBERLAND SUB-BASIN OF NOVA SCOTIA

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Evaporites are unique when compared to other sedimentary rocks. Windsor Group evaporites in Atlantic Canada have been significantly deformed since the Carboniferous; previous work has not accounted for unique evaporite characteristics when creating maps and models. The objectives of this research are two-fold: to examine the accuracy of the current geological map on a small section of the Cumberland sub-basin in Nova Scotia and to produce an environmental risk assessment. The current geological map of the Oxford-Pugwash area in Cumberland County, Nova Scotia, includes three sizeable independent salt diapirs mapped along a NE-SW trend. However, this map predates developments in salt tectonics that lend credence to the notion that the three diapirs are likely part of a larger salt structure. The areas between the diapirs are examined to determine if there is evidence of a salt wall connecting them. One type of evidence includes mapping sinkholes in the area, as sinkholes have been recognized above Windsor Group evaporites in the Cumberland sub-basin. Sinkholes are mapped using manual identification and an automated sinkhole delineation program developed in ArcGIS. To address the second part of this project, we survey the local populace about sinkhole risks in the area through informal interviews and surveys. Throughout these discussions, it becomes apparent that most locals are unaware of the potential geological hazards. The overall goal of this second objective is to increase public awareness of geohazards to mitigate the potential impact of sudden structural collapses.

A WORKFLOW FOR RESERVOIR CHARACTERIZATION: AN EXAMPLE FROM THE FLEMISH PASS BASIN

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Following the Bay du Nord discovery (ca. 2013), 13 additional exploration and appraisal wells have been drilled by Equinor in the Flemish Pass Basin. Each well has a suite of geophysical, geological, and petrophysical data, which represent various scales of interpretation, from micrometres to kilometres. Given the complexity of the data, associated uncertainties, and often amongst a sparse collection of wells, careful consideration is needed to establish a workflow for reservoir characterization. This is critically important as reservoir characterization translates a geological understanding or concept(s) to a static reservoir model. Therefore, utilizing all available datatypes and capturing uncertainties will produce a static model that best represents the reservoir and will be most suitable for calculating resources, planning wells, and designing optimum drainage strategies. Conventional core forms the framework for foundational reservoir interpretations and subsequent data acquisition. As a tangible representation of the subsurface, it provides sedimentological insight; from process to lithofacies and hierarchal depositional environments. Following core interpretation, core sampling can provide higher resolution of chronostratigraphic, paleoenvironmental, petrological, and routine or special core analysis (RCA, SCAL). Chronostratigraphy will help resolve relative ages, but can also yield useful bioevents that can serve as datums for stratigraphic correlation of reservoirs. Paleoenvironmental analysis can identify specific depositional settings (including bathymetries), oxygen content, and salinities, which support core observations and interpretations. Additional core support comes from petrological studies, including framework, diagenetic, and grain size analysis, which can also be compared against RCA or SCAL data. The incorporation of petrophysical logs, such as gamma ray (GR) and shale volume (VSh), and well bore image logs (structural and sedimentological), provide calibration from cored to uncored stratigraphic intervals, strengthening intra- and inter-well interpretations. With expanded interpretations beyond the wellbore, the inclusion of regional to detailed seismic mapping can be incorporated to understand basin architecture, fault timing, reservoir presence, and build relationships between structure and depositional systems. As geologic concepts mature, with continuous data integration, a combination of outcrop, subsurface, and modern analogues can be included to best represent concepts and uncertainties. Using wells from discovery areas from the Flemish Pass Basin, examples of these integrated data types will illustrate reservoir characterization and the development of conceptual models.

FIELD EVIDENCE FOR THE FORMATION OF TWO COMMON STRAIN-INDUCED STRUCTURES CONFLICTS WITH THE STARTING GEOMETRY OF NUMERICAL MODELS

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When modelling two common deformational structures, mirror-symmetrical winged inclusions derived from fragments of competent layers and monoclinic flanking folds due to translational faulting, most workers did not simulate the entire progressive deformation. Instead, in the former case the numerical models started with a highly viscous lens representing a straight-tailed lenticular boudin and in the latter case fixed linear discontinuities were used instead of analogues of tensile cracks or slip surfaces that propagate continuously during progressive deformation. In the westernmost Grenville Province, highly strained banded orthogneisses contain fragments of competent layers that resemble symmetrical winged inclusions derived from lenticular boudins. Although visually similar to modelled winged inclusions, field evidence indicates that most of them are remnants of disrupted tight to isoclinal S-Z folds rather than distorted lenticular boudins. In the same gneiss bodies, gentle to open asymmetrical flexures flank 10 m-scale extensional faults that are commonly marked by nondeformed or only weakly strained pegmatite dykes. In contrast to the starting assumption of the models, field evidence suggests that the extensional faults nucleated as mm- to cm-scale slip surfaces that propagated multilaterally to reach their final size. Other field evidence suggests that gentle to open monoclines continually formed at the transient tip lines of the propagating slip surfaces, but were progressively truncated by these surfaces, thereby becoming pairs of asymmetrical flexures (apparent flanking folds).

EXHUMATION OF TACONIC ECLOGITE IN THE OLD HOUSE COVE GROUP (NORTHERN NEWFOUNDLAND)

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Taconic eclogite bodies in northern Newfoundland are hosted in geologic units situated along the eastern edge of the Humber margin, which is delineated by the suture zone of the Taconic orogen, the Baie Verte-Brompton line. They are exposed in Old House Cove Group units (e.g. East Pond Metamorphic Suite), as mafic layers, pods or lenses that crosscut the structures of their host rocks. These eclogites are interpreted as the evidence that the hyperextended Laurentian margin was subducted to deep levels during the Taconic orogenic cycle (495–461 Ma). Although the area has been extensively investigated since the second half of the last century, there is still considerable debate about the structural relationships between the eclogitic mafic bodies and their host rocks. Additionally, preliminary P-T work suggests that the mafic pods were subjected to higher pressures than their hosts, and the reasons for this are unclear. Finally, the variability of the radiometric ages do not permit unequivocal interpretation of the exhumation mechanisms of the subducted Humber margin units. The importance of these eclogites for understanding the Taconic orogeny and hence, the initial stages of the closure of the Iapetus Ocean (and related seaways) justifies a more detailed structural, petrological and geochronological analysis. The goal of my research is to define the timing and the exhumation mechanism of Taconic eclogite in the context of the Taconic orogenic cycle and, ultimately, the Cambrian–Ordovician evolution of the Laurentian realm in the northern Appalachians.

ENVIRONMENTAL CONTROLS ON THE GENERATION OF SUBMARINE LANDSLIDES IN ARCTIC FIORDS: AN EXAMPLE FROM PANGNIRTUNG FIORD, BAFFIN ISLAND

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High-latitude fiords are susceptible to submarine and subaerial landslides that can affect low-lying coastal communities and damage essential infrastructure. Most

fiords surveyed in Baffin Island, including Pangnirtung Fiord, show evidence of submarine landslides, although their timing is relatively unknown. Using multibeam echosounder data, sub-bottom profiles, and gravity cores collected in 2019, this study sought to generate a comprehensive understanding of the distribution, timing, and potential trigger mechanisms of submarine landslides in Pangnirtung Fiord. In total, 180 submarine landslides were delineated, with an average area of ~0.13 km^2. Of eleven landslides dated using ^{14}C AMS dating and ^{210}Pb/^{137}Cs activities, eight are younger than 500 years, indicating that modern processes should be considered to determine potential triggering mechanisms. Four categories of landslide triggers were identified; 53% are associated with subaerial sources and 31% are influenced by shallow-water, non-subaerial triggers. This suggests that most landslides in Pangnirtung Fiord are triggered by processes such as rapid flood-water input, subaerial debris flows, and sea-ice loading during low tide. Most submarine landslides do not appear to have the capacity to initiate a tsunami because of their small size. However, tsunami modelling simulations for the largest submarine landslide (2.1 km^2; 25 million m^3), which occurred about 2500 years ago offshore the Kolik River delta, show that it had the ability to generate 2 m-high waves. The interaction of subaerial and submarine processes suggests that a potential rise in the occurrence of subaerial debris flows and flooding due to climate change may increase the frequency of submarine landslides.

WAS THE HURONIAN GLACIATION REALLY A SNOWBALL? A DETRITAL ZIRCON PERSPECTIVE

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Glacial records are recognized in Earth history from 2.9 Ga to the present and provide important information regarding the climatic, sedimentary, and tectonic evolution of our planet. Glaciers are highly effective agents of erosion that generate and transport large amounts of sediments for 100's of kilometres. Therefore, detrital zircon geochronology of glaciogenic sedimentary rocks provide important insights to the provenance and patterns of the sedimentary record through time. In this study we investigate the Siderian glaciation event that is hypothesized to be the oldest global glaciation in Earth's history. In the period from 2.45 Ga until 2.22 Ga three glaciation cycles are recorded in the Huronian Supergroup, in the eastern portion of Canada. These are represented by the diamictite of the Ramsay, Bruce and Gowganda formations. The oldest Ramsay Formation is commonly correlated to the Polisarka Formation, located in the Immandra-Varzuga Greenstone Belt in Russia, and the Duistchland Formation in the Transvaal Supergroup, South Africa. The Snowball Earth model implies that all cratons are covered by ice. Although this theory is widely accepted to explain the Siderian glaciation, some questions remain uncertain. In the supercraton model, two landmasses are proposed during the Archean–Paleoproterozoic boundary: Superia and Sclavia. Glaciogenic units are observed in all cratons of Superia (Superior, Kaapvaal, Kola/Karelia, Wyoming, Hearne, Pilbara cratons), while these records are absent in the Sclavia supercraton (São Francisco, Zimbabwe, Slave, Dharwar and Yilgarn cratons). Nevertheless, the high-obliquity hypothesis suggests a high-obliquity degree (49° to 54°) between the magnetic field and the spin axis, proposing that equatorial regions were colder during the Proterozoic. To test the Siderian "Snowball Earth" hypothesis, this paper presents compiled detrital zircon ages from sedimentary successions that are either pre-glaciation (> 2.5 Ga), syn-glaciation (2.5–2.2 Ga) or post-glaciation (> 2.2 Ga) from nine cratons to better understand changes in detrital zircon provenance, the transport of sediment from source to sink, and the configuration of the cratons. This study proposes two distinct provenance patterns related to the Archean supercratons Sclavia and Superia along with the absence of clear Sclavian glacial deposits, indicating that the Siderian glaciation may not have been a global event, but was the product of regional glaciation.

SYN-OROGENIC SEDIMENTATION OF THE GIBBETT HILL AND QUIDI VIDI FORMATIONS (LOWER SIGNAL HILL GROUP), AVALON PENINSULA, NEWFOUNDLAND

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The Gibbett Hill and Quidi Vidi formations record ca. 560–550 Ga deltaic progradation at the base of the Signal Hill Group, the youngest Neoproterozoic unit exposed in the Newfoundland Avalon Zone. Structural and stratigraphic relationships in the Signal Hill Group exposed on the Avalon Peninsula provide evidence of progressive deformation coeval with the Avalonian orogeny. The most notable evidence is from the Flatrock thrust in the eastern Avalon Peninsula, where as much as 3.5 km of displacement and synchronous alluvial growth strata sedimentation occurred in the upper units of the Signal Hill Group. Other more subtle structural and stratigraphic evidence from the deltaic Gibbett Hill and Quidi Vidi intervals in the same region suggest that sedimentation was coeval with hypothetical blind faulting and folding that affected isopach distribution during changes in the basin configuration. To test this hypothetical blind faulting, we present stratigraphy, facies analysis, and paleoflow data from Gibbett Hill and Quidi Vidi formations in the Avalon Peninsula, Newfoundland. The Gibbett Hill Formation records continuous south/southeast progradation of a river-dominated delta-front comprising amalgamated mouth bars and terminal distributary channel fills gradationally overlying fine-grained prodelta facies of the St. John's Group. The contact between the Gibbett Hill and the overlying Quidi Vidi Formation varies from sharp north of the hypothetical blind thrust to gradational south of the thrust. Similarly, the delta plain facies of the Quidi Vidi Formation and its lateral equivalent Ferryland Formation vary from north and south of this hypothetical structure. To the north of the hypothetical blind thrust, predominantly thick-bedded distal distributary channel fills and mouth bars overlie delta-front facies. Near the hypothetical blind thrust, deep laterally confined distributary channel fill complexes are in sharp contact with delta-front facies, and to the south of the blind fault, unconfined, subaqueous, interdistributary bay floodplain deposits overlaying delta-front facies dominate. The apparent facies continuity of the Gibbett Hill Formation suggests that sedimentation was not accompanied by local uplift. On the other hand, the variations in the basal contact of, and distribution of facies of, the Quidi Vidi Formation could be explained by emergence of a blind thrust, causing subsidence and preservation of unconfined interdistributary deposits to the south and erosion and deep, laterally confined channelization to the north, particularly near the hypothetical thrust.

CHANGING HOW WE VIEW CONSERVATION EFFORTS WHILE MAKING PALEONTOLOGICAL FIELD EXPERIENCES MORE SUSTAINABLE AND INCLUSIVE ALONG THE BAY OF FUNDY

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Smaller rural science museums often struggle with gathering the needed resources each year to have a successful field season. Lack of adequate funding affects the ability to secure the necessary staff and equipment needed to conduct research, while museums in remote locations often lack amenities desirable to a potential workforce. The Fundy Geological Museum is a small, provincial museum that is two hour's drive from city amenities but sits along the coast of the world-famous Bay of Fundy, home to the world's highest tides. Field sites all along the shoreline surrounding the Museum are where Canada's oldest dinosaurs are found and the flora, fauna, and ichnofauna of the Triassic–Jurassic boundary are stunningly preserved. Unfortunately, due to the tidal nature of these areas, field sites are inaccessible for six hours, twice per day, every day. The cliffs that make up the shoreline along the Bay of Fundy are under constant erosion, which is a double-edged sword as they regularly expose new fossil material which are then subject to the tides, cliff collapse, and storms along the coast. This raises the question, how does an underfunded museum in a remote location manage to collect and conserve this steady supply of fossil material before it is lost to the sea? The Fundy Geological Museum has attempted to increase our observation and collection of fossils by engaging citizen scientists to collaborate with our efforts in numerous ways, including paid opportunities, volunteer efforts, and hands-on educational programming. The most unique experience we offer is the Fossils on Horseback half-day excursion, where guests ride to and from the field site on horseback and sieve through 200 million-year-old sandstone for dinosaur and reptile fossil remains. Other programs include weekly trips to active field sites that are open to the public as well as private group tours. Local community members and research collaborators often assist in summer field activities as well, but the grade-school outreach field excursions that target underrepresented students in STEM are by far the most meaningful fieldwork we accomplish each year. All these efforts combined have significantly increased the amount of time spent assessing and excavating fossil materials at our field sites while maintaining the best prac-

tices for fossil collecting. This has resulted in numerous scientific finds, peer-reviewed publications, considerable revenue for the museum, community goodwill in terms of promoting local tourism, and has created increased opportunities for the public to contribute to modern scientific discoveries.

CONSTRUCTION OF A VENUSIAN GREENSTONE BELT: A PETROLOGICAL PERSPECTIVE

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The crustal evolution of Venus appears to be principally driven by intraplate processes that may be related to mantle upwelling as there is no physiographic evidence of Earth-like plate tectonics. Rocks with basaltic composition were identified at the Venera 9, 10, 13, and 14, and Vega 1 and 2 landing sites whereas the rock encountered at the Venera 8 landing site may be silicic. The Venera 14 rock is similar to terrestrial olivine tholeiite but bears a strong resemblance to basalt from terrestrial Archean granite-greenstone belts. Forward petrological modeling (i.e. fractional crystallization and partial melting) and primary melt composition calculations using the rock compositions of Venus can yield results indistinguishable from many volcanic (i.e. ultramafic, intermediate, silicic) and plutonic (i.e. tonalite, trondhjemite, granodiorite, anorthosite) rocks that typify Archean granite-greenstone belts. Evidence of chemically precipitated (e.g. carbonate, evaporite, chert, banded-iron formation) and clastic (e.g. sandstone, shale) sedimentary rocks is scarce to absent, but their existence is dependent upon an ancient Venusian hydrosphere. Nevertheless, it appears that the volcanic-volcaniclastic-plutonic portion of granite-greenstone belts can be constructed from the known surface compositions of Venusian rocks and suggests that it is possible that Venus and the early Earth had parallel evolutionary tracks during the initial growth stages of proto-continental crust.

LONG-LIVED ASSOCIATION BETWEEN AVALONIA AND THE MEGUMA TERRANE DEDUCED FROM ZIRCON GEOCHRONOLOGY OF METASEDIMENTARY GRANULITES

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The Acadian Orogeny of the Northern Appalachians was caused by accretion of the peri-Gondwanan terranes Avalonia and Meguma to the eastern margin of Laurentia during the Devonian. The lithotectonic relationship between Avalonia and Meguma prior to accretion is uncertain. Radioisotopic dating of detrital zircons from metasedimentary granulite xenoliths from the structural basement to the Meguma terrane indicates that Avalonia and Meguma were proximal and likely contiguous as they transited the Rheic Ocean. The zircon ages range from the Cryogenian to late Silurian with a minor Paleoproterozoic peak. Mesoproterozoic zircons are also identified and, coupled with the Ordovician to Silurian zircons, distinguish the rocks from those of the Meguma terrane. Furthermore, three distinct metamorphic events are identified at 399.0 ± 2.1 Ma, 376.9 ± 1.6 Ma, and 353.8 ± 3.3 Ma. We conclude that the granulite facies metamorphism experienced by the metasedimentary rocks occurred 10 to 20 million years after deposition of their protoliths during the initial stages of the Acadian Orogeny whereas the younger events are related to syn- and post-collisional episodes. The implication is that Avalonia and the Meguma terrane jointly transited from Gondwana.

CALIBRATING THE SHURAM CARBON ISOTOPE EXCURSION FROM BAYESIAN AGE MODELING AND ASTROCHRONOLOGY OF THE EDIACARAN NAFUN GROUP IN OMAN

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Oman is the type locality for the Mid–Late Ediacaran Shuram negative carbon isotope ($\delta^{13}C$) excursion, which represents one of the most extreme, global negative $\delta^{13}C$ excursions in Earth's history. In Oman, the anomaly occurs within the Shuram and Buah formations of the Nafun Group, where it has been reproduced widely in drill core and outcrop. A well-defined chronology for the Nafun Group is therefore essential to understanding the Shuram excursion and its relationship to other global climatic and biogeochemical events during this critical transition in Earth's history. Here, we apply Bayesian age modelling to the Nafun Group as recorded in the Miqrat-1 Well reference section to better temporally calibrate this important succession. The age model leverages a combination of U–Pb and Re–Os dates both from Oman and from other Ediacaran successions globally that can be correlated with the Miqrat-1 Well using chronostratigraphic tie points, including chemostratigraphy ($\delta^{13}C$). We further condition the timescale for the Shuram excursion using astrochronological constraints on the duration of the Shuram excursion, which indicate that it lasted ca. 7.7 ± 0.2 Myr, with the initial drop in values spanning about 1 Myr, followed by a protracted, nearly 7 million-year recovery. Our results suggest that the Shuram excursion initiated after both the Gaskiers glaciation and the first appearance of Ediacaran biota in Newfoundland (Avalon assemblage) and that recovery occurred prior to the appearance of the White Sea and Nama Ediacaran assemblages. The estimated duration for the Shuram excursion in Oman is consistent with recently proposed estimates of presumably correlative excursions in South China, South Australia, and the United States, supporting the synchroneity of the Shuram excursion worldwide. These results lend credibility to the hypothesis that the Shuram excursion represents an extreme perturbation to the global carbon cycle, even if its origin remains highly controversial. Our age model also identifies a major inflection in sediment accumulation rates within the Nafun Group ca. 605–570 Ma. We interpret the sharp rise in sediment accumulation to reflect the onset of flexural subsidence related to the collision of Oman with the Arabian Nubian shield during the final phase of the East African Orogeny.

VERTICAL HYDRAULIC CONDUCTIVITY; FROM MEASUREMENTS TO MODELS

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Layered heterogeneities (i.e. strata) are a fundamental characteristic of geological media that manifests themselves at scales from micrometres to kilometres. Layering can occur in all three main lithotypes (sedimentary, metamorphic, and igneous), but is most prevalent in sedimentary deposits, which host most of the world's aquifers. Layering imparts a basic hierarchy in the permeability tensor with the vertical components usually lower in magnitude than the horizontal, with consequent effects on groundwater flow and transport. Hydraulic testing of geological media historically has been dominated by testing for horizontal hydraulic conductivity (Kh) as most testing methods are associated with measuring and analyzing horizontal hydraulic perturbations with vertical boreholes. Nevertheless, there is a growing body of work since the 1990s that focusses on testing and evaluation of vertical hydraulic conductivity (Kv). Published results from this testing indicate that the vertical anisotropy (i.e. Kh/Kv) is usually less than 10 (around 60% of estimates), but mostly from a representative vertical length scale of less than 10 m (around 90% of estimates). Translating these data into models is problematic as 'field measurements are typically not representative of vertical anisotropy at the scale of a model and usually Kh/Kv is estimated during model calibration'. A preliminary review of models simulating groundwater flow and transport in sedimentary strata published since 2000 shows that around 30% of model Kh/Kv is set at 10 and is not part of calibration. Model Kh/Kv can be high with around 30% of models having a Kh/Kv of 100 or greater. Calibrated Kh/Kvs are influenced by calibration data (e.g. availability of multi-level piezometry; existence of vertical aquifer gradients/stresses), calibration strategy (steady-state and/or transient; trial and error vs automated/inverse methods) and model code (the layer paradigm of MODFLOW vs more flexible finite element codes). This paper assesses in broad terms the conceptual model support for model Kh/Kv and the extent that Kh/Kv is potentially affected by modelling artefacts.

USING SELENIUM STABLE ISOTOPES TO ASSESS REMEDIATION EFFORTS

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Assessing Se remediation efforts in groundwater can prove difficult due to the nature of subsurface contamination. Even if Se concentrations are decreasing over the length of a groundwater plume, determining the removal mechanism is highly important in assessing whether a continuous source may still pose an environmental hazard. Selenium stable isotope ratio measurements can give insights into the removal processes occurring in the subsurface. Laboratory experiments were conducted to determine the Se isotope fractionation associated with multiple processes, including reduction by zero valent iron (ZVI), and $H_2S_{(g)}$. Selenium reduction by ZVI was investigated in both batch and column experiments. The batch experiment was run both with and without dissolved $CaCO_3$, to determine the effect of this common groundwater constituent. A column experiment was conducted at a synchrotron to obtain real-time XANES measurements during reduction of Se (VI), to better link the removal mechanism with the degree of isotopic fractionation. Samples were taken for cation and isotope analysis by fraction collector while XANES data were collected. To investigate fractionation caused during Se (IV) reduction by $H_2S_{(g)}$ alone without any contribution from direct microbial reduction, Na_2S was used as an abiotic source. Increasing concentrations of Na_2S were added to vials of Se (IV), which formed an orange, red, or yellow precipitate. Vials were sacrificially sampled for cations, sulphur speciation, Se isotopes, and precipitates. The precipitates were analyzed by PXRD. The results will be compared to systems with abiotic S sources and reduction by sulphur-reducing bacteria. Laboratory experiments are necessary to link removal mechanisms to fractionation factors so that Se isotope measurements can be used as a tool in the field.

INVESTIGATING THE TIMING AND DURATION OF DUCTILE SHEAR IN THE GREAT SLAVE LAKE SHEAR ZONE, NORTHWEST TERRITORIES, USING IN SITU TITANITE AND APATITE GEOCHRONOLOGY

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The Paleoproterozoic Great Slave Lake shear zone (GSLsz) is a crustal-scale dextral transcurrent structure that accommodated up to 700 km of oblique convergence between the Rae and Slave cratons during the assembly of the supercontinent Nuna. Although it is one of the largest and best exposed Paleoproterozoic continental transform boundaries in the world, little is known about the precise timing and duration of ductile shear on the structure. Previous geochronologic work indirectly dates the onset of shear to ca. 1950 Ma, however, those data were largely based on cross-cutting relationships and are not directly linked to deformation fabrics. This project aims to establish the timing and duration of ductile deformation in the GSLsz through a combination of field mapping, petrography and in situ U–Pb dating of fabric-linked accessory minerals via laser ablation-inductively coupled plasma-mass spectrometry. A complete (30 km) north–south transect was mapped across the southwestern segment of the GSLsz, which itself is separated into two distinct structural domains by the northeast–southwest-striking Laloche River Fault (LRF). We analyzed apatite and titanite in ten samples of mylonitic rocks collected across the transect, which preserve a range of retrograde metamorphic conditions from upper amphibolite through to lower greenschist facies. Seven apatite samples from south of the LRF yield ages that range between ca. 1860 and 1760 Ma, while two apatite samples from north of the LRF yield ages of 1918 ± 10 Ma and 1915 ± 12 Ma. Nine of the ten titanite samples, which span the entire transect, have populations that range in age between ca. 1910 and 1820 Ma, while the remaining titanite sample, collected immediately to the south of the LRF, has a single age population of 1742 ± 9 Ma. One of the nine older titanite samples also has a younger age population of 1692 ± 46 Ma. Based on textural observations, the two younger (< 1750 Ma) titanite populations are likely associated with late fluid infiltration events. The apatite and older titanite populations are associated with ductile fabrics and therefore reflect the age of ductile recrystallization. Based on our results, we interpret the GSLsz had a near continuous history of ductile shear spanning from ca. 1920 to 1760 Ma. These revised ages for ductile shear in the GSLsz are broadly coincident with other regional tectonic events linked to the formation of supercontinent Nuna, including the Snowbird and Trans-Hudson orogenies.

DECIPHERING THE METAMORPHIC AND STRUCTURAL ARCHITECTURE OF THE PONTIAC METASEDIMENTARY SUBPROVINCE (SUPERIOR CRATON, CANADA)

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The Pontiac Subprovince (PS) of the Superior craton, Canada, is a Neoarchean metasedimentary terrane with a highly debated tectonothermal evolution. Previous studies that focused on the seismic, detrital, volcanic, and magmatic records have led to contrasting tectonic models in which the PS formed and evolved as either an exotic terrane, a forearc accretionary wedge, or a rift-fill basin. However, less attention has been given to the metamorphic and structural evolution of the PS supracrustal rocks, yet those supracrustal rocks contain widespread metapelitic rocks that can allow a detailed investigation and reconstruction of the tectonothermal evolution of the continental crust during orogenesis. Previous investigators reported a north to south Barrovian metamorphic field gradient and SE-verging fold-and-thrust structures in the northwestern PS. Nevertheless, it remains unclear whether the metamorphic gradient is continuous or disrupted by an inferred thrust fault separating two nappes with different tectonic fabrics and metamorphic P-T-t (pressure-temperature-time) paths. Results from fieldwork, detailed petrography, phase equilibria modelling, and petrochronology from the biotite, garnet, staurolite, kyanite, and sillimanite zones suggest that the supracrustal sequences followed a common clockwise metamorphic P-T path with estimated peak conditions of ~5.5–7.5 kbar and ~550–680°C. Garnet Lu–Hf geochronology constrains subsolidus garnet growth at 2657 ± 4.2 Ma, representing the timing of prograde metamorphism. Pre-kinematic cordierite porphyroblasts along with syn-kinematic sillimanite, staurolite, and post-kinematic garnet characterize the higher-grade rocks. Microtextural relationships indicate that cordierite is overprinted by Barrovian-type assemblages, suggesting an early LP-HT (low pressure-high temperature) thermal event followed by a Barrovian event associated with the main stage of deformation. Peak conditions of this earlier LP-HT event are estimated at ~3–3.5 kbar and ~550–670°C. Our results are consistent with a tectono-metamorphic evolution involving early LP-HT metamorphism prior to ca. 2657 Ma, possibly reflecting an extensional tectonic setting, followed by syn-tectonic Barrovian metamorphism, likely in response to crustal thickening upon continental collision with the Abitibi Subprovince. This detailed investigation of the metamorphic and structural history suggests the Barrovian field gradient is continuous and developed in one coherent structural block. Our study provides insights into the Neoarchean evolution of the Superior craton and highlights the benefit of applying an integrated quantitative approach to decipher polymetamorphism and to link metamorphic styles to tectonic processes when reexamining field gradients.

UNDERSTANDING LITHOSTRATIGRAPHY AND DEPOSITION OF THE RÄVLIDEN Zn-Pb-Ag-Cu DEPOSIT, SWEDEN

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The lithostratigraphy of the Rävliden Zn-Pb-Ag-Cu deposit near the long- established Kristineberg Mine, northern Sweden, is studied to better constrain ore formation and formulate a rigorous lithological and lithogeochemical classification scheme. The Rävliden deposit is a volcanogenic massive sulphide (VMS) deposit in the Skellefte district, which rocks formed in a Palaeoproterozoic continental arc environment and have seen hydrothermal alteration, metamorphism and polyphase deformation overprinting many primary features. The principal lithostratigraphic

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units are: 1) predominantly felsic–intermediate, ca. 1.90–1.88 Ga volcanic rocks of the Skellefte group (SG) deposited in an intra-arc submarine basin, and 2) overlying siliciclastic ca. 1.88–1.87 Ga sedimentary rocks and lesser volcanic rocks of the Vargfors group (VG). The SG–VG contact is of crucial importance to exploration since most VMS deposits are located at or adjacent to it. Thus, distinguishing lithologies belonging to each group and mapping facies variations along their contact is an important task for indicating both proximity to volcanic vents and the palaeoenvironments favourable for hosting VMS deposits. However, the contact is commonly complex and laterally discontinuous, reflecting palaeotopography caused by differential uplift and subsidence along synvolcanic faults. This, together with difficulty in interpreting relict textures, makes systematic mapping of the volcanic facies along the SG–VG contact a potentially challenging and subjective task. Furthermore, the geological framework established at Kristineberg is not applicable to Rävliden since they are different deposits regarding stratigraphic position, host lithologies, and alteration minerals. What is required is a thorough study of lithology and facies at Rävliden from a first principal perspective. This study addresses that with detailed logging of core intervals containing the SG to VG transition. This is complemented by detailed petrographic and lithogeochemical characterization. Through these methods, lithological, facies and lithostratigraphic division of rocks at Rävliden is established and standardized under a rigorous classification scheme. In turn, this allows the lithostratigraphy of the deposits to be better placed in the broader tectonic and stratigraphic framework of the region, providing better constraints on ore formation as well as improved tools for the identification and correlation of key units for exploration. The rigorous classification scheme will also form a framework for future efforts, aiming at using machine learning for semi-automated characterization of the host package based on core photographs and compositional data, allowing key horizons to be better modelled and propagated into new areas with less data resolution.

EVALUATING THE ROBUSTNESS OF DIFFUSION CHRONOMETRY

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Diffusion chronometry can illuminate timescales of magmatic transport with a resolution as short as minutes. In these studies, it is commonly assumed that mineral zoning results from diffusive re-equilibration induced by a change in melt composition. However, diffusion is not the only way to produce compositional zoning in minerals. Crystal growth can produce zoning profiles that mimic diffusion profiles. Several methods have been proposed to distinguish between diffusion- versus growth-induced zoning: (1) multi-element modeling, (2) the crystal growth argument, (3) diffusion anisotropy, and (4) stable isotopes. This study evaluates the strengths and weaknesses of each of these strategies. For illustrative purposes, discussion will be focused on Mg-Fe zoning in olivine. (1) Multi-element modeling: In 2005 it was suggested that if diffusion modeling of multiple elements in a crystal converge to the same timescale, then diffusion is likely responsible for generating mineral zoning. Validation of this method is difficult as element diffusivities have order-of-magnitude uncertainties. Furthermore, the initiation of diffusion depends on the boundary condition, so the onset of diffusion may occur at different times for different elements. (2) The crystal growth argument: In 2015 it was suggested that olivine growth does not induce Mg-Fe zoning when growth occurs in a large volume of melt; in these instances, zoning can be interpreted to be diffusion-driven. However, in 2013 and 2022 it was shown that olivine crystals grown both early and late in the crystallization sequence can be accompanied by Mg-Fe zoning, so growth-induced zoning can occur regardless of the co-existing melt volume. (3) Diffusion anisotropy: Mg-Fe interdiffusion in olivine is 6 times faster along the c-axis than the a- and b-axes. If zoning is diffusion-controlled, then the Fo# profile should be longer along the c-axis. This method requires that the crystals be sectioned along a specific crystallographic plane. (4) Stable isotopes: Chemical diffusion induces large isotope fractionations because light isotopes diffuse faster than their heavier counterparts. Mg-Fe interdiffusion results in negatively coupled Mg-Fe isotopes because they diffuse in opposite direction. In diffusion-limited growth, however, Mg-Fe isotopes would be positively correlated as both Mg and Fe are diffusing towards the crystal to provide nutrients for crystal growth. From the list above, (3) and (4) are viable strategies for distinguishing diffusion- vs growth-controlled zoning, and their implementation should be a pre-requisite for robust diffusion chronometry studies.

GEOCHEMICAL IMPLICATIONS OF PERMAFROST THAW ON RELEASE OF GEOGENIC CONTAMINANTS IN GROUNDWATER

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The chemistry and flow of groundwater in cold regions are heavily influenced by permafrost. Permafrost minimizes connectivity between shallow and deep (subpermafrost) groundwater systems, while frozen conditions inhibit chemical reactions between water, minerals, and organic carbon and thus control water chemistry. Degradation of permafrost under a warming climate will therefore have widespread implications for biogeochemical processes. Our study assesses effects of permafrost thaw on mobilization of naturally occurring and potentially hazardous trace elements in groundwater, with an emphasis on uranium and arsenic. Geochemical analyses of thawed permafrost cores collected at pristine Yukon field sites show aqueous concentrations of uranium and arsenic frequently exceeding water-quality guidelines for human and ecological health. Relationships between uranium, arsenic, and the redox-sensitive elements iron and sulphur suggest that redox processes can act as an important control on metal(loid) mobility. Permafrost thaw will be accompanied by the release of previously frozen stores of organic carbon, increased microbial activity, greater groundwater fluxes, and faster mineral weathering rates. These coupled processes create non-intuitive outcomes for metal release with important implications for northern communities and mining industry.

A DECADE OF YEAR-ROUND HYDROGEOCHEMICAL MONITORING IN SMALL TRIBUTARIES OF THE YUKON RIVER BASIN UNDERLAIN BY DISCONTINUOUS PERMAFROST

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Permafrost exerts a dominant control on hydrology and water chemistry in cold regions. Permafrost degradation due to recent subarctic climate warming is driving widespread change in biogeochemical and hydrological processes with potential impacts on water quality. Our understanding of these processes is limited by logistical challenges associated with high-resolution environmental monitoring in remote northern regions. Here we present 10 years of year-round hydrological, climatological, and geochemical data from small (~3 to ~500 km^2) and well-instrumented subarctic and permafrost-bearing catchments from west-central Yukon that drain into the Yukon River. Natural weathering of mineralized terrains contributes to mobilization of sulphate, arsenic, and uranium. Relationships between the occurrence of elevated trace-element concentrations (e.g. uranium) and major inorganic and organic constituents reflect different flow contributions to streams, which are in turn influenced by permafrost coverage. A detailed understanding of these relationships under present-day conditions is a prerequisite towards understanding long-term baseline water quality shifts associated with permafrost thaw in sub-arctic regions.

THE ROLE OF PRE-GLACIAL VALLEY DEPOSITS ON GROUNDWATER–STREAM INTERACTION IN CENTRAL ALBERTA

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Extensive pre-Laurentide buried valley systems have incised into bedrock formations in western Canada and often contain sand and gravel deposits that are subsequently covered by finer-grained Quaternary sediment. Some pre-glacial valleys have little to no surface expression on the modern landscape while others coincide with modern streams and rivers. We examine the role of pre-glacial valley fill deposits as a controlling factor on the exchange between groundwater and surface water. Geological mapping, water sampling, and stream transport modelling were completed along Strawberry Creek, a tributary of the North Saskatchewan River near Edmonton, Alberta that aligns with a pre-glacial bedrock valley. The geometry of the pre-

glacial valley was defined by mapping depth to bedrock from publicly available water well records and the locations of bedrock outcrop. Lithostratigraphy of the valley fill sediment was defined from the water well records and two surface exposures using a simplified ternary classification of fine and coarse sediments, and diamict. Groundwater interaction was assessed by synoptic stream sampling during low flow conditions and stream transport modelling. Water samples were collected from eight locations along a 70 km segment of the stream, which spanned most of the watershed. Samples were analyzed for a suite of environmental tracers and geochemistry. The variation in groundwater discharge along the stream was modelled by fitting longitudinal concentrations of environmental tracers and gauged stream discharge. Results indicate a transition in groundwater interaction that coincides with the lateral continuity of coarse basal sediment in the underlying pre-glacial valley. Where this small valley aquifer is present, the stream is supported by groundwater discharge, even though the stream is not in continuous or direct connection with the aquifer. Where basal coarse sediment is absent, the stream appears to have minimal groundwater interaction. This study demonstrates the effect of heterogenous pre-glacial valley fill sediment on focusing groundwater flow to the parafluvial zone of a modern-day stream.

PLUME-RELATED DIAMOND FORMATION AT VOORSPOED IN THE CENTRAL KAAPVAAL CRATON

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The lithospheric mantle below the oldest continents defines a cool conductive geothermal gradient compared to the adiabatic convecting mantle. These cool geotherms are conducive to diamond formation, and the majority of the world's diamonds form in the mantle 150–200 km deep, below ancient cratons. While diamond formation (and preservation) usually requires cool lithospheric conditions to avoid graphitization, recent studies show that plumes and large igneous provinces are not always destructive to the lithosphere and its diamonds. A detailed Sm–Nd geochronological study of garnet and clinopyroxene inclusions in lithospheric diamonds from the Voorspoed kimberlite in the central Kaapvaal Craton in South Africa was undertaken to explore the relationship between plume magmatism and diamond survival. Peridotitic diamonds formed at 2736 ± 27 Ma (n = 28), coeval with the Ventersdorp Supergroup. The Ventersdorp large igneous province (LIP) extruded lavas across massive regions of the western and eastern blocks of the Kaapvaal Craton between 2791 and 2654 Ma, which caused ultra-high temperature metamorphism in the lower crust and initiated melt depletion in mantle peridotite across nearly the entire craton (Re–Os TRD modes between 2.8–2.4 Ga). Eclogitic diamonds are younger and formed at 2190 ± 66 Ma (n = 17), coeval with the Hekpoort LIP. Basaltic lavas related to the ~2.25–2.23 Ga Hekpoort LIP are recognized throughout the Transvaal Basin in the eastern block of the Kaapvaal Craton. Initial ratios of both the peridotitic and eclogitic isochrons, show that diamond formation occurred during melt infiltration into much older mantle lithologies. The peridotitic isochron has an initial $^{143}Nd/^{144}Nd$ ratio of 0.508549 (ε_{Nd} 2.74 Ga CHUR = –10.57) indicating that the peridotitic diamonds formed in peridotites that were least 3.2–3.0 Ga. The eclogitic isochron has an initial $^{143}Nd/^{144}Nd$ ratio of 0.509321 (ε_{Nd} 2.19 Ga CHUR = -9.45) indicating that the eclogitic diamonds formed in eclogites of at least 2.7–2.5 Ga. The diamond populations at Voorspoed formed during periods of intense heating, plume impingement and melt depletion of the lithospheric mantle. The Ventersdorp and Hekpoort (and Bushveld) LIPs caused thermal reworking of the crust and mantle, yet did not destroy certain Archaean diamonds such as those at Jwaneng, Finsch, Bobbejaan, Kimberley and Cullinan. At Voorspoed, plumes appear to have been conducive to diamond growth, potentially because diamond-forming fluids in the lithosphere crystallized diamonds away from the main plume impingement site and areas of the highest heat flow.

PATTERNS AND DYNAMICS OF GROUNDWATER TEMPERATURES IN NOVA SCOTIA

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Groundwater temperature is a critical determinant of groundwater quality, subsurface energy potential, and the health of groundwater-dependent ecosystems; however, the spatiotemporal variability of shallow groundwater temperature remains poorly understood. For example, changes in climate, land cover, and geology are known to exert influence on groundwater thermal regimes, yet there is considerable disagreement in the literature regarding the relative future warming of aquifers vs surface water bodies and the associated vulnerability for groundwater-dependent ecosystems. Few studies have considered interannual groundwater temperature dynamics and how these are influenced by atmospheric regimes, land cover, and geology. In this study, we present groundwater temperature time series from a spatially dense observation well monitoring network in Nova Scotia, Canada for differing land cover types, winter snowpacks, geology, and groundwater systems. We consider the relationship between air and aquifer thermal regimes at seasonal and interannual time scales by performing dynamic harmonic regression and longer-term trend analysis. The results vary widely among sites and indicate that groundwater temperature is damped and lagged compared to air temperatures on both seasonal and interannual timescales. The long-term trend in the aquifers (warming/cooling) is strongly dependent on aquifer depth, atmospheric regimes, and geology. Results will be interpreted in the context of the thermal sensitivity of groundwater-dominated streams and well as groundwater-sourced thermal refuges for cold-water species. Best practices for establishing monitoring well networks to also track groundwater temperature change will be presented.

COMPARISON OF THE PHYSICOCHEMICAL PROPERTIES OF FOREST FIRE GENERATED PYROGENIC CARBON AND SYNTHETIC BIOCHAR

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Pyrogenic carbon (PyC), commonly referred to as biochar, results from the thermal decomposition of organic materials at high temperatures and in low oxygen environments (known as pyrolysis). Commercial biochar, which is produced in industrial or laboratory furnaces, is pyrolyzed under constant temperatures, typically up to 700°C, for long periods of time (up to ~6 hours). Biochar is also produced naturally during forest fires, where it burns at higher temperatures (up to 1200°C) and for very short periods of time (176 s for temperatures > 300°C). While its commercial analogues are well studied, there is scarcity of data pertaining to forest fire-derived biochar with respect to its chemical reactivity and composition. Here we investigated the differences in physicochemical properties of biochar produced during a natural forest fire with biochar produced using conventional laboratory furnace conditions. We sampled both unburnt biomass and forest fire-derived PyC (FF-PyC) from five locations within a recent forest fire along the western slope of Mount Hunter, near Golden, British Columbia, and compared the physicochemical properties of this FF-PyC with biochar produced in a standard tube furnace from unburnt biomass from the site of the fire. Properties including the porosity, specific surface area, total surface reactivity, metal adsorption potential, CHNOS elemental analysis, anion exchange capacity, cation exchange capacity, mobility, as well as extracted nanoparticles inherent to the PyC were studied in both the laboratory biochar and FF-PyC, and compared. Our results provide insights into the conditions needed to produce biochar equivalent to FF-PyC in a laboratory setting, critical to understanding the factors in a fire that control carbon reactivity and PyC colloidal release into soils and groundwater.

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EVOLUTION OF TDS IN A FRACTURED CRYSTALLINE ROCK ENVIRONMENT: ROLE OF DENSITY-DEPENDENT COUPLING

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The Canadian Shield is composed of fractured Precambrian rock and is known to have high total dissolved solids concentrations (TDS) in the groundwater, in some cases reaching over 300 g/L (for comparison, seawater is 35 g/L). Multiple theories have been postulated to explain the presence of TDS in the Canadian Shield, including an in situ source through rock-water interaction, and marine intrusion. The high TDS values observed in the Shield affect fluid density, resulting in the coupling of the groundwater flow equation with the solute transport equation for TDS. In this study, numerical groundwater models were developed as a means to assemble, integrate and illustrate the role of coupling on the evolution of TDS in a hypothetical fractured Shield setting. A three-dimensional finite-element groundwater model mesh covering an area of approximately 153 km^2 was developed. Model boundaries were selected to correspond with surface water divides. The numerical groundwater modelling was performed using HydroGeoSphere, a dual continuum computational model that includes both porous media and discrete fracture zones. A discrete fracture zone network model, generated using MoFrac and delineated from surface features, was superimposed onto the three-dimensional mesh using quadrilateral elements. The MoFrac code enables the generation of geostatistically and structurally possible fracture network models and is capable of creating 3-D discrete fracture network models at the tunnel, site and regional scale. Model parameterization includes depth-dependent permeability profiles for both the EPM rock mass and fracture zones. A first-order source term for brine is applied. The evolution of TDS over geologic time scales is assessed by comparing coupled and de-coupled groundwater flow and solute transport. The role of density-dependent coupling is demonstrated through performance measures which include a comparison of time to TDS equilibrium, mean time to discharge for the groundwater system, and total TDS mass at equilibrium.

CHARACTERIZING THE ISOTOPIC ABUNDANCE OF Cl AND Br IN THE THERMAL SPRINGS OF THE SOUTHERN CANADIAN ROCKY MOUNTAINS

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Thermal springs have been described as expressions of fluids deeply circulating in the subsurface, and so are key indicators of potential geothermal energy extraction targets in western Canada. Additionally, they are often associated with formation of valuable mineral deposits and may provide niche ecosystems for endemic species. Stable isotopes of chlorine, bromine, calcium and strontium have been applied to understand the geochemistry of thermal springs although relatively few studies have been conducted for the southern Canadian Rocky Mountains. This research characterizes $\delta^{37}Cl$ ($^{37/35}Cl$), $\delta^{81}Br$ ($^{81/79}Br$), $\delta^{44}Ca$ ($^{44/40}Ca$), and $^{87}Sr/^{86}Sr$ for selected thermal springs in the region sampled between 2006 and 2021. In total, samples from 17 springs from 13 geographically distinct locations were incorporated within this analysis, 14 of which were sampled multiple times. Isotopes of chlorine and bromine were analyzed using continuous flow isotope ratio mass spectrometry (CF-IRMS), while thermal ionization mass spectrometry (TIMS) was used for calcium and strontium isotope determinations. Although some analyses are still pending completion, a number of interesting results are already available. Values for $\delta^{37}Cl$ (n = 14) ranged from 0.24 to 0.88 (SMOC), with the lowest values found at Red Rock Warm Spring and the highest values at Miette Hot Springs. Strontium isotope ratios ranged from 0.708138 at Miette Hot Springs to 0.715705 at Vermillion Warm Springs. Of the 11 thermal springs where $^{87}Sr/^{86}Sr$ was measured, radiogenic strontium values were also measured at Ram Creek Hot Spring and Lussier Hot Spring. Bromine concentrations at all springs were below analytical detection limits (< 0.3 mg/L), making isotopic determinations challenging. The results of the analyses are being applied to better understand fluid flow systems and subsurface processes. For example, samples enriched in ^{37}Cl relative to SMOC can indicate that dissolution of halite along water flow paths may be a major factor. Microbial processes potentially play a role in isotopic fractionation for both $\delta^{37}Cl$ and $\delta^{81}Br$. Other processes such as diffusion, ion filtration, and salt precipitation may also control the fractionation of $\delta^{37}Cl$, $\delta^{81}Br$ and $\delta^{44}Ca$, which are currently being evaluated. This ongoing study will ultimately provide greater insight into the different pathways and geochemical evolution of groundwater between the various thermal springs.

MOUNTAIN GROUNDWATER UNDER CLIMATE CHANGE: THEORY AND CASE STUDY IN THE CAPE BRETON HIGHLANDS

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Mountain water resources are of particular importance for downstream populations but are threatened by decreasing water storage in snowpack and glaciers. Baseflow (groundwater discharge) sustains mountain streamflow during times of low precipitation, snowmelt or ice melt. Recent advances suggest that groundwater may provide some resilience—at least temporarily—to mountain water resources under climate-driven glacier and snowpack recession. However, as mountain climates change, increased evapotranspiration could lead to declining groundwater recharge in some mountain ranges. Given the lack of observation wells in mountains, we know little about changing groundwater dynamics in mountains and the consequences for downstream water resources. We explore key groundwater processes and aquifers in mountain regions based on our recent review paper. We summarize the hypothesized direct and indirect impacts of climate change on mountain groundwater systems. These impacts include direct mechanisms (more or less precipitation and increased evaporation with rising air temperatures) as well as indirect impacts through the cryosphere (e.g. loss of glacier melt recharge, changing snow-rain fraction), ecosystem (increasing evapotranspiration) and human interventions (e.g. land use and adaptation). Next, we present preliminary data from a case study in the Cape Breton Highlands, Nova Scotia. We summarize recent climate and hydrological change in this low mountain region and discuss future research directions to assess potential impacts of climate change on water resources and ecosystems.

A PRELIMINARY INVESTIGATION OF ZIRCON-HOSTED MELT AND MINERAL INCLUSIONS FROM INTERMEDIATE AND FELSIC INTRUSIONS WITHIN THE YELLOWKNIFE GREENSTONE BELT, NWT, CANADA

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The Yellowknife greenstone belt (YGB) consists of mafic and felsic metavolcanic sequences that are crosscut by at least three generations of dykes, all located in the Archean Slave province in the Northwest Territories, Canada. This study focuses on the magmatic history of the YGB including feldspar-quartz and quartz-feldspar porphyry dykes (FQP and QFP), aplitic dykes with a granitic composition, and episodically emplaced plutons ranging from tonalite to granite. These include the Ryan Lake pluton (2675 Ma), Defeat Suite (2630–2620 Ma), and the Duckfish Granite (2608 Ma). The YGB hosts two historic high-grade, shear zone-hosted gold mines, the Giant and Con mines which produced a total of 14.2 Moz gold. Throughout the YGB, gold mineralization is spatially associated with FQP and QFP dykes and has been documented in shear zones that crosscut other plutonic bodies. However, it is poorly understood whether these magmatic bodies contributed to the overall metal budget of the YGB. Therefore, analysis of zircon-hosted melt and mineral inclusions from these lithologies was undertaken to obtain primary geochemical data and assess metal endowment. Melt inclusions represent a sample of magma trapped in a growing crystal during the emplacement, fractionation and/or crystallization of an intrusion. Such inclusions can provide a window into magmatic evolution, pre-existing metal endowment, and pressure and temperature conditions during entrapment. Zircon-hosted melt and related mineral inclusions were chosen due to the robust nature of zircon and the low diffusivity of elements between the inclusions and host. Zircons from mineral separates were obtained, mounted in epoxy and polished

until the melt inclusions were close to the surface but not exposed. Homogenization experiments were not performed due to the abundance of fractures in the zircons and the possibility of melt migrating during heating. LA-ICP-MS analysis was conducted for major, minor, and trace element data for 39 zircon-hosted melt inclusions. The melt inclusions were spherical to ovoid and often had a crystallized appearance, therefore the inclusions were analyzed in their entirety and deconvolution of the zircon-host and melt inclusion signal was done offline. Although the data obtained is qualitative, many ablations of dark brown-black inclusions were found to be metal-rich, likely due to the presence of sulphide melt or mineral phases; these inclusions were variably enriched in Cu, As, Sb, Pb, Co, and Bi. These metal-rich inclusions may have impacted the metal tenor of related magmas and could implicate an intrusion-related component to gold mineralization in the YGB.

AN INSIGHT INTO SNOWBALL EARTH: THE IMPACT OF DEGLACIATION ON MICROBIAL COMMUNITIES IN THE CANADIAN HIGH ARCTIC

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Marine microorganisms play an integral role in mediating global biogeochemical cycles. For instance, they modify the redox state and concentrations of biologically important trace metals through the uptake of trace metals from seawater. Upon cell lysis, trace metals are then liberated from sinking biomass via organic matter remineralization, thus enriching deeper waters, or the biomass may accumulate in the sediment column where it is diagenetically modified, leading to the lithification of unconsolidated detritus into sedimentary rocks. Collectively, the assimilation of bioavailable trace metals for microbial processes, such as primary production by phytoplankton, influences global atmospheric CO_2 levels, trace metal availability, and ultimately plays an important role in modulating Earth's climate on geologic timescales. Despite considerable research on the role of marine microorganisms in trace metal cycling, there remains a paucity of data constraining the contribution of their ancient ancestors to the evolution of Earth's surface environment in the geologic past. It has been hypothesized that enhanced bioproductivity following the Paleoproterozoic Snowball Earth (2.4 Ga) may have induced the evolution of important metabolic pathways, such as manganese oxidation through the evolution of manganese superoxide dismutase enzymes. This hypothesis, however, has not been ground-truthed in a modern analogue setting, nor has the link between deglaciation and the subsequent response of the marine biosphere been evaluated. To fill this gap in knowledge, we undertook a sampling campaign in the Canadian Arctic Archipelago (CAA). The CAA is one of the largest contributors of glacier meltwater to the global ocean, and this meltwater may be a key crustal trace metal source to marine microorganisms. Importantly, climate change amplification in the Arctic has led to increased glacial melt and runoff, thus in the future the marine ecosystem in the CAA will disproportionately experience the effects of these changing glacial fluxes. To better constrain the impact of deglaciation on marine microbial communities, we compared regions with tidewater glaciers to those without at the height of the summer melt season. Additionally, samples were collected in the spring from underneath the sea ice, before the onset of glacial melt, to explore the dynamics in microbial community composition in ice covered regions. We conducted ^{16}S rRNA gene amplicon sequencing to identify microbial community members and predict their functional potential, with a focus on trace metal cycling pathways. Results from this study will provide valuable insights into how the ancient marine biosphere may have responded to Snowball Earth deglaciations.

SOME LIKE IT HOT: ENIGMATIC OROGENS OF THE MID-PROTEROZOIC

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Since the Archean, secular change in orogenic style is demonstrated through evolution of metamorphic conditions and geochemical proxies. Linked to orogenic style is the amount of crustal thickening and elevation, whereas orogenic vigour is related to the supercontinent cycle. An array of Proterozoic orogens spanned the assembly of supercontinents Columbia and Rodinia, but the vigour of orogenesis is debated, with proposals for both Mesoproterozoic quiescence and climax. We show mid-Proterozoic orogenesis occurred globally and was broadly continuous. Furthermore, orogens exhibit elevated metamorphic thermobaric ratios with large volumes of high-temperature felsic magmatic rocks. These features reflect higher mantle heat flux leading to increased mid-crustal flow and lower elevation. In this context, proposals that geochemical proxies for crustal thickness record orogenic quiescence are inconsistent with the geological record. Alternatively, secular change in crustal thickness is attributed to orogenic style, namely the prevalence of hot, thin, and low orogens in the Mid-Proterozoic.

NICHE PARTITIONING DRIVING EVOLUTION OF THE ATRYPIDAE (BRACHIOPODA) DURING THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT IN LAURENTIA

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Although the increase in biodiversity in most fossil groups through the Great Ordovician Biodiversification Event (GOBE) is becoming increasingly clear, the underlying evolutionary dynamics driving this event remain less certain. Brachiopods, as one of the most common and diverse shelly fossils from this interval, make an excellent tool for studying these mechanisms. The Atrypidae were one of the brachiopod orders that evolved during this interval. In Laurentia, the most common of these atrypides in the epicontinental seas were the genera *Anazyga* and *Zygospira*. Other genera such as *Catazyga, Cyclospira*, and *Idiospira,* became established in localized deeper-water settings on the continent but were more common closer to the continental margin. In the early Katian, *Anazyga* was widespread across eastern North America, commonly clustered in low-diversity shell beds. Although morphometric analysis of this genus is still ongoing, preliminary observations suggest that most species share a similar morphology and are significantly smaller than later members of the lineage. The more derived forms within the later *Zygospira* show a broader morphological disparity and exhibit diverging patterns of shell development not only in different regions but also on the same platform. This disparity may have been at least partially produced through evolution driven by niche-partitioning in the rapidly evolving shallow marine ecosystems of eastern North America at this time. Unlike in many other lineages (e.g. the Strophomenida, Rhynchonellida, and Orthida), the smaller, earlier species of *Zygospira* persisted alongside the larger, later species. These smaller shells formed close associations with other filter feeders in the rapidly diversifying shallow marine ecosystem that may have enabled a greater degree of tiering. So far, there is no direct evidence of the later, larger species developing these associations, perhaps reflecting adaption to life on the seafloor. This is an example of peripatric speciation in the fossil record where exploitation of different niches drives evolution along two different evolutionary trajectories. Although the GOBE was probably driven by several factors, these findings provide direct evidence that ecological factors such as coevolutionary relationships and the division of niches played an important role in the evolution of benthic ecosystems. This underscores the importance of detailed specimen-based research on individual fossil lineages to complement broader studies of evolutionary trends over geological time.

FORMATION OF PRINCIPALLY LHERZOLITIC DIAMONDS BENEATH VICTOR, ATTAWAPISKAT KIMBERLITE FIELD, EASTERN CANADA

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The James Bay area on the Superior Craton hosts the Jurassic Attawapiskat kimberlite field with the former Victor mine. The area was affected at ~1.1 Ga by a thermal event that likely represented the northern extension of the major Mid-continent Rift. Diamonds in the Jurassic Victor kimberlite, however, show low nitrogen aggregation states (23 ± 14% B; mean ± 1 s) and normal mantle residence temperatures

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(1150 ± 20°C), indicative of diamond formation after thermal relaxation following the Mid-continent Rift event. Correspondingly, radiometric dating of sulphide inclusions in Victor diamonds documented diamond formation at 720 ± 50 Ma. The inclusion paragenesis of 99 studied Victor diamonds is predominantly lherzolitic (n = 84), with minor wehrlitic (n = 2) and eclogitic (n = 13) associations. The mean carbon isotope ($\delta^{13}C$) composition of the lherzolitic diamonds is -5.2 ± 0.6‰ and their mean nitrogen isotope composition ($\delta^{15}N$) is -6.9 ± 1.6‰. Wehrlitic diamonds are distinct by having elevated $\delta^{13}C$ (~-2.3‰) and unusually low $\delta^{15}N$ (-11 to -14‰). Eclogitic diamonds fall into two groups, one with low $\delta^{13}C$ (-22.4 to -17.7‰) and high $\delta^{15}N$ (-0.7 to + 0.3‰), the other with mantle-like carbon (-5.5 to -4.3‰) and nitrogen (-6.8 to -2.6‰) isotope values. The internal structure of Victor lherzolitic diamonds, based on CL imaging and FTIR analysis of 19 diamond plates, is consistent with a single principal diamond-forming event, characterized by regular internal structures and smoothly outward decreasing nitrogen contents. SIMS profiles across seven plates yielded an outward (core-rim) decrease in nitrogen content of 160–850 at.ppm, associated with small variations in $\delta^{13}C$ of 0.19–0.61‰. In three diamond plates, coherent trends of outwardly increasing $\delta^{13}C$ indicate growth from an oxidized carbon species or a CO_2-CH_4 mix, whilst in one case a gradual outward decrease in $\delta^{13}C$ and [N] suggests possible involvement of a reducing (CH_4-rich) fluid. Ten of the 19 diamond plates imaged with CL contain sharply confined polygons with low CL response that clearly crosscut regular growth and hence may represent potential diamond inclusions. The crystallographic orientation of these "inclusions", however, coincides with that of their host diamonds, based on electron backscatter diffraction data. SIMS analyses of these "inclusions" yielded nitrogen contents between 5–17 at. ppm, much lower than the 95–940 at. ppm range observed for their host diamonds. The carbon isotope composition of the inclusions is, however, very similar to their diamond hosts ($\Delta_{host\text{-}inclusion}$= 0.07–0.37‰), suggestive of a possible genetic relationship.

CLIMATE-DRIVEN SALTWATER INTRUSION DYNAMICS IN A CONFINED SMALL-ISLAND AQUIFER IN ATLANTIC CANADA

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Many small island communities rely solely on groundwater from a freshwater lens, and climate change is projected to have significant impacts on these hydrological systems and their critical groundwater resources. Coastal aquifers may suffer salinization due to lateral saltwater intrusion (SWI; e.g. sea-level rise, erosion, or recharge reduction), or by vertical salinization processes that follow seawater flooding (e.g. during coastal storms). In this study, we investigate the effects of climate change stressors on a small island (~1.5 km wide) off the northern coast of Prince Edward Island, Canada. The groundwater system consists of an unconfined aquifer overlying a confined aquifer that supplies water to the Lennox Island First Nation. Field instrumentation and methods include piezometers, monitoring wells, and time-domain EM geophysical mapping. Numerical modeling with HydroGeoSphere was used to estimate flushing times and freshwater lens dynamics under different atmospheric and marine perturbations, including the combined effects of the various climate change stressors. Initial results suggest that the aquifer system is relatively resilient to climate change due to the presence of confining layers and seaward groundwater flow, but somewhat sensitive to changes in recharge. The outcomes of this study will advance our understanding of how geologic conditions influence an aquifer's response to various stressors and will be useful for informing groundwater management for small-island communities facing environment change.

GLACIAL DISPERSAL AND TILL GENESIS IN MARITIME CANADA

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A succession of ice caps called the Appalachian Ice Complex developed in the Maritimes-Gulf of St. Lawrence region during the last glaciation that were drained by ice streams into the bordering deep submarine channels. These local centres evolved and migrated during the last glaciation due to changes in climate and sea-level producing areas with widely differing flow patterns, landform assemblages and deposits. Early regional phases of ice flow (Caledonian and Escuminac phases) were characterized by wide ice-streams that formed thick, exotic, fine-grained tills largely confined to drumlins in upland regions. The type section for these drumlin tills on the Atlantic coast is at West Lawrencetown just east of Halifax, where three distinct tills were deposited. The lower grey Hartlen Till with a strong SE-trending fabric is overlain by the distinctly red Lawrencetown till deposited by basal melt out from a southward-flowing ice stream emanating from a red bed area in the Gulf of St. Lawrence. In a later phase, an ice divide developed over the Atlantic Uplands in Nova Scotia (Scotian Phase) underlain by metamorphic and igneous rocks, forming a ground moraine of stony locally-derived tills (e.g. Beaver River Till). Dispersal zones characterized by distinct transport histories and till stratigraphic sequences were produced by the successive Maritime ice sheets. Glaciers interacting with previously deposited tills formed hybrid tills by two reworking processes: inheritance and overprinting. Inheritance is the incorporation of till components and/or fabric into a younger till by erosion and entrainment of material from an older till. Overprinting is the injection or imprint of matrix, clasts into older tills by overriding ice and the resetting of clast fabrics. At the West Lawrencetown drumlin section, the uppermost till unit is a hybrid created by reworking of the allochthonous red Lawrencetown till during the Scotian Phase. Glacier dispersal in the complex glaciated terrain of the Maritimes is largely controlled by the location of former ice divides and ice streams. Simple, unidirectional trains are preserved in relict terrains preserved under these divides and in areas where ice flow phases were confluent. In ice marginal areas, reworking processes result in complex dispersal fans by smearing and widening of previously formed fans forming palimpsest dispersal fans. These complex palimpsest dispersal fans can be modelled by vector addition of the discrete flow events within each dispersal zone.

CARBONATE- AND SULPHATE-RICH MELTS: CRITICAL AGENTS FOR MOBILIZING CRITICAL METALS

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Analyses of fluid and melt inclusions hosted in apatite, actinolite, diopside and magnetite from iron oxide-apatite deposits worldwide indicate a central role played by carbonate- and sulphate-rich melts. Here, we summarize our recent results of analyses of ore-forming fluids from numerous iron oxide-apatite deposits around the world, which consistently record polycrystalline melt inclusions composed predominantly of calcium sulphate and/or carbonate minerals, iron oxides, and silicates. In all cases, the ore-forming liquids have compositions dominated by sulphate and carbonate, contain 10's of wt.% Fe, and re-melt at igneous temperatures ≥ 700°C with iron oxides on the liquidus. In addition, our detailed microtextural and geochemical analyses show that these carbonate- and sulphate-rich melts play a key role in mobilization and mineralization of Th and REEs in these systems.

GOLD TRANSPORT IN AN ALPINE GLACIATED ENVIRONMENT: INSIGHTS FROM PLACER MINE EXPOSURES NEAR THE CORDILLERAN ICE SHEET LIMIT, GRANITE CREEK, YUKON

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Yukon has been affected by the Cordilleran Ice Sheet (CIS) multiple times during the Quaternary. The study area is located in upper Granite Creek, 1 km outside the Marine Isotope Stage (MIS) 2 CIS limit. Local alpine glaciers formed in the drainage during at least the last two glacial cycles. Placer mining operations target gold-bearing gravel and till in the Granite Creek area, and mineral exploration projects identified mineralized gold veins in the cirques. Traditional placer deposits are concentrations of heavy minerals formed by fluvial action. In glaciated terrain, placer deposits may underlie or be incorporated into glacial sediments, increasing the complexity when exploring for the deposits, but also introducing opportunities for thicker economic units, multiple pay zones, or elevated zones closer to the surface. These placer operations provide exposures, which allowed detailed study of sedimentary units and provide insights into gold transport within an alpine glacier environment. Here we report on the extent, timing, and relationship of cirque glaciers with the Selwyn Lobe of the CIS and describe the distribution and deposition of these plac-

ers. Initial interpretations, in the absence of dating control results, are that the oldest unit is a weathered, gold-bearing alpine till from MIS 4 or 6. This is overlain by an interglacial stream gravel containing abundant placer gold. An alpine gravel outwash unit, with disseminated placer gold, has eroded into the till and interfingers with glaciolacustrine sands above. This glacial lake was formed when the CIS blocked lower Granite Creek, constraining the outwash and glaciolacustrine deposits to MIS 2. These glaciolacustrine sediments were overridden and deformed by alpine tills that extended beyond the well-defined moraines that were thought to represent the maximum MIS 2 cirque advances. Transport of gold grains occurs through glacial, periglacial, fluvial and glaciofluvial processes. Gold-bearing veins were eroded, transported by alpine glaciers, and deposited down valley in a variety of settings. A buried fluvial deposit indicates previous interglacial periods played a role in gold transport. Gold-enriched till with economic concentrations suggests high-grade mineralization sub-crops in the drainage. Advance glacial outwash contained significant gold volumes, especially where eroding into previously deposited till, which acted as a false bedrock for gold deposition. Post-glacial incision by modern creeks has continued to disperse gold and re-concentrate it in Holocene fluvial deposits. This study highlights the variety of processes contributing to gold dispersal, and the range of depositional environments within an alpine valley.

SELLING PLANET EARTH: RE-PURPOSING GEOSCIENCE FOR SUSTAINABLE HUMAN WELLBEING

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In 1788, the father of modern geology, James Hutton, opened his seminal 'Theory of the Earth' with the remark: *"This globe of the earth is a habitable world, and on its fitness for this purpose, our sense of wisdom in its formation must depend"*. In the intervening two centuries, geologists have fueled and fed the industrial advancement of society by finding and exploiting natural resources, but the resulting economic growth now threatens the enduring habitability of the planet. To address the planetary-scale unsustainability, geoscientists urgently need to rediscover their sense of fundamental 'fitness for purpose'. This talk will examine the role and responsibility of geoscientists facing up to 21st century challenges, the new (and old) skillsets and mindsets that will be required to tackle those challenges, and the changes needed in the geoscience education pipeline (schools, universities and professional development) for Earth science to find its 'purpose' – an ambitious, clear, enduring and motivating overarching goal which helps deliver long-term wellbeing for all.

INVERTEBRATE ICHNOFAUNAL ASSEMBLAGES ACROSS THE MISSISSIPPIAN OF NEW BRUNSWICK: IMPLICATIONS FOR ICHNOBIODIVERSITY AND ICHNODISPARITY DURING ROMER'S GAP IN NB AND THE INVASION OF CONTINENTAL LACUSTRINE AND ALLUVIAL ECOSYSTEMS OF THE ALBERT, BLOOMFIELD, STILESVILLE, AND MARINGOUIN FORMATIONS OF NEW BRUNSWICK

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The continental invasion of invertebrates occurred during the Silurian however literature reports that lacustrine and alluvial settings were not colonized by ichnofossils assemblages until the Devonian. Much like the disparity in vertebrate remains in Romer's Gap, similar disparity can be seen in the invertebrate realm. Rare arthropods, including body fossils of xiphosurans, are known from the neighboring Horton Bluff Formation, Nova Scotia (NS). In New Brunswick (NB), only rare fragments of eurypterid cuticles and isolated conchostracans are known from the Albert Formation, and no invertebrate body fossils are known from other Mississippian strata in the province. The invertebrate trace fossil record in the Maritimes Basin of NS and NB can give insight into the biodiversity and disparity across Romer's Gap, offering insight into local paleoecology and paleoenvironments. In NB the Mississippian lakes were stratified and deep lacustrine depositional settings were not colonized during the Mississippian. Ichnofossils are preserved within marginal lacustrine Albert Formation (Scoyenia-Mermia transitional ichnofacies), alluvial/fluvial deposits of the Kennebecasis, Albert, Bloomfield, Maringouin formations, (Scoyenia ichnofacies), interdistributary settings within the Albert Formation (Batrachichnus ichnofacies) and ephemeral playa lake deposits of the Stilesville Formation (Scoyenia ichnofacies) depositional settings across the Devonian to Mississippian strata. Previous work in Romer's Gap of NB documented a *Palaeophycus* and a *Rusophycus* ichnocoenosis in the Albert Formation near Norton, NB and suggested that all trace fossils were subaquatic. This included what was previously thought to be a non-marine *Paleodictyon*. New outcrops of the Albert Formation near Norton, NB have yielded fossil microbial mats (*Rugalichnus maclaughlinensis*) associated with abundant invertebrate ichnofossils that are attributed to arthropod trace makers, representing a diversity of behaviours in both subaquatic and subaerial conditions expanding the known ichnocoensis'. Invertebrate trace fossils were not previously recognized in other Mississippian continental depositional settings in NB. Ichnofossil assemblages and ichnodiversity across the Mississippian differs between the Moncton Subbasin of NB and adjacent Windsor Subbasin of NS. The presence of xiphosuran body fossils and abundant xiphosuran ichnofossils from the Horton Bluff Formation greatly differs from the roughly time equivalent Albert Formation which lacks all evidence of xiphosuran activity but preserves rare body fossil cuticle and abundant ichnofossil evidence for eurypterids, crustaceans, arachnids, myriapods, conchostracans, and vermiform annelids. This difference in invertebrate assemblage could reflect the differences in paleoenvironments, and proximity to open-water settings between the two Atlantic Canadian Romer's Gap localities.

THE FIRST EVIDENCE OF TERRESTRIAL VERTEBRATES FROM THE LOWER MISSISSIPPIAN ALBERT FORMATION OF NEW BRUNSWICK: IMPLICATIONS FOR THE INVASION OF CONTINENTAL LACUSTRINE ECOSYSTEMS AND BIODIVERSITY DURING ROMER'S GAP IN ATLANTIC CANADA

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Romer's Gap marks the start of a critical divergent point in the history of life, as tetrapods transitioned from solely aquatic to terrestrial ecosystems. This expansion into dry environments set the stage for the radiation of all terrestrial life on Earth, including all of the crown groups of tetrapods, yet it is one of the least understood intervals of Earth's history. The exact timing for the radiation of tetrapods and other terrestrial biota into inland continental environments is poorly understood due to a lack of continental body fossils or ichnofossils from terrestrial deposits. New discoveries of body and trace fossils from sites in Scotland, England, and Nova Scotia, represent rare exceptions offering a glimpse into terrestrial ecologies during Romer's Gap, however these sites have evidence for an open-water connection suggesting a coastal paleogeographical position. Lower Mississippian sedimentary rocks deposited in the Moncton subbasin of southern New Brunswick (NB) are interpreted to represent freshwater, and intra-continental conditions (lacustrine, wetland, fluvial, alluvial settings). Within the Moncton Subbasin, a horizon in the Tournaisian Hiram Brook Member of the Albert Formation, and another within the Bloomfield Formation exposed near Norton, NB, have yielded abundant tetrapod footprints. Preliminary assessments of these trackways suggest at least four ichnogenera are preserved including: *Characichnos*, *Matthewichnus*, *Paleosauropus*, and *Batrachichnus*. Footprints range in size from 1 to 3 cm, suggesting that tetrapods were smaller than those documented from time-equivalent sites in Nova Scotia, but are comparable in size to skeletal remains described from Scotland that could be considered possible candidate trace makers. These footprints are interpreted to be preserved on the margins of small channels associated with dense wetland forests dominated by *Lepidodendropsis* lycopods and *Aneimites* ferns preserved in their ecological context. The large sample size of tetrapod footprints, in addition to previously studied invertebrate traces, suggests that a community of tetrapods were present and part of a diverse ecosys-

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tem, adapted to terrestrial and semi-aquatic continental environments in the Early Mississippian (early Tournaisian). Additional trackways from younger redbed alluvial plain or playa lake deposits in the Sussex Group (Stilesville Formation) and Mabou Group (Maringouin Formation) suggest tetrapods were venturing into semi-arid continental environments during the late Tournaisian through the latest Visean, similar to those described from the Mauch Chunk Formation of Pennsylvania. All Mississippian stratigraphic localities in New Brunswick and those described in literature from Pennsylvania, England, and Nova Scotia, show little ichnotaxonomic variation despite paleogeographic and allostratigraphic position.

THE ADVANTAGES OF USING HIGH-RESOLUTION DATASETS IN GROUNDWATER RESOURCE INVESTIGATIONS: AN EXAMPLE IN A COMPLEX END MORAINE TO WETLAND SETTING, GUELPH, ON

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The heterogeneous nature of unconsolidated ice-marginal settings and fractured sedimentary bedrock, as well as the dynamics of groundwater flow in multilayered aquifer systems used for water supply, make these complex environments difficult to characterize. We show that high-resolution spatiotemporal monitoring provides important insights to better understand the role of distinct hydrogeologic units from a water resources perspective. The study area in Guelph, Ontario is situated in a complex end moraine setting overlying fractured Silurian dolostone aquifers with a new deep bedrock municipal supply well (MSW) proposed adjacent to a provincially significant wetland (PSW). The objectives of this study are to determine the vertical hydraulic connectivity throughout the bedrock and overlying Quaternary sediment, improve the conceptualization of hydrogeologic units within the complex lithostratigraphic sequence, and quantify physical parameters (transmissivity (T), storativity (S), and vertical saturated hydraulic conductivity Kv) in response to a 30-day pumping test. Multiple high-resolution datasets were collected at one bedrock borehole and four Quaternary boreholes to characterize the subsurface geological and hydrogeological variability and create a conceptual site model (CSM) of the multilayered flow system. Continuous cores and multiple geophysical and hydrophysical logs revealed both a vertically and laterally complex hydrogeological system of carbonate bedrock and glacially derived Quaternary sediment. Custom depth-discrete G360 multilevel systems (MLSs) and a four-packer string were installed in the Quaternary and bedrock boreholes, respectively. Each of these zones were instrumented with transducers providing continual recordings of fluid pressure (1-second to 5-minute frequencies) to inform depth-discrete vertical profiles of hydraulic head, vertical gradients, and transient responses to anthropogenic and natural signals (pumping from multiple MSWs, precipitation, barometric pressure, and Earth tides). Regression deconvolution was used to filter out the 'noise' of unwanted responses, providing 'cleaned' water level data that is easier to interpret and provides hydrogeologic insights from the loading response functions (LRFs), and pumping response functions (PRFs) from multiple MSWs around the city. This method of generating PRFs allows estimation of T, S, and Kv not only for the pumping test well, but for multiple, actively, and intermittently pumped MSWs around the city, providing multiple distance and direction-oriented estimates. This research will support decisions regarding municipal well capture zones and sustainable pumping rates to minimize impacts to shallow groundwater and the natural environment.

FROM DEPOSITION TO BURIAL AND EXHUMATION: THE STORY OF AN ECLOGITE TERRANE IN NEWFOUNDLAND

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On the Baie Verte Peninsula, Newfoundland the East Pond Metamorphic Suite tells a geologic story that spans from the Mesoproterozoic to the Silurian. Within the suite is a metamorphosed bimodal volcanic and sedimentary sequence, the Pine Pond succession, between Grenvillian basement and Ediacaran–Ordovician Laurentian rift margin rocks. In the Pine Pond succession, least deformed blocks are separated by highly deformed zones of the same lithologies which preserve evidence of massive fluid infiltration in the form of albitization. The succession is composed predominantly of quartzofeldspathic rocks with minor mafic and pelitic layers. Quartzofeldspathic rocks preserve primary textures and are composed of granite, tuff, tuffaceous sandstone/siltstone and minor conglomerate. Mafic layers have amphibolite and eclogite assemblages with eclogite layers preserving laminations and lithic fragments and amphibolite layers containing aggregates of zoisite (former lapilli?) leading to their interpretations as tuffs. A youngest magmatic age of 952 ± 10 Ma has been determined for the succession by U–Pb LA-ICP-MS dating of a cross-cutting granite sheet and felsic tuff. These ages and lithologies together with ca. 1491 Ma granitic gneiss to the west and tectonic reconstructions, suggest that the Pine Pond succession may represent an extension related sequence overlying Pinware terrane basement, possibly linked to the opening of the Asgard Sea. Two igneous populations, each of zircon and titanite with ages ranging from 979 ± 14 to 973 ± 55 Ma and 1076 ± 14 to 1057 ± 15 Ma, were also identified in felsic tuffs from one of the least deformed blocks with no evidence of metamorphic zircon or titanite identified to date. In the same block, Lu–Hf (464.3 ± 1.4 Ma) and Sm–Nd (456 ± 11 Ma) garnet-omphacite isochrons from a mafic tuff interlayered with the felsic units, date peak eclogite facies conditions (preliminary 550–620°C and 15.8–19.8 kbar), while 429.4 ± 9.5 Ma metamorphic titanite (U–Pb LA-ICP-MS dating) within an albitized dyke from a deformation zone provides a youngest age limit on exhumation. Field relations together with these igneous and metamorphic ages, tell the story of a volcano-sedimentary succession deposited on Pinware terrane crust during Tonian extension that was subducted to eclogite facies during the Ordovician Taconic orogeny (during which the least deformed blocks remained dry, preserving primary textures) and exhumed along fluid-rich channels prior to or during the Silurian Salinic orogeny.

CHARACTERIZATION OF CANTUNG MINE TAILINGS FOR GEOCHEMICAL ANALYSIS OF FILTERED TAILINGS STABILITY

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Conventional tailings management strategies are under scrutiny because of failures that have resulted in catastrophic consequences. One alternative strategy to reduce the risks associated with tailings storage is filtered tailings. Filtered tailings storage involves the creation of a stable landform by compacting dewatered tailings to a solids contents of greater than 80% by weight. The applicability of this method to potentially acid generating (PAG) tailings remains uncertain because of the potential for acid rock drainage (ARD) as the tailings are stored in an unsaturated state and sulphide oxidation may occur. The former tungsten mine, Cantung Mine, Northwest Territories, is currently under care and maintenance. Approximately 6.5 Mt of tailings are impounded on site and 0.2 Mt of tailings were deposited directly on the floodplain of the Flat River during the first years of mining. The mine is in a seismically active area and tailings impoundments on steep slopes are not geotechnically stable. The tailings are characterized by recrystallized limestone with abundant pyrrhotite. Static testing classifies most tailings samples as PAG, confirmed by the Flat River tailings which are generating ARD. The impounded tailings, however, exhibit limited oxidation with pH-neutral pore waters likely because of neutralization by carbonates. Converting the tailings storage to filtered tailings has been proposed to reduce geotechnical risk and provide a more sustainable closure option. Mineralogical characterization suggests substantial concentrations of tungsten remain in the tailings. Value could be added to the conversion process by reprocessing the tailings to salvage tungsten and separate sulphides to mitigate the ARD risk. Geochemical analysis has shown significant spatial variation in the chemical composition of tailings within and between impoundments, probably reflecting fluctuations in ore processing and tailings deposition systems. Iron and sulphur concentrations across 182 samples range from 8 to 34 wt.% Fe and 2 to 20 wt.% S. Scanning electron microscopy (SEM) with automated mineralogy and synchrotron-based XRF and XRD analyses, indicate up to 31 wt.% pyrrhotite with varied crystal morphologies and degree of oxidation in pre- and post-column test samples. Data from this study will be used to inform the interpretation and design of filtered tailings sulphide oxidation experiments to better understand how PAG tailings will behave in a filtered stack.

TIDAL SIGNAL PROPAGATION IN A COASTAL AQUIFER ALONG A MACRO-TIDAL RIVER UNDERGOING DYKE REALIGNMENT, TRURO, NOVA SCOTIA, CANADA

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Low lying coastal communities are facing an increased risk of marine flooding due to changing sea levels and more frequent and intense coastal storms. The town of Truro, Nova Scotia, Canada, is implementing an ecosystem-based coastal defense strategy to help mitigate flooding through the realignment of several kilometres of historic dykes along the macrotidal Salmon River estuary. The aim of the realignment is to facilitate a buffer zone which will be periodically flooded during high water events, such as spring tides, resulting in lower water levels near the town. Research is being conducted to assess the impact of the periodic overland flooding on near-surface sediment and groundwater. This study presents preliminary data related to groundwater conditions throughout the site. Prior to the realignment 12 piezometer wells were installed and instrumented with pressure transducers at various locations within the buffer zone to monitor head and electrical conductivity conditions. Tidal constituents in the river, a tidal creek draining to an aboiteau, and in the groundwater levels observed in the piezometers prior to the breach were used to identify the impact tidal forcing is having on the aquifer. Fast Fourier transform analysis and the MATLAB toolbox T_TIDE were used to determine the frequency of the surface water and groundwater level variations. The primary diurnal and semi-diurnal tidal constituents were apparent in the river and resultant groundwater signals, and tidal signal decay with distance mostly conformed to classic theory. Hydraulic characterization of the aquifers is strengthened using tidal data from multiple observation wells, analogous to the application of the distance-drawdown approaches in aquifer hydraulic testing. This forcing is predicted to extend inland up to 260 m from the shoreline in the coastal sediment over an approximately 12 hour period. Understanding the impacts of tidal forcing on coastal groundwater will supplement future work related to the salinization of coastal aquifers and near-surface sediments in a changing climate.

THE APPLICATION OF MELT INCLUSIONS TO EVALUATE MAGMA ORE METAL FERTILITY, OXIDATION STATE, SULPHUR SATURATION AND VOLATILE CONTENTS IN THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA, CANADA

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The South Mountain Batholith (SMB), the largest granitoid body in the Appalachian orogen, outcrops over a large portion of central and western Nova Scotia, Canada. The SMB has been the target of sporadic mineral exploration since the late 1800s and mining in the mid-1980s to early 1990s (e.g. Sn greisen deposit at the East Kemptville Mine) while extensive research has yielded a comprehensive geochemical classification of the granitoids, with the distinction made between Stage 1 and Stage 2 plutons. However, there are no comparative studies that focus on the metal and volatile "fertility" of magmas associated with the formation of dominantly barren Stage 1 and commonly mineralized Stage 2 plutons. Additionally, there have been no studies of melt inclusions in these intrusive rocks. This study aims to quantify and compare the metal and volatile content, and oxygen fugacity of magmatic liquids from Stage 1 and 2 plutons in the SMB. This will be done by analyzing aliquots of the former magmatic liquids directly from preserved silicate and sulphide melt inclusions (trapped samples of crystallized melt) hosted in zircon and combining high spatial resolution microanalytical methods (laser ablation-inductively coupled plasma mass spectrometry, scanning electron microscopy, Raman spectroscopy, electron microprobe analysis, and cathodoluminescence) with detailed zircon and inclusion petrography. Petrography reveals melt inclusions of primary origin are abundant in zircon from the SMB, and occur in groups of up to 6 inclusions (size range 10–30 μm) in a single zone within zircon. SEM-EDS analysis of zircon-hosted melt inclusions show significant variation in total alkali-silica content, ranging in composition from granodioritic to syenitic within a single sample, indicating variations in magma composition during zircon growth (not recognized in associated whole rock data) that may be related to the differential metal associations and tenors of Stage 1 and Stage 2 plutons. The project will aim to establish the temporal variations in melt and volatile composition and associated entrapment conditions, as well as develop exploration indicators and mass balance constraints for the mineralized systems within Stage 2 plutons. The planned integration of coupled zircon-melt inclusion analysis to define the above parameters is innovative and will lead to quantitative, predictive criteria for differentiating barren or sub-economic from well-endowed plutonic suites.

UTILIZING PETROCHRONOLOGY TO REVEAL THE POLYCYCLIC DEFORMATION HISTORY OF THE HOWARD LAKE SHEAR ZONE AND EVOLUTION OF SOUTH RAE CRATON ARCHITECTURE

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This study characterizes the polyphase tectonometamorphic history of a 450 km-long shear system in the south Rae craton, the Howard Lake shear zone (HLsz). Prior work established a Mesoarchean mantle model-age discrepancy in basement rocks across the HLsz. Furthermore, a localized ~12.5 kbar and ca. ~800°C overprint at ca. 1.86 Ga in the south Rae craton is abruptly truncated to the northwest by the HLsz and by crustal domains with much older (2.4 to 2.3 Ga) cooling ages. The metamorphic and structural history of the HLsz and adjacent crustal domains prior to, and during, ~1.86–1.80 Ga Trans-Hudson orogen (THO) accretion remains poorly known. Furthermore, it is unclear how or if prior geological events aided the localization of related shear zones and localization of metamorphic overprints. Our work combines new bedrock mapping, structural analysis, thermobarometry and petrochronology on the HLsz and related structures, as well as bounding crustal domains. The HLsz abruptly separates 2.36 Ga granulite-facies metamorphic units to the east from 2.4 Ga greenschist-facies metamorphic basement rocks to the west. Subsequent reactivation of the HLsz during THO time (~1.86 to 1.82 Ga) accommodated burial and formation of high-grade rocks in its footwall coeval with Sask craton collision, followed by exhumation of these rocks. Deformation in metaigneous rocks and a newly discovered < 2.04 Ga schist preserve evidence for right-lateral transpression within the HLsz at ca. 1.82 Ga, which is coincident with the terminal collision of the Superior craton over 800 km away. Combining petrochronological work both within the HLsz and within adjacent domains allows us to show that the HLsz is one of several major crustal-scale anisotropies in the south Rae craton, and that strain has been repeatedly partitioned into the HLsz during multiple tectonic events over a wide range of time; perhaps up to one billion years. The polycyclic deformation history of the HLsz, along which regional burial and exhumation was strongly localized, demonstrates the considerable influence crustal-scale anisotropies can have on the evolution of craton architecture and the first-order control these structures may play in focusing mineralizing fluids.

crASSPHAGE IS A SENSITIVE INDICATOR OF GROUNDWATER-BORNE POLLUTION IN COASTAL ECOSYSTEMS

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As coastal ecosystems are continuously impacted by climate change and population redistribution towards the coast, sensitive approaches for monitoring coastal water quality and identifying associated contaminant sources are becoming increasingly important. One such monitoring tool, crAssphage, a virus that develops in the human gut and is shed with waste, is gaining interest as an indicator of human fecal contamination to surface and groundwater systems. By performing DNA assays that target crAssphage genetic fragments, we successfully detect pollution in the coastal ocean derived specifically from onsite wastewater treatment systems discharging to the shoreline via submarine groundwater discharge. This novel detection method was integrated with a field study on the north shore of Nova Scotia, where we characterized the physical hydrogeology (hydraulic conductivity, seepage fluxes, and hydraulic gradients), as well as surface water and groundwater quality during two distinct field campaigns. Water quality sampling towards the end of the summer cottage

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season revealed widespread detection of crAssphage in coastal surface waters and submarine groundwater discharge, resulting from increased use of onsite wastewater treatment systems. This is in stark contrast to the complete absence of crAssphage in pre-summer sampling. Evaluation of classic fecal pollution indicators (human-specific *Bacteroidales* genetic marker (HF183) and *Escherichia coli*) based on bacterial targets, were not detected, likely due to the greater attenuation of bacteria in the vadose zone and groundwater system compared to viruses. This research demonstrates crAssphage is a sensitive indicator of human fecal contamination where classic indicators could fail to detect sparse levels of contamination. This is the first study demonstrating the application of crAssphage in coastal groundwater and contributes to a growing body of research highlighting and validating this emerging tracer for application in a range of environments impacted by sewage pollution sources.

INGREDIENTS OF CA. 2.3 GA "PUDDINGSTONE": A CLAST PROVENANCE ANALYSIS OF A JASPER PEBBLE CONGLOMERATE FROM THE LORRAIN FORMATION, HURONIAN SUPERGROUP

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A jasper-pebble conglomerate ("puddingstone") from the Lorrain Formation of the ca. 2.45 to 2.22 Ga Huronian Supergroup (HSG) is composed of a white, coarse, quartz-rich matrix and variably coloured pebbles of red jasper, cherts, vein quartz, and siliciclastic rock fragments. The Lorrain Formation hosts some of the oldest post-glacial fluvial red beds, which capture the newly oxidative surface weathering and/or diagenesis conditions during the Great Oxidation Event (GOE). Previous studies have addressed the conglomerate's fluvial depositional environment, as well as stratigraphic changes in clast types and proportions at locations near Bruce Mines, Ontario. The conglomerate has been overprinted by post-depositional weathering, hydrothermal alteration, and metamorphism, but clasts tend to retain original textures (e.g. early reddening, primary layering, and microcrystalline chert) and thus presumably chemical information. As such, they have potential to reveal new insights into exposed landmasses and surface processes at the time of the GOE. However, an in-depth analysis of clast sedimentary provenance has yet to be conducted. It has long been hypothesized that the jasper and layered chert clasts were eroded from Archean banded iron formations (BIF), yet some characteristics of the clasts (e.g. their lack of magnetite and low metamorphic overprint/deformation) are unlike possible BIF sources. Thus, the initial provenance interpretations have been questioned, and other sources, such as reworked Paleoproterozoic deposits, have been proposed. We present preliminary textural and trace element lithogeochemical analyses to better constrain provenance of the chert/jasper clasts of the "puddingstone". Shale-normalized rare earth element and yttrium (REE+Y) patterns show predominantly light REE enrichment relative to the heavy REEs (with most $Pr_N/Yb_N >> 1$), even in clasts with low abundances of insoluble/immobile elements (e.g. low Ti), and thus argue against a BIF-hosted chert origin, expected to have hydrogenous signatures, for the majority of clasts. Instead, features such as near-chondritic/crustal Y/Ho and Zr/Hf ratios, and Pr_N/Yb_N ratios similar to intermediate-to-felsic igneous rocks/average upper continental crust suggest a non-hydrogenous chert source. Additional trace element proxy analysis and comparison to published potential source rock data (e.g. proximal IF-associated cherts and other siliciclastic rocks from the HSG) is ongoing and expected to unveil further details on provenance and weathering/erosional processes at the time of formation.

PHYSICAL GEOGRAPHY 110: A NEW COURSE FOR NEW BRUNSWICK HIGH SCHOOL LEARNERS

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A new Physical Geography 110 high school course for New Brunswick learners is nearing completion. This endeavor has been co-led by the Department of Earth Sciences at the University of New Brunswick and seeks to replace the current course published in the mid-1990s. New curriculum writing supports the International Geoscience Syllabus and is consistent with the Earth Science Literacy initiative outlined by the National Science Foundation. The curriculum embeds the New Brunswick Global Competencies and United Nation's Sustainable Development Goals. Aspirational ideas for the enactment of this course include aspects of human knowledge, culture, and equity. For the final summative assessment, educators will be encouraged to engage learners in a comprehensive field project instead of a traditional paper-based exam. The new positioning of the Physical Geography 110 course will provide a science credit for graduation and the acquisition of science skills, and appeal to a broader range of learners and interests. Presenters share aspects of the curriculum writing journey, gather feedback, and facilitate general science education discussion.

ARTIFICIAL INTELLIGENCE TO IMPROVE LOW-RESOLUTION AIRBORNE MAGNETIC DATA INTERPRETATION

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Regional airborne magnetic surveys have played a key role in geological mapping and resource exploration since the 1960s. Since that time, both government and industry have spent a considerable amount of money to acquire new data. The continuous effort to collect new datasets is explained by the constant improvement of survey techniques that provide higher resolution and image more accurately the geometry of geological bodies, which ultimately allows a better targeting of mineral exploration. However, at the regional scale, the coexistence of datasets with variable resolutions represents a significant technical issue, because magnetic grids are usually merged together at the lower resolution. Consequently, there is a significant loss of information on the maps provided to geologists compared to what is contained in the raw data. New strategies to integrate magnetic datasets are thus needed and the analysis of the statistical relationships between collocated high- and low-resolution data through deep learning methods appear to have the greatest potential. In recent years, deep learning algorithms have been used in geophysics for automatically analyzing faults in 3-D seismic data, seismic modeling and tomography. Deep learning algorithms based on Generative Adversarial Networks (GAN) have demonstrated their potential in image processing. They have been successfully used in the medical imaging domain for segmentation, image translation and data augmentation. The goal is first to develop digital artificial intelligence (AI) tools to integrate raw data at the highest scale through super-resolution GAN training. This will allow, in a second step, to generate high-resolution maps from the low-resolution ones. The technical challenge here is to build a numerical optimization function, called loss that takes data sampling characteristics into account. Ultimately, the synthetic high-resolution maps including both vintage and recent surveys will minimize information loss and support more robust geological interpretations. As a result, the decisions made by geologists regarding mineral exploration will be improved and more cost effective.

A NOVEL APPROACH INTEGRATING 3-D GEOLOGICAL MODELLING AND KINETIC MODELLING TO INFORM UPSTREAM MINE WASTE CLASSIFICATION

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Mine waste classification before mining, known as upstream mine waste classification, constitutes a proactive solution to segregate mine waste into geo-environmental domains based on the magnitude of their potential environmental footprints. Previous work focused on integrating 3-D geological modelling and stochastic simulation to establish the spatial distribution of a given contaminant within the ore body and to guide mining operations and waste management accordingly. Furthermore, incorporating kinetic modelling of the preliminary kinetic tests in the development stage (e.g. feasibility) of a mining project was suggested to perform a parametric analysis of the effluent's geochemistry. The present work aimed the integration of the two aforementioned approaches to inform upstream mine waste classi-

fication based on the effluent pH that could be generated from the interaction of the main acid-generating and acid-neutralizing minerals. The 3-D geological modelling coupled to the stochastic simulation and geological logging was used to depict the 3-D spatial distribution of pyrite, albite and calcite considered as the main acid-generating and acid-neutralizing minerals in a given case study. Along the central mining plan, a block model was created for each mineral. The dimension of the block grid was dictated by the prevalence of the drill cores. Accordingly, this approach complies with advanced exploration stages and operation stages as they imply high drilling frequency. Each block grid was considered as a homogeneous entity (40 × 40 × 40 m). The kinetic modelling approach was performed for each block model using PHREEQC coupled to VS2DRTI to consider variably saturated conditions, assuming that the block model is submitted to atmospheric alteration conditions. Both software are freeware issued by the United States Geological Survey. The kinetic approach simulated one weathering cell test for each block grid. Consequently, the resulting pH for different intervals of time provides insight into the geo-environmental behaviour, used herein, for mine waste classification.

RECOVERING, COUNTING, AND CHARACTERIZING PLATINUM-GROUP MINERALS IN GLACIAL TILLS USING AUTOMATED SCANNING ELECTRON MICROSCOPES

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Economically viable platinum-group minerals (PGM) deposits are difficult to explore due to their faint geophysical or geochemical signature. Current exploration approaches are heavily driven by geological models and rock geochemistry, such as associations with certain ultramafic facies, or is incidental to nickel exploration. However, in the absence of detailed geological data, as for areas buried under glacial sediments, detection of a PGM deposit is difficult and regional reconnaissance has to rely on indirect geological or mineralogical evidence. Some minerals other than PGM, such as chromite, olivine, or sulphide minerals, can be used as indicator minerals to detect proper geological settings, but they remain proxies that require careful and detailed interpretation to obtain only indirect evidence. Platinum-group minerals themselves are not sufficiently abundant to provide statistically meaningful results if counted by conventional methods. The issue is further hindered by the complex nature of this family of minerals, with hundreds of documented platinum-group minerals species, either sulphide minerals, sulphosalts and alloys, and endless possible chemical substitutions of both PGE and other metals, which lead to a wide varieties of colours and shapes. A sensitive method circumventing these difficulties which relies upon platinum-group mineral counting is here presented. A few years ago, an automated technique was deployed for concentrating, detecting and characterizing gold grains. Although the technique has proven to be highly successful for gold grain counting in the 0–50 µm size fraction, it enabled the simultaneous recovery and characterization of PGM with a similar efficiency. For example, a background signal of about one grain per two samples (samples are weighing 10 kg unsieved) is recovered from till collected in the Canadian Shield, while mentions of single grains were seldom with conventional techniques. Approximately 3000 grains have been recovered and documented so far in till samples, including high-definition BSE images and EDS chemical analysis for each of them. Whereas sperrylite and braggite are dominant, more than 60 different mineral species, including rarities such as minakawaite (RhSb) or undocumented rhenium-enriched alloys were found. While a large proportion of these grains seems related to orogenic gold deposit, a few genuine PGM occurrences were documented with distinctive mineral signature. A pandora box was opened.

GO-GTM: A GLACIAL EROSION AND TRANSPORT MODEL CONSTRAINED BY ICE FLOW PATTERNS AND CHRONOLOGY, GLACIAL TRANSPORT DISTANCES, AND EROSION RATES FROM COSMOGENIC ISOTOPES

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The assessment of glacial transport in terrains that underwent multiple ice flow episodes and polythermal regimes represents a complex modelling problem that can be aided with glacial erosion rates modelled from cosmogenic nuclides and glacial transport data. GO-GTM (for Geological Observations Glacial Transport Model) is a newly designed model in R, in which resultant dispersal patterns from successive ice flow patterns can be modelled. The glacial transport of distinct bedrock sources eroded by multiple ice flow phases is reconstructed using GO-GTM for two regions of the Canada's Arctic (Gulf of Boothia and Frobisher Bay), where multiple types of field data and interpretations (e.g. landforms, ice flow patterns, striation records, landforms, deglacial chronology and glacial/marine sediments stratigraphy) are available to constrain the modelling. The proxy for transport velocity is computed using the geometry of ice-flow patterns, the distance from the ice divide to the ice margin and by combining the effects of both convergence and divergence on glacial transport velocity. The glacial transport model is resolved along linear profiles (1-D) stemming from seed points located near the local and regional ice divides. The model is calibrated using model results within various glacial terrains (ice streams, warm-based versus cold-based glacial landsystems) and its performance assessed by comparing the outputs with glacial transport values calculated from pebble lithology in till and erosion rates calculated from cosmogenic nuclides in quartz-bearing bedrock and detrital quartz in tills and regolith (under alternating glacial and interglacial periods). The preliminary results obtained show that the fit between calibration data and results from the model is acceptable, within the resolution of the computation, and that the shape of the modelled glacial transport patterns is similar to data, where available. Results from the GO-GTM model demonstrate its capacity to evaluate glacial sediments erosion and transport budget at a regional scale to support mineral exploration in complex glacial terrains. Testing the model in different areas and at different scales will provide ideas on how the model behaves to different ice flow configurations and chronology and geomorphological settings.

RESOLVING < 1 MYR METAMORPHIC PROCESSES USING HIGH-PRECISION Lu–Hf CHRONOLOGY OF LASER-MILLED GARNET DOMAINS

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Constraining the timing and rates of metamorphic processes requires linking composition of petrogenetic indicator minerals to time. Garnet is a key mineral in this regard, not in the least because it best records P-T conditions and can be dated using Lu–Hf or Sm–Nd chronology. Bulk-grain garnet ages are the norm and can provide important and precise time-brackets on garnet growth. Dating individual growth zones moves beyond that in constraining the precise timing of garnet growth reactions. Sample size requirements, nevertheless, make this type of analysis very challenging for 'ordinary' mm- to cm-sized garnet grains, especially considering sample loss using conventional micro-mill sampling. We developed a new method, combining low-loss micro-sampling by laser cutting with a refined Lu–Hf routine. To test capabilities and analytical resolution, we applied the technique to date multiple growth zones in single garnet grains of two distinct samples, each representing a specific metamorphic facies: (1) a sub-cm-sized garnet in a blueschist from Syros, Greece, (2) a 1.5 cm-sized garnet from an amphibolite-facies metapelite from the Schneeberg Normal Fault Zone, Austria. Both samples were chemically characterized by major- and trace-element mapping (EPMA, LA-ICPMS) and distinct micro-domains were extracted using a laser mill. Five zones were sampled in the garnet grain from a glaucophane-bearing micaschist from Syros. The three core and inner mantle zones are chemically comparable and identical in age within an uncertainty of 0.1 Myr (2σ). The outer two zones are chemically distinct and resolvably younger (0.2–0.8 Myr). In the Austrian garnet, four zones corresponding to ca. 85% of the total garnet volume were extracted and yielded an age of 98.4 ± 0.1 Ma (MSWD = 0.4). The outermost zone yielded a distinct age of 97.8 ± 0.3 Ma (MSWD = 0.7). For each zone, two aliquots were analyzed and demonstrate the excellent precision and reproducibility of the method. The timing of distinct garnet-growth episodes, together with the variations in trace-element chemistry, can be tied to specific mineral reactions and constrain important fluid-release reactions, such as chloritoid-breakdown. The data show that the integral history of garnet growth, in both cases, may be extremely short (< 1 Myr), but may, even in that short timeframe, consist of

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multiple short pulses. Our new protocol for Lu–Hf domain geochronology of "common-sized" garnet allows to resolve distinct pulses and pauses of garnet growth within < 1 million years. This opens new possibilities for constraining the causes and rates of garnet growth and determining the pace of tectonic processes in general.

POST-BREAKUP PALAEOBATHYMETRY AND TECTONIC CONTEXT OF SALT DEPOSITION IN THE SCOTIAN RIFTED MARGIN

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Breakup of Pangea during the Triassic and Early Jurassic generated a series of rift basins along the Scotian margin filled by continental deposits passing up-section into evaporites and carbonates. Late Triassic to Jurassic depositional environments are fairly well constrained over the Scotian shelf thanks to decades of exploration, but the distal Scotian margin remains to be well understood. We investigate the post-breakup subsidence evolution of the distal Scotian margin and the tectonic context of evaporitic sequences and of the overlying Jurassic sequences. We apply a 3-D flexural backstripping technique, which incorporates decompaction and post-breakup reverse thermal subsidence modelling to provide high-resolution predictions of the palaeobathymetry and palaeostructure through the Jurassic down to the Late Triassic base salt. Quantitative analysis of seismic reflection and gravity anomaly data together with subsidence analysis have also been used to determine crustal thickness variations and along strike variability in breakup-related magmatism, both controlling isostatic response. Reverse post-breakup subsidence modelling to the Late Triassic predicts base salt near sea level at breakup in the proximal domain where the continental crust was only slightly thinned during rifting. In contrast, predicted palaeobathymetry of base salt at breakup time is greater than 2 to 3 km in the distal parts of the margin seaward of the necking domain where the continental crust is highly thinned (<10 km). Our interpretation of this is that while the proximal salt underwent post-rift thermal subsidence only, the distal salt was deposited during the latest stage of rifting which focused into the distal margin domains and underwent tectonic subsidence from crustal thinning in addition to post-rift thermal subsidence. The deposition of evaporites occurred both before and after the emplacement of the Central Atlantic Magmatic Province (CAMP). The impact of the CAMP on rifting, crustal structure and palaeobathymetric evolution of the Scotian margin remains to be determined. We do not exclude additional dynamic uplift at breakup time related to the CAMP magmatic event.

MINERALOGICAL, GEOCHEMICAL, AND VEGETATION-RELATED CONTROLS ON THE MOBILITY OF METAL(LOID)S IN MINE WASTES AND SEDIMENTS IN COBALT, ONTARIO, CANADA

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Silver (Ag) was mined and processed in Cobalt, Ontario, periodically from 1903 to 1989. Hosted in a five-element-vein deposit, Ag mineralization in Cobalt is associated with economic and potentially hazardous metals and metalloids, including cobalt (Co) and arsenic (As). Ore processing methods in Cobalt contributed mercury (Hg) to the mine waste. As a result of widespread Ag mining, there are dozens of unremediated sites, including 18 unconfined tailings deposits. Cobalt is an increasingly important critical metal used for rechargeable batteries and could potentially be recovered from these tailings. Since mining ceased, some of the tailings have migrated along creeks and rivers and are partially covered in natural vegetation. This research aims to characterize tailings and contaminated sediments at four waste sites (Crosswise Lake, LaRose Pond Tailings, Cobalt Lake, and Farr Creek Wetland) and benthic sediments collected from a pond adjacent to tailings (LaRose Pond). *Equisetum* spp. (horsetails) growing in the tailings were collected to examine their role in metal(loid) cycling. Tailings and sediment samples were digested using aqua regia, then analyzed by ICP-MS. Horsetails were cleaned with deionized water, separated into roots and shoots, digested using hydrogen peroxide and nitric acid, and analyzed using ICP-ES/MS. Mineralogical analysis of the tailings and sediment was performed using electron microprobe and scanning electron microscopy with automated mineralogy. Arsenic, Co, and Hg were elevated in the tailings and sediment samples (514–20,000 ppm As; 308–8900 ppm Co; 0.22–41.2 ppm Hg), relative to CCME guidelines for freshwater sediments (5.9 ppm As; 0.17 ppm Hg), residential soils (50 ppm Co), and industrial soils (300 ppm Co). Horsetail tissues were also enriched in As, Co, and Hg (276–15,615 ppm As; 52–429 ppm Co; 0.01–0.26 ppm Hg). We observed higher As, Co, and Hg content in horsetail roots compared to the shoots. Revegetation of mine wastes may impact metal(loid) mobility in the Cobalt region. During preliminary mineralogy work, primary ore minerals, including cobaltite and skutterudite, were identified as common Co- and As-bearing minerals in the mine waste. Arsenic was also hosted in a secondary Fe-As-Ca phase at all four sites. Understanding the controls on metal(loid) mobility is necessary to characterize the risks associated with multi-element mine waste contamination and inform long-term waste management decisions.

POSSIBLE SPONGE FOSSILS IN THE TONIAN OF NORTHWESTERN CANADA

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Charles Darwin regarded the most concerning weakness in his theory of evolution as the complete absence of fossils prior to the sudden appearance of taxonomically diverse mineralized fossils at the beginning of the Paleozoic. After 160 years, why has "Darwin's dilemma" not been resolved? Perhaps biases in the way we think about animal preservation, in the types of animals we attempt to look for, or in the rock types or rock ages we target, have led us in unfavourable directions in the search for evidence of Precambrian animal life. Recently published physical evidence of possible animals in Tonian rocks involves an unusual type of body-fossil preservation, a hitherto overlooked animal type, a generally dismissed category of rocks, and rocks of an age that is commonly thought of as too old for animal life. A type of microstructure that is familiar from Phanerozoic stromatolites but was recently reinterpreted as body fossils of non-spiculate keratose demosponges has been discovered in ~890 Ma microbial reefs in northwestern Canada. The millimetric to centimetric organisms lived in shadowy crevices in giant cyanobacterial reefs, which probably served as oxygen oases in an otherwise low-oxygen world. If this material is accepted as the fossilized soft tissue of keratose demosponges, it would (a) be the oldest body-fossil evidence of animals known to date, (b) indicate that at least some animal types emerged prior to both the Neoproterozoic oxygenation event and the Cryogenian glacial episodes, which are commonly posited as precursor events necessary for the advent of animals, and (c) confirm molecular clock estimates for the emergence of animals.

TOCHILINITE-VALERIITE GROUP MINERALS IN SERPENTINIZED PERIDOTITE FROM THE SAMAIL OPHIOLITE

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The Oman Drilling Project is a multi-national, IODP-ICDP collaboration to explore the oceanic crust as exposed in the Samail Ophiolite of Oman. A total of 384 X-ray diffraction (XRD) measurements were obtained and analyzed during Phase 2, Leg 4 of the Oman drilling project. Samples consisted of both bulk rock powders, taken at periodic intervals over the combined 1007 m of the three cores, and micro-drilled powders obtained at locations of interest specified by the shipboard science party. Although minor amounts of sulphide minerals were commonly observed petrographically, only three samples, all of which were micro-drilled powders, contained modal percentages of sulphide minerals large enough (greater than ~5%) to permit positive identification by XRD. In two of these samples, the identified sulphide mineral was pyrrhotite ($Fe_{1-x}S$), while a single measurement indicated the presence of a

tochilinite-valeriite group (TVG; approximate formula: FeS?(Mg,Fe,Al)$(OH)_2$) mineral. In this sample, the mineral occurs as a discrete, porous, opaque phase within a serpentine vein. We have characterized this mineral using a range of physical and chemical techniques, including XRD, Raman spectroscopy, X-ray computed tomography, scanning and transmission electron microscopy coupled to energy dispersive spectroscopy, X-ray fluorescence mapping, X-ray absorption near-edge structure (XANES) spectroscopy, and sulphur isotope analysis. The combined evidence suggests that TVG minerals formed during serpentinization of mantle peridotite are characterized by inherently high surface area and the potential for significant ion substitution, which, together, suggests they may play a role in organic catalysis. TVG minerals have been previously identified in hydrated ultramafic rocks, including in ODP Expedition 173 cores recovered from the Iberia Abyssal Plain, serpentinites at Mount Keith, Western Australia, as well as in carbonaceous chondrites. Recent hydrothermal experiments have also demonstrated pathways for their formation during seafloor serpentinization. This combined evidence suggests that this underappreciated group of minerals may provide a missing link that connects serpentinization to Fe-S clusters at the core of metalloenzymes and prebiotic synthesis in alkaline vent hypotheses for the origin of life.

LITHOTECTONIC CLASSIFICATION OF SEAFLOOR MASSIVE SULPHIDES (SMS) USING CRITICAL METAL ENDOWMENTS

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Seafloor massive sulphide (SMS) deposits are characterized by an abundance of critical metal-bearing sulphide minerals, which are precipitated from hydrothermal fluids that circulate through oceanic crust. These hydrothermal convection cells are driven by an anomalous heat source, making them a relatively common occurrence at plate margins and intra-plate hot spots. There is currently a lack of consensus upon the classification scheme of SMS deposits, largely due to the geochemical and lithotectonic variability between deposits. SMS deposits adjacent to mid-ocean ridges (MOR) are relatively well-classified, and this has enabled researchers to compile geochemistry databases, and to subclassify the deposits (mainly according to host lithology). Back-arc basin, arc volcanic, and intraplate SMS deposits are not yet subclassified, despite the potential for widespread contrasting host lithology, depth, and hydrothermal fluid properties between SMS sites. This is problematic, because arc volcanic and back-arc basin deposits exhibit a known preservation bias, whereas MOR deposits are typically subducted and recycled. Therefore, it is important to subclassify arc volcanic and back-arc basin-related SMS sites, in order to understand the controls on SMS critical metal endowment relative to lithotectonic setting, mineralogy, mineral texture, paragenesis, and hydrothermal fluid properties (temperature, pH, redox, salinity, magmatic volatile contribution, boiling, depth). Our ongoing research utilizes EPMA, and LA-ICP-MS data, as well as previously established literature values, in order to consider the distribution and controls on critical metals. Newly acquired geochemical data from the Niua Volcanic Complex's volcanic arc-related SMS deposit, VOLPA, displays a host of controls on critical metal abundances, including effects of boiling and structural controls on sulphide formation, in addition to the suspected presence of magmatic volatiles. Preliminary results indicate that SMS chimneys are most prone to critical and precious metal enrichments when fluids can freely exploit extensional fractures as a highway to the surface, and when an impermeable cap rock restricts fluid mixing with oceanic sea water. These factors not only complicate the subclassification scheme of SMS deposits based solely on host lithotectonics (as is the current status of MOR deposit classification), but also provide important context to our current classification scheme of ancient volcanogenic massive sulphide deposits (VMS). Further research will characterize and compare the remaining lithotectonic settings, which will more adeptly allow for comparison of critical metal endowments between SMS and VMS sites, both spatially and temporally.

SOURCES AND TRANSPORT OF METALS IN MAGMATIC-HYDROTHERMAL SYSTEMS

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Magmatic intrusions are critical to many ore-forming environments in the crust. They supply the thermal energy that drives the hydrothermal convection cells in which elements are mobilized, segregated, and concentrated into ore deposits. Moreover, magmatic systems are commonly an important contributor of ligands (e.g. Cl^-, SO_4^{-2}, HS^-, F^-), and given the strong dependence of element solubility on ligand concentrations, thereby control the element load of these fluids. What is less clear is the role of magmas in supplying (ore) elements to the hydrothermal system. Although magmatic gases have been shown to be highly and selectively enriched in certain metals compared to their source magma, element leaching during water-rock interaction is still commonly regarded as the dominant source of metals to hydrothermal systems. One argument in favour of water-rock interaction is its longevity compared to magmatic degassing, although this argument mostly holds for single magmatic events. Resolving this major question on element sourcing is complicated by a lack of direct samples of the hydrothermal fluids involved. Surface manifestations of magma degassing (e.g. fumaroles) have commonly undergone processes including scrubbing and boiling, and are therefore unlikely to be representative of the magma degassing flux at depth. Mass balance on progressively altered rocks provides an alternative estimate, but this only gives the time-integrated net result and is therefore not a sensitive recorder of changes in fluid composition as the system evolves, such as an early injection of elements from the magmatic system. Here, we present results for deep hydrothermal fluids sampled directly in production wells of the basalt-hosted Theistareykir and Krafla geothermal fields in the Northern Volcanic Zone of Iceland. These fluids are from magmatic-hydrothermal systems that we have shown in earlier work to receive input from both magma degassing and water-rock interaction. The elemental signature of the fluids indicates that magma degassing is the dominant element source, and thermodynamic modeling of the fluids and their host rock secondary mineralogy allows us to place constraints on the physico-chemical state of the fluids and the modes of metal transport.

INTENTIONS ARE NOT ACTIONS; ENGAGING IN POLICY DEVELOPMENT TO PROMOTE EQUITY, DIVERSITY, AND INCLUSION IN SCIENTIFIC SOCIETIES

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Implementing and promoting diversity initiatives within scientific societies is an ongoing challenge and opportunity for society members and office holders. Geoscience as a field is still one of the least diverse in the sciences and has made little progress in substantially improving representation within the field. Scientific societies are an important part of the culture and community within geoscience, and improvements in that culture can have a positive impact on the experiences of under-represented groups and individuals in the earth sciences. A major initiative for the Geological Association of Canada (GAC) over the last 2 years has been to revise and improve existing policies in order to support initiatives related to equity, diversity, and inclusion (EDI). The first of these was the development of a Code of Conduct for events which covers conferences, workshops, field trips, and any other events sponsored by GAC. This Code of Conduct is supplemented by a member Code of Ethics and an official position statement on EDI which serves to make our guiding principles explicit. This work has expanded into conference and event plan-

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ning as well. We created a new position of "Safety Officer" on the local organizing committee (LOC) that will be a part of all future committees in order to better align our new policies with actions by the LOC. The Safety Officer position is a liaison between the LOC, the event location, and individual organizer of field trips and other events. This position supplements existing association-level safety policies and insurance, and makes it possible to have all policies consistently applied while providing a critical link to the venue's own security and safety procedures, and facilitates reporting and documentation of policy violations. Policy sets the tone for interactions and defines the norms that are acceptable within an organization. Individual actions can drive policy development, but individual actions alone cannot be expected to effect change if policies are not implemented. This is particularly important when organization cultures are involved. This work will discuss some of the processes and pitfalls associated with developing policies that support improving the culture of equity, diversity, and inclusion in volunteer-run scientific societies.

METAMORPHISM IN FAULT-BOUNDED CRUSTAL BLOCKS OF THE CENTRAL CAPE BRETON HIGHLANDS, NOVA SCOTIA, CANADA

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The central Cape Breton Highlands in the Appalachian-Caledonide orogen contains well preserved variably metamorphosed rocks that record the pre-and post-collisional tectonic history of the Ganderian, Aspy, and Bras d'Or terranes now juxtaposed along the Eastern Highlands shear zone (EHSZ). The metamorphic rocks of the Bras d'Or terrane are intruded by voluminous Ediacaran plutons whereas those in the now-adjacent Aspy terrane are intruded by Silurian to Devonian plutons. The northernmost segment of the EHSZ is stitched by the ~375 Ma Black Brook granitic suite. The trend of the EHSZ is predominantly NNE-SSW but segmented, with segments linked by E-W transfer zones. The kinematics of fault movement indicate Bras d'Or-over-Aspy in the north, but Aspy-over-Bras d'Or in the south, with a significant transpressional component. Three contrasting metamorphic units make up most of the central Highlands: (1) the Ordovician to Silurian Calumruadh Brook formation and (2) Middle River metamorphic suite in the Aspy terrane, and (3) the Neoproterozoic McMillan Flowage Formation in the Bras d'Or terrane. The boundaries between the Aspy terrane metamorphic units are major shear zones. The Coinneach Brook shear zone juxtaposes mid-amphibolite facies Middle River metamorphic suite with predominantly greenschist facies Calumruadh Brook formation. On its eastern margin the Calumruadh Brook formation is strongly deformed by the EHSZ and juxtaposed against the variably metamorphosed McMillan Flowage Formation in several places. New mapping and geochronological data suggest the Calumruadh Brook formation may be correlative with the low-grade Clyburn Brook Formation. Similarly, the Middle River metamorphic suite is correlative with similar rocks in the Pleasant Bay complex in the northwestern Aspy terrane. The Middle River metamorphic suite preserves staurolite-garnet-biotite and kyanite-garnet-biotite assemblages that are generally strongly retrogressed in areas adjacent to the bounding shear zones, suggesting that the crustal structures may have promoted fluid infiltration into the high-grade rocks. It is likely that the major shear zones juxtaposing these metamorphic units also formed important crustal conduits for younger magmatic events. The Late Devonian Margaree pluton and the West Branch North River pluton are both elongate intrusions that are mostly undeformed. They cut all surrounding units and both have an *en cornue* shape characteristic of plutons emplaced into major shear or fault zones, in this case the Aspy Fault and the Coinneach Brook shear zone. The geometry of the two faults suggests that they could be conjugate faults that initially formed in the Late Silurian to Early Devonian within the Aspy terrane.

PALEOZOIC TECTONIC EVOLUTION OF LAURENTIA'S MARGINS

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Neoproterozoic to Cambrian rifting of Laurentia resulted in hyperextension along large segments of its Paleozoic margins, which created a complex paleogeography with isolated continental fragments and exhumed continental lithospheric mantle. This paleogeography led to a significant time lag along its eastern margin between the entrance of the leading edge of peri-Laurentia in the trench and the arrival of trailing Laurentia, since it was situated in a lower plate setting during all initial collisions. Cambrian assembly of Gondwana was followed by a global plate reorganization, which initiated multiple subduction zones (515–505 Ma) in Iapetus outboard of Laurentia, West Gondwana and Baltica. Accretion of infant and mature intra-oceanic arc terranes along the complex margins of Iapetus started at the end of the Cambrian (Taconic-Grampian cycle) and continued until the onset of the Scandian-Salinic collision at ca. 430 to 426 Ma, between Laurentia and Baltica, Ganderia and East Avalonia, which created a loosely coupled Laurussian continent and closed nearly all vestiges of Iapetus, except at its northern termination. Closure of the Iapetus Ocean in the Appalachians was followed by the Devonian Acadian and Neoacadian orogenic cycles, which were due to dextral oblique accretion of West Avalonia, Meguma and the Suwannee terranes following the closure of the Acadian seaway and outboard oblique subduction of the Rheic Ocean beneath Laurentia. Continued underthrusting of Baltica and Avalonia beneath Laurentia during the Devonian created wide orogens with orogenic plateaux in New England and Late Devonian eclogite in northeast Greenland, which indicates that convergence continued between Laurentia, Baltica and composite Avalonia. Convergence was sinistral in the Caledonides and dextral in the Appalachians, which are probably due to a southeasterly motion of Laurentia. Paleozoic subduction zones formed in the oceanic realm between Laurentia and Baltica continued into the Arctic realm and began interacting with Laurentia by the Late Ordovician during sinistral displacement of terranes with Laurentian, intra-oceanic and Baltican provenances along the Franklinian margin. Any intervening seaways were closed during the Mid to Late Devonian Ellesmerian orogeny. Exotic terranes such as Pearya and Arctic Alaska became stranded in the Arctic realm while other terranes such as Alexander and Eastern Klamath were translated further into the Panthalassa Ocean. The Mid to Late Devonian to Mississippian Antler orogeny along the Cordilleran margin of Laurentia records the first interaction with an outboard arc terrane. The Carboniferous–Permian Alleghenian-Ouachita orogenic cycle was due to closure of the vestiges of the Rheic Ocean and assembly of Pangea.

ANOMALOUS CARBON CYCLING IN EDIACARAN MARINE CARBONATES OF THE CANADIAN ROCKIES

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Values of $\delta^{13}C$ measured from marine carbonates from the Ediacaran Period display tremendous variability. Many of these variations are considered excursions and often are interpreted as reflective of changes in either oceanic dissolved inorganic carbon (DIC) values, or local, post-depositional changes – collectively known as "diagenesis". Ediacaran carbonates of the ~607.8 Ma Old Fort Point Formation in the Canadian Rockies outcropping in Jasper and Lake Louise, Alberta, display $\delta^{13}C$ values ranging from +3‰ to -12‰. To explore lateral variability in $\delta^{13}C$ values, we measured and sampled several stratigraphic sections in the Canadian Rockies, separated by approximately 250 km from McBride, British Columbia, to Lake Louise, Alberta. To test the hypothesis of a diagenetic origin, prevalent carbonate-clast breccias found in numerous stratigraphic sections were sampled to conduct 'isotope conglomerate tests' (ICTs) to determine the relative timing of acquisition of the $\delta^{13}C$ values measured. Results indicate that very low values (down to values of -12‰) are present across the Canadian Rockies in the Old Fort Point Formation with remarkable consistency. Further, clasts ($n > 900$) sourced from within interbedded carbonate breccias that may have formed through erosion of this strata, contain the full range of $\delta^{13}C$ variability found in entire sections from +3‰ to -12‰. We present similarities between the Old Fort Point excursion (~607.8 Ma) and the Shuram carbon isotopic excursion event (~574 to ~567 Ma) with implications for Ediacaran carbon cycling.

ON THE IMPORTANCE OF PUBLIC ENGAGEMENT PRIOR TO RESOURCE EXTRACTION DURING THE ENERGY TRANSITION: A CASE STUDY FROM COAL MINING AND EXPLORATION IN ALBERTA, CANADA

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As the energy sector begins to move away from the long-standing "brown economy" and towards sustainable, low-carbon solutions, the development of critical energy resources will continue to be essential for enacting these new goals. The mining sector has a societal responsibility to follow suit by ensuring economic deposits are mined in a sustainable and carbon-neutral manner. Public engagement by earth scientists on sensitive issues surrounding the mining industry is essential to achieving these goals; however, it comes down to policymakers to regulate these necessary changes. In June 2020, the Government of Alberta (GoA) rescinded the 1976 Coal Policy Act without consultation. This policy was put in place decades prior to limit open-pit mining in the Foothills and Rocky Mountains ecosystems. This caused a surge of metallurgical coal exploration with the intent to establish open-pit mines within the Alberta Foothills and Rocky Mountain regions, which host threatened species such as fish (e.g. west slope cutthroat trout) and plant (e.g. whitebark pine). However, this surge of exploration was met with public outroar, and with continued pushback, the public succeeded in overturning this policy change. But, even after the Coal Policy Act was reinstated, this did not entirely stop continued coal exploration programs. Since January 2021, I have been heavily involved in community engagement across the province of Alberta regarding the proposed open-pit coal mining in the Eastern Slopes. Communities and individuals across Alberta have expressed their concerns over the protection of the environment and potential environmental impacts of coal mining, but needed scientific support in ensuring their concerns were validated and clearly presented to governing bodies. My goal for this public engagement work has been to educate citizens and communities on various environmental, economic, and social impacts of open-pit coal mining. I worked to achieve this goal through various platforms (e.g. Facebook groups and personal messages), podcast talk shows, fundraiser talks, and delegate presentations to various towns and counties. This presentation discusses the success found in public engagement throughout this movement, the limitations to engagement during the Covid-19 pandemic, and how geoscientists may be restricted in supporting the public. As we move towards a sustainable future, resource development will likely see increased public scrutiny with new mining projects. As a result, the geoscience community will need to engage in more robust public outreach and communication to ensure that public trust is earned for environmentally sustainable and necessary projects.

INFLUENCE OF TRACE METALS ON MINERAL CARBONATION PRODUCTS AND EFFICIENCIES: A SPECTROSCOPIC STUDY

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Integrating carbon capture, utilization, and storage (CCUS) into mine operations and closure plans can significantly offset associated CO_2 emissions and could be used to design carbon-neutral mines. Of particular interest, is the process of mineral carbonation, where CO_2 is stored in benign Ca- and Mg-carbonate minerals that remain stable on geological timescales. Alkaline mine tailings are an ideal substrate for mineral carbonation due to their high particle surface area, the availability of reactive phases {i.e. brucite [$Mg(OH)_2$]}, the elevated pH, and the high Ca and Mg concentrations found within tailings storage facilities. Passive carbonation rates of alkaline mine wastes are typically 2–3 times greater than background carbon removal, but when mine design is optimized for carbon sequestration, carbonation of waste material could significantly reduce mining-related greenhouse gas. Although carbonation products and rates have been well characterized for pure brucite, the remobilization and partitioning of common trace metals [e.g. iron (Fe)] during carbonation of brucite remains poorly constrained. To address this, we carbonated synthetic Fe(II)-substituted brucite (5, 20, and 40 mol% Fe) in oxic and anoxic conditions, and in the presence of different background anions (Cl^-, SO_4^{2-}, $H_4SiO_4^0$). Fe(II)-brucite suspensions (50 g L^{-1}) were bubbled for 4 h with 10% CO_2 mixed with 90% N_2, or 10% CO_2 in compressed air for anoxic and oxic systems, respectively. Solids were collected and preserved at 30 min, 2 h, and 4 h; all samples were analyzed by X-ray diffraction (XRD), while final samples were also characterized using scanning electron microscopy (SEM) and Fe K-edge X-ray absorption spectroscopy (XAS) combined with finite difference modeling of the near-edge spectra (FDMNES). Combined XRD and XAS results indicate carbonation rates and efficiency are dependent on initial Fe(II) content and background anion species, where carbon sequestration efficiency decreased with increasing Fe substitution. XAS results revealed complex Fe partitioning into: kerolite/stevensite-like silicates {$[Mg,Fe(II),Fe(III)]_3Si_4O_{10}(OH)_2.nH_2O$}, chukanovite [$Fe_2CO_3(OH)_2$], fougèrite-like phases [$(Fe(II),Mg)_4Fe(III)_2(CO_3)(OH)_{12}.nH_2O$], ferrihydrite [$Fe_{10}O_{14}(OH)_2$], nesquehonite [$(Mg,Fe)CO_3.3H_2O$], and dypingite [$(Mg,Fe)_5(CO_3)_4(OH)_2.\sim5H_2O$]. Unlike Mg-carbonates, long-term carbon sequestration potential in Fe-bearing phases is typically limited to siderite ($FeCO_3$) and pyroaurite [$Mg_6Fe(III)_2CO_3(OH)_{16}.4H_2O$]. However, due to the redox sensitive tendencies of Fe-bearing phases, captured CO_2 can be released during redox fluctuations and environmental changes. Overall, these results highlight the importance of considering metal substitution when estimating the CO_2 sequestration potential and metal recovery of both mine wastes in surficial environments and serpentinites under subsurface conditions.

COLLIDING CRATONS: LINKING THE VARISCAN OROGENY IN WEST AFRICA AND LAURENTIA (OR NORTH AMERICA?)

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The Variscan orogen concerns the closure of the Rheic ocean and the collision between the North American and the West African cratons by the late Palaeozoic. The main collisional episode was protracted (360–254 Ma) and includes three distinct tectonic events. The first event (359–330 Ma) corresponds to the indentation of the Reguibat Shield into the central Appalachian belt. This explains the Soutoufide eastward thrusts, the Akjoujt eastward nappes and the southward motion of the Senegalese block. This motion is coeval with: (1) the folding of the northern part of the Bove Basin, (2) the N-S sinistral strike-slip motions in the Wa-Wa Group, and (3) the end of sedimentation in the Bové and Taoudeni basins by the Late Devonian. The second tectonic event (330–300 Ma) is related to the eastward motion of the Appalachian block against the Senegalese block. This "Alleghanian" motion provides (1) the closure of the central Carboniferous basins concealed underneath the Senegalo-Mauritanian Basin, (2) a dextral SW-NE strike-slip motion in the northern part of the Bove Basin and Appalachian terranes, (3) the thrusting to the east of the Simenti Group over the Koulountou Group in the Bassaride belt, (4) the thrusting to the east of the Wa-Wa Group, (5) the thrusting of the Mauritanide Belt onto the Taoudeni Basin in the central Mauritanide Belt, and finally, (6) the thrusting of the Agualilet Group over the Akjoujt nappes. The third tectonic event (300–254 Ma) corresponds to the filling of the Upper Diourbel basin concealed by the Senegalo-Mauritanian Basin and its folding around 270 Ma. This last tectonic event is coeval with the metamorphic ages recorded in the Simenti Group and in the Wa-Wa Basin. But the molassic episode is lacking and no large oceanic basins and volcanic arcs related to the subduction of the Rheic Ocean have been observed similarly to the Appalaches domain. It is suggested that the record of subduction of Rheic lithosphere was fragmented by strike-slip faulting with remnants now preserved in Mexico and Central America.

THE ENERGY TRANSITION - OUR WINTER OF DISCONTENT

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Access to energy has been recognized by The United Nations Economic Commission for Europe (UNECE) as "critical for assuring quality of life", These are the UN SDG (sustainable development goal) #7 "Affordable and Clean Energy, and SDG #13 "Climate Action". Eighty percent of the energy usage in the UNECE region is fossil-fuel based. Many countries are reliant on non-renewable sources for their

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energy security and economic well-being, yet there is a growing global urgency to transition to a more sustainable energy future with increased dependence on renewable energy sources, improved energy efficiency, and reduced global carbon emissions. But these energy sources are being disrupted by severe spikes in energy prices, unreliable delivery networks and severe shortages in the supply chain of both fossil and renewable energy systems. Canada has carbon reduction targets that the energy transition must help achieve. In Atlantic Canada, the provinces are in a unique position to become a green energy powerhouse, with reduced dependence on fossil fuels to help lead Canada in the transition to clean energy. An area we call the Energy Corridor, straddling the New Brunswick and Nova Scotia boundary, adjacent to Prince Edward Island, has all the components for green energy success, including regular wind patterns in the nearby Gulf of St. Lawrence, salt deposits suitable for energy storage, and a central location with power links to the northeastern USA. Research into the Scotian and Cumberland basins for carbon storage for emissions reduction, renewable energy sources such as biomass, geothermal, tidal, hydrogen, and wind energy, and the energy storage potential in salt caverns will be reviewed with other issues contributing to the overall energy situation in Atlantic Canada. This lecture will present an overview of the 'greening' of the Atlantic Canada provinces, present the vision for the energy future, and highlight opportunities to improve energy sustainability in the region. With energy costs spiking and the World still reeling from the effects of a "winter of discontent" the energy transition is never more critical.

GEOFORENSICS AND THE APPLICATION OF GPR FOR THE STUDY OF GRAVEYARDS AND CRIMINAL INVESTIGATIONS

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Geoforensics is the application of geological techniques to forensic and archaeological investigations where accurate representations of the subsurface are needed but cannot be acquired by invasive techniques that may disturb the ground in culturally sensitive areas, or areas involving a criminal investigation. Ground-penetrating radar (GPR) is a non-invasive, non-destructive geophysical technique for the accurate reconstruction of the shallow (< 10 m) subsurface for numerous disciplines and environments including locating utilities, engineering, law enforcement, mining and quarrying, geotechnical and environmental work, archaeology, military, agriculture and forestry, and imaging through ice and snow. Detecting foreign objects or anomalies in the subsurface has a near endless range of applications if the accuracy of data collection and modelling can be optimized. Reconstructions have largely been completed and presented as 2-D vertical and horizontal planes, limiting visualization of subsurface 3-D shapes and their spatial relationships. With technological advancements, including the availability and integration of various software platforms, 3-D modelling of GPR data is now emerging as the new standard. Our team was invited to conduct a geoforensic study in a church graveyard near Halifax in 2019. Tombstones and plot plans indicated locations and ages of burial sites, as well as the types of burial sites and practices (single-casket, multi-casket, and urns). However, the plot plans indicated unmarked, known burial sites, confirmed by the cemetery warden, which have no tombstones, or other indication of a burial site. A GPR grid survey was conducted in the graveyard to generate 2-D and 3-D model reconstructions of these unmarked burial sites. Data collection and processing was completed using a Sensors and Software Incorporated PulseEKKO™ Pro SmartCart GPR system and EKKO_Project™ software with modelling completed using a Schlumberger's Petrel™ software platform. The subsurface patterns in the 2-D, and 3-D reconstructions closely matched the graveyard plot plan, validating our collection, processing, and modelling methods. The 2-D model proved adequate for visualization of reflection patterns at specific depths. However, the 3-D model was superior with enhanced visualization, identification of companion burial plots (stacked caskets) and possible leachate plumes at burial sites, which were not evident in the 2-D model. This highlights the benefits of 3-D modelling for discerning subsurface objects. We applied these techniques to aid law enforcement in criminal investigations in Nova Scotia several times from 2018–2022. We expect this work to be of value to future GPR studies, with particular significance to geoforensics and criminal investigations.

WHAT DROVE THE ACADIAN OROGENY?

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Most orogenic events in the northern Appalachians and the Caledonides have relatively clear tectonic drivers. The Taconian–Grampian orogeny (latest Cambrian to Ordovician) represents a collision of the hyperextended Laurentian margin with an arc above a SE-dipping subduction zone. Salinian deformation (mainly Silurian) recorded accretion of Ganderian fragments at the now-active Laurentian margin, culminating in the Scandian collision of Baltica (and East Avalonia, already connected along the 'Tornquist line'). Late Paleozoic Alleghanian deformation resulted from the arrival of Gondwana. The Silurian (~423 Ma) to Devonian (~385 Ma) Acadian orogeny is more difficult to interpret. It is widely attributed to Avalonia-Laurentia collision, following NW-dipping subduction recorded by the coastal igneous belt (Maine, New Brunswick, Cape Breton Island, and southern Newfoundland). Nonetheless major nappes in the Acadian orogen in southern New England are rooted to the SE. The orogeny has been interpreted to involve transpression, but authors have been divided as to whether transpression was dextral or sinistral. Further complicating the issue is the 'Neoacadian' orogeny, a term used to describe 370–350 Ma shortening (also known as Quaboagian) in New England, coincident with extension in Atlantic Canada. The term 'Neoacadian' has also been applied to earlier shortening (~400 Ma) in the Meguma terrane. Transpression provides a potential solution. In Scotland, a major mismatch occurs across the Great Glen Fault. To the NW, major Scandian deformation occurred, but Grampian deformation was insignificant. Rocks to the SE show major Grampian tectonism, but were little deformed in the Silurian. British geologists have suggested up to 1200 km of sinistral slip, juxtaposing these terranes in the late Silurian to Devonian. Because of the sinuous shape of the Laurentian margin, sinistral shear would have caused transpression in the Appalachians, consistent with sinistral Acadian shear zones in Newfoundland, Cape Breton Island, Maine, and southern New England. This convergence may have brought West Avalonia into oblique collision with the NW-dipping subduction zone that fueled the coastal igneous belt. Collapse of the Mascarene backarc led to the vergence change responsible for the southern New England nappe pile. A change to dextral motion in the Mid Devonian led to Quaboagian transpression in New England but transtension in Atlantic Canada. The scenario envisaged here, involving a sinuous margin, transcurrent motions that changed over time, transported accreted terranes, and contemporaneous basin development and transpression at different points on the margin, is analogous to that of the Western Cordillera during Cretaceous through Eocene time.

THE LATE PALEOZOIC MARITIMES BASIN OF ATLANTIC CANADA: MORE THAN A PINCH OF SALT

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The Maritimes Basin of Atlantic Canada is a large and deep sedimentary basin underlying large parts of Atlantic Canada. The basin fill is predominantly late Paleozoic (Devonian–Permian) non-marine clastic sedimentary rocks, but the Viséan Windsor Group, and the correlative Codroy Group of Newfoundland, contain substantial evaporites, including gypsum and anhydrite, halite, and potash. Laterally correlative limestone-evaporite-shale cycles have been traced throughout the middle and upper parts of the Windsor Group. The role of Windsor evaporites in the tectonics of the Maritimes Basin has long been recognized. In addition to diapiric features generated by primarily vertical tectonics, there are extensive low-angle deformation surfaces characterized by anomalous breaks in the basin-wide stratigraphic succession. These breaks were originally interpreted as thrust faults, but later investigations, noting substantial omission of stratigraphy, led to their re-interpretation as a single low-angle detachment—the Ainslie Detachment. The availability of industry seismic reflection data allows these structures to be again reinterpreted as salt welds,

in the light of recent advances in evaporite tectonics on passive continental margins. For example, the famous Joggins Pennsylvanian succession was rapidly deposited in accommodation space created by salt expulsion, showing that Windsor Group salt remained in place until the Pennsylvanian before rapidly moving into diapiric salt walls. In contrast, in the eastern Cumberland sub-basin, evaporite expulsion was already controlling sedimentation during Mississippian deposition of the Windsor and Mabou groups. Field relations in other parts of the Maritimes Basin suggest that this history of early evaporite expulsion is more usual. These observations suggest an interpretation in which movement of the thick lower Windsor evaporites began within a few million years of their deposition. Feedback between halokinesis and sedimentation occurred from middle Viséan onward. Multiple minibasins were simultaneously flooded by eustatic sea-level rises, related to glacial cycles on Gondwana, accounting for the laterally correlative limestones. Differences in the overlying stratigraphic successions are best explained, therefore, by deposition above a changing configuration of moving evaporite bodies that culminated in complete expulsion of salt beneath some minibasins. The tops of evaporite diapirs have probably remained near the surface, producing areas of subsidence and karst development, throughout much of Nova Scotia's subsequent history. The distribution of near-surface evaporites continues to be marked by widespread development of sinkholes at the present day.

BATHURST MINING CAMP, NORTHERN NEW BRUNSWICK, CANADA; TECTONO-STRATIGRAPHIC FRAMEWORK FOR VMS EXPLORATION BENEATH CARBONIFEROUS COVER

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The Bathurst Mining Camp (BMC) is one of the World's great volcanic massive sulphide (VMS) districts with a pre-mining total sulphide resource in excess of 0.5 billion tonnes. Much of this resource, including the giant Brunswick No. 12 (± 300 Mt massive sulphide), Brunswick No. 6, and Austin Brook deposits, occur within the Brunswick Belt on the western limb of the regional scale Portage River Anticline (PRA). The stratigraphy of the Brunswick Belt comprising the Miramichi and overlying Tetagouche groups is well understood. Cambrian–Ordovician clastic sedimentary rocks of the Miramichi Group underlie the Tetagouche Group. The Nepisiguit Falls Formation (± 470 Ma) is the base of the Tetagouche Group and includes first-erupted felsic volcanic rocks (quartz-feldspar crystal tuff) in the Tetagouche-Exploits back arc basin. A 2 to 5 Myr hiatus, marked by the accumulation of massive sulphide and laterally continuous Algoma-type iron formation (Austin Brook Member), followed eruption of the Nepisiguit Falls Formation. This was followed by a second voluminous pulse of felsic volcanism (Flat Landing Brook Formation) and subsequently mafic volcanic and related sedimentary rocks (Little River Formation). Incorporation of this sequence into the Brunswick subduction complex led to deposition of syn-subduction clastic sedimentary rocks of the Tomogonops Formation. On the east limb of the PRA, adjacent the unconformity with Carboniferous strata, a small outlier of Tetagouche Group hosts the Key Anacon deposit. Drilling through Carboniferous rocks 1.3 km to the northeast discovered the Key Anacon East deposit. Tetagouche Group stratigraphy encountered in drilling along strike and to the east of Key Anacon is not identical to the Brunswick Belt. The Miramichi Group is locally overlain by intermediate (andesitic) volcanic rocks of the Straughn Brook Formation (477 Ma). These rocks have no correlative in the BMC and may be related to the Popelogan Arc. The Straughn Brook Formation gives way up-section to the Nepisiguit Falls Formation which includes the previously recognized Grand Falls and Little Falls members, and feldspar phyric rocks of the McKay Brook member (new name); however, iron formation of the Austin Brook member is absent. The Nepisiguit Falls Formation is locally overlain by aphyric to locally fine feldspar phyric rhyolite of the Flat Landing Brook Member that in turn is overlain by mafic volcanic and related sedimentary rocks of the Little River Formation. In the central part of the study area gravity indicates large felsic plutons, whereas the southeast part of the area may be underlain by ultramafic rocks at depth.

A REFINED PARAGENESIS FOR THE SCOTIA MINE, NOVA SCOTIA, CANADA, REVEALED FROM A TEXTURAL AND TRACE-ELEMENT STUDY OF GANGUE AND SULPHIDE PHASES

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The Scotia Mine deposit (the 'Gays River deposit'; Nova Scotia, Canada) is a Zn-Pb sulphide carbonate-replacement deposit (reserves 13.6 Mt @ 3.09% ZnEq, resource 25.5 Mt @ 2.84% ZnEq; ScoZinc report) hosted by the Viséan Gays River Formation dolostone. Previous work, conducted over 25 years ago, demonstrated that mineralization occurred ca. 300 Ma from heated (< 200°C for sphalerite) saline (20–28 wt.% equiv. NaCl-$CaCl_2$) fluids. To refine the understanding of the mineralizing fluids, this study addresses the Scotia Mine mineral paragenesis using optical microscopy, SEM-EDS, and major- and trace-element signatures of the host, gangue, and ore phases acquired using in situ LA-ICP-MS analysis. Petrography and SEM imaging indicate multiple generations of dolomite, one of which postdates mineralization, and local calcite pseudomorphs after pre-ore baryte. Dolomite is grouped into 2 chemical types: near-stoichiometric and non-stoichiometric (Fe- and Mn-rich) with Fe and Mn (both 0.3–2.5 wt.%) strongly correlated. PAAS-normalized REE diagrams of dolomite and calcite depict at least 3 different REE+Y patterns; most patterns are LREE-depleted (i.e. La/Lu normalized < 0.1) and exhibit positive Ce and Eu anomalies. Sphalerite is subdivided into Pb-rich (to 2600 ppm) and Pb-poor (< 500 ppm) types, is uniformly depleted in Ge, Sb, and Ag (< 30–50 ppm), but variably enriched in Cd (2000–13,000 ppm). The presence of pre- and post-ore dolomite, with intervening calcite precipitation, suggests variation of Mg in the fluid(s) over time. Positive Ce and Eu anomalies combined with high Fe and Mn in dolomite reflects a reduced nature for the pre- and post-ore dolomitizing fluids. Calcite pseudomorphs after pre-ore baryte suggest that at least some of the sulphur was sourced in situ. The Pb-rich sphalerite is possibly the result of the replacement of galena, as seen petrographically, with high Pb and possibly Cd concentrations a product of inheritance. Alternatively, because sphalerite precipitated at several different times, the variable metal enrichment could instead be due to precipitation from different fluids, or precipitation at different times during the evolution of a single fluid.

SCREENING ONTARIO'S DEEP SALINE AQUIFERS FOR CARBON SEQUESTRATION

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Canada has pledged to reduce CO_2 emissions 40–45% below 2005 emissions by 2030, and to increase the carbon tax to $170/tonne by 2030. For many industrial facilities, such as steel mills, cement kilns, and petrochemical plants, emissions of millions of tonnes per year are typical. For a plant emitting 4 MT per year, a $170/T tax would cost $670 million per year. This tax burden could bankrupt Canadian heavy industry in short order, and conversion to non-CO_2 emitting processes is in many cases equally uneconomical, or technically impossible, especially within 8 years. Our need for steel, cement, or chemicals will not abate – and so production (and emissions) will simply relocate to jurisdictions with a lower (carbon) tax burden. Thus, we see that carbon capture and sequestration (CCS) in southern Ontario is absolutely critical to our continued economic wellbeing. Currently, the most promising formation for CCS in Ontario is the Cambrian sandstone, the oldest and deepest Paleozoic sedimentary formation in the Michigan and Appalachian basins. This formation is thought to be permeable, but there are relatively few measurements, and work needs to proceed quickly to assess CCS feasibility at selected sites – as governed by injectivity, capacity, and isolation criteria. Injectivity is the ability to inject CO_2 at a sufficient rate without risking fracturing of the formation. Capacity refers to how much CO_2 can safely be stored in the formation. Isolation quantifies the long term to isolation of the CO_2 from other aquifers and the atmosphere. In addition to the mechanical and petrophysical properties of the rock, we must also consider the presence of faults, and legacy abandoned wells. Given limited information, we must

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proceed cautiously, but with haste to meet target dates set by the federal government. We envision a program of integrated field work and numerical modeling, punctuated by a series of decision points at which the assessment of various feasibility criteria will be refined. For instance, the easiest criterion to assess is likely injectivity. After selecting potential sites based on a review of historical data, we must drill and hydraulically test an exploration borehole. If sufficient injectivity can be established, we can proceed to baseline data collection, widespread drilling, new 3-D seismic, or pilot-scale CO_2 injection testing. At each critical stage, new field data will be used to update numerical models developed in parallel, to provide a quantitative basis for the decision to proceed.

OPPORTUNITIES TO IMPROVE ABANDONED-MINE RECLAMATION OUTCOMES

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Current trends toward greater use of high technology and renewable energy sources are driving increased exploration and mining for rare and critical commodities needed to sustain these trends. Increased mining activity may benefit from more sustainable mining and reclamation practices that allow former mined lands to attain beneficial reuse. Against increased exploration and mining pressure stands the legacy of contamination on mine lands largely abandoned before the advent of modern regulations in developed countries. Reclamation of abandoned mine lands presents multiple challenges including funding, liability concerns, limits of available technology, remote location of some sites, and gaps in comprehensive understanding of which waste sources contribute the most to ecosystem degradation; and therefore, most warrant cleanup. Some of these issues are beyond science (funding and liability concerns). However, progress on other issues is possible through scientific investigation and engineering solutions. Some of the most lingering and vexing challenges of reclamation are contamination to waterways and ecosystems from mine-affected water, including drainage from abandoned mine tunnels and seepage from mine waste and tailings. In Colorado, in the southwestern United States, bulkheads have been constructed to limit drainage from multiple abandoned and draining mine adits and to protect downstream areas from potential uncontrolled releases of degraded adit water. Although bulkheads improve safety and water-quality conditions at the mouth of the adit, elevated hydraulic pressure behind the bulkhead often causes water from the impounded mine pool to flow to the surface at new locations, perpetuating negative water-quality effects to waterways and ecosystems. Solutions to improve water-quality effects from bulkheads might include in situ or active treatment of mine-pool water that continues to leak into waterways after installation, but costs of the latter are usually prohibitive. Examples of limited to no water-quality improvement after bulkhead emplacement at two sites in Colorado is presented. An example of in situ mine-pool treatment in Montana that showed limited water-quality improvement is presented. Other potential avenues for success include extracting rare commodities from mine water as part of active treatment. To identify techniques to improve reclamation as a whole at a site, it is important to identify which parts of a reclamation strategy are successful versus which are lacking. For example, bulkheads improve safety but may have a limited positive effect on water quality. The presentation will focus on seeking innovative, multipronged solutions to improve mine reclamation outcomes for mine-affected water.

THE MUNSUNGUN–WINTERVILLE BELT OF NORTHERN MAINE, USA: AN ORDOVICIAN VOLCANIC ARC DEVELOPED ON A LAURENTIA MASSIF

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The Munsungun–Winterville Belt (MWB) of Maine is a major volcano-tectonic belt in the northern Appalachians, characterized by widespread volcanic rocks. The floor of the volcanic rocks is the Chase Brook mélange. The MWB has long been considered as an Ordovician arc developed on the leading edge of the peri-Gondwanan Ganderia terrane, and as part of the Bronson Hill–Popelogan arc. New detrital zircon data (of 252 grains) from the mélange, however, demonstrate a typical Laurentia spectrum. A few youngest zircon grains give the earliest sedimentary age of 556 Ma, suggesting that the "Munsungun massif" named here, was developed on the Laurentia margin in Ediacaran–Cambrian time. The massif is comparable with the Chain Lakes massif in western Maine and Dashwoods in Newfoundland. Consequently, the Iapetus suture (the Red Indian Line) must be relocated to the east side of the MWB. Based on recent mapping, the MWB includes several small inliers in the headwater of the East Branch Penobscot River and Aroostook River and connects with the Caucomgomoc inlier. Its southeast boundary (or the Red Indian Line) is a hidden tectonic contact with the Weeksboro–Lunksoos Lake Belt (WLLB), another volcanic belt characterized by Early Ordovician (485–481 Ma) arc volcanic rocks. The WLLB now represents the leading edge of the peri-Gondwanan Ganderia terrane. The MWB is dominated by several NE-striking distinct submarine volcanic units that constitute the Munsungun–Bald Mountain sub-belt and the Spider Lake–Mule Brook Mountain sub-belt. Both are fault bounded. The former includes the Munsungun Lake (471–467 Ma) and Round Mountain (465 Ma) formations. The Munsungun Lake is predominantly calc-alkaline island arc affinity, whereas the Round Mountain is a tholeiitic, rifted arc setting. The Winterville Formation (465 Ma) is coeval and comparable with the Munsungun–Bald Mountain sub-belt. A 456 Ma age obtained from the Munsungun Lake Formation suggests a younger phase of volcanism in the sub-belt. The Spider Lake–Mule Brook Mountain sub-belt includes the fault-bounded Mule Brook Mountain, Ingalls Brook Road, Rocky Brook Mountain, and Spider Lake formations. They are predominantly island arc tholeiitic and dated at 457–451 Ma. The 20 million year span may indicate a northwestward arc migration associated with a NW-dipping advancing subduction system. Detrital zircon spectra of several early Late Ordovician successor basin formations deposited on the MWB point to Laurentian provenance, suggest that the MWB was accreted to Laurentia in the early Late Ordovician as result of the Taconic orogeny.

DEPTH-DEPENDENT CONSISTENT CHANGES IN WATER CONTENT AND FABRIC IN THE LITHOSPHERIC MANTLE FROM THE SLAVE CRATON

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Peridotite xenoliths from the Jericho kimberlite in the Slave Craton (Canada) provides a window to investigate composition and thermal structure of the subcontinental lithospheric mantle. Here, we calculated equilibrium temperatures and pressures of 9 fresh peridotite xenoliths from the Jericho kimberlite pipe, using garnet-orthopyroxene barometer and two-pyroxene thermometer. Coarse-grained granoblastic spinel-garnet peridotites and garnet peridotites have equilibrium temperatures of 575–843°C and pressures of 2.4–3.6 GPa. In contrast, porphyroclastic spinel-garnet lherzolite records temperature of 1109°C and pressure of 5.0 GPa, and experienced an early ascent from ~156 km to the mid-lithospheric depth by kimberlite melts and the final emplacement by the Jericho kimberlite in the Jurassic. The water contents in olivine are 11–70 ppm (40 ± 30 ppm in average) for spinel peridotites, 60–128 ppm (94 ± 34 ppm in average) for spinel-garnet peridotites, and 69–171 ppm (120 ± 51 ppm in average) for garnet peridotites. Combined with Mg# in olivine and trace element concentrations, spinel peridotites preserved the high-degree partial melting in the shallow mantle, whereas the deep lithospheric mantle has been modified by metasomatism by kimberlite and silicate melts. Although the water contents in olivine are only 24 ppm for porphyroclastic spinel-garnet peridotite, this sample may be water-rich due to the presence of phlogopite. The electron backscatter diffraction analysis reveals different fabrics of olivine in our samples. Olivine from spinel peridotite sample develops [100](010) slip system (the A-type fabric) under water-poor and low stress condition or the activation of both [001](010) and [100](010) slip systems (the AG-type fabric). With increasing water contents, spinel-garnet peridotites develop both [100](001) and [001](100) slip systems, whereas olivine in garnet peridotite at greater depths develop the C-type fabric. The B-type fabric of olivine is observed in spinel-garnet peridotite and garnet peridotite with high water contents and relatively low temperature. Porphyroclastic spinel-garnet peridotite also develop the AG-type fabric but the B-type fabric is much stronger, implying two deformation events during its emplacement to a shallow level. Therefore, peridotite xenoliths from the Jericho kimberlite pipe show a consistent increase in water content and related changes in the olivine fabrics in the shallow depleted lithospheric mantle and the deep metasomatized lithospheric mantle. Our results not only confirm that kimberlite pipes only sampled "the metasom-

atized mantle" of cratons, but also provide new insights to interpret complex seismic anisotropy, electrical conductivity and rheology of the lithospheric mantle in cratons.

ASSESSING STREAM pH CHANGES AT MULTIPLE TEMPORAL SCALES WITH IMPLICATIONS FOR THE RELEASE AND RETENTION OF STREAMBED SEDIMENT PHOSPHORUS

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Eutrophication of freshwater systems due to excessive phosphorus (P) loads is a major challenge worldwide. Streambed sediments can temporarily store P acting as a sink and limiting release of P further downstream. However, stored P can later be re-mobilized and released to the stream in response to changes in stream water chemistry. While prior studies have identified stream redox conditions as an important control on P retention-release from streambed sediment, pH is also known to influence P sequestration to sediments. pH in streams varies over multiple time scales including diurnal, seasonal and long-term scales. For instance, as a result of acid rain control plans implemented in the 1970s, stream pH has been observed to be increasing in some streams and lakes across North America. Despite its potential importance on sediment P release-retention, the influence of pH on P exchange dynamics in streambed sediments is unclear. This study explores changes in stream pH at multiple time scales and the potential implications for the retention-release of P from streambed sediments. This was achieved by combining analyses of current and historical stream pH time series data with a synthesis of sediment P desorption data from prior literature studies. Analysis of historical stream data showed that 84% of 236 monitored streams across Ontario experienced a significant long-term pH increase (> 0.07) over the last 35 years. The median pH increase was 0.14 for streams in Southern Ontario (glacial till region) and 0.53 for streams in Northern Ontario (exposed bedrock). Seasonally, stream pH was higher in the summer than winter by 0.32 on average. Large diurnal pH fluctuations were common with some streams experiencing fluctuations of up to 1.3 pH units. Rapid declines and subsequent recoveries of pH (up to 1.7 pH units) following precipitation and snowmelt events were also observed. Combining pH analyses with the prior laboratory data suggests that these pH changes may be associated with substantial release and retention of P from streambed sediments. Furthermore, the long-term pH increase across streams in Ontario may exacerbate P release-retention in response to the diurnal, seasonal, and event-triggered pH changes as P release-retention has been found to be more sensitive to pH changes above 7.8–8.2. This study provides new insights needed to better understand the release-retention of P in streambed sediments and therefore to predict and model downstream stream water quality.

SPATIAL DECLUSTERING OF GLOBAL ZIRCON DATABASE POINTS TO RAPID ARCHEAN CRUSTAL GROWTH AND NEOPROTEROZOIC TECTONIC EQUILIBRIUM

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The timing, rates, and geodynamic conditions of the continental crust's formation, destruction, and evolution into its present form are still controversial. Different studies have concluded that plate tectonics began at times from Hadean to Neoproterozoic. Numerous studies used the Lu–Hf isotopes in U–Pb dated zircon to characterize the nature and evolution of the magmatic source of zircon crystallization and determine the model age of crustal formation. Constraining the growth and evolution of the continental crust provides insight into the secular change of tectono-magmatic processes through time. We perform a declustering algorithm to a newly compiled zircon Lu–Hf database to evaluate the growth of the continental crust. We explore approaches that indicate how continental crust grew and differentiated during the Earth's history and when modern-style plate tectonics became the dominant global regime. The declustered geological record reflects more rapid Archean continental crust growth than previous estimates. The high net rates of continental growth in the Archean propose that the generation of continental crust may be a feature of pre-tectonic magmatic processes. The Neoproterozoic transition to modern-style tectonics, as heralded by the appearance of low temperature–high pressure metamorphism, was accompanied by little to no net continental growth. The attribution of increased rates at which differentiated continental crust was destroyed is taken to reflect the onset of modern-style plate tectonics as the dominant global regime. We posit that plate tectonics has evolved since the Archean and stabilized to the modern style around 1.0 to 0.7 Ga. These results refine previous crustal growth estimates and provide a clear connection between the evolution of plate tectonics and the growth of the continental crust.

EARLY BIOGEOCHEMICAL DEVELOPMENT OF COAGULATED-FLOCCULATED MATURE FINE TAILINGS FOR OIL SANDS MINE RECLAMATION

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Bitumen extraction from mined oil sands in northern Alberta, Canada, generates large volumes of fluid tailings. Various treatment technologies have been developed to promote progressive reclamation of fluid tailings. These technologies often involve coagulant and flocculant addition to accelerate dewatering before treated tailings are transferred to terrestrial or aquatic reclamation landforms. We examined the early biogeochemical development of coagulated-flocculated mature fine tailings (cfMFT) produced using the Permanent Aquatic Storage Structure (PASS) technology developed by Suncor Energy Inc. The coagulant is designed to precipitate selected dissolved metals and organic acid contaminants in the pore water, and minimize methane ebullition, while the flocculant aggregates the fine minerals into flocs for quicker initial settlement after deposition. Here, we describe results of meso-scale column experiments examining spatial and temporal changes in aqueous, solid, and gas chemistry in cfMFT prepared using different doses of coagulant (i.e. aluminum sulphate or ferric sulphate) and flocculant (i.e. polyacrylamide). Five acrylic columns (5.5 m tall, 0.61 m inner diameter) were filled with 5.0 m of cfMFT, which was sampled over time (i.e. 0, 1, 3, 6, 12, and 24 months) from a series of ports installed at 0.25 m intervals along the length of each column. Slight increases in pore-water pH and alkalinity over time generally corresponded to decreasing dissolved CO_2 concentrations. Pore-water SO_4 concentrations also decreased with time, whereas dissolved H_2S and Fe concentrations increased over the first 6 months before again decreasing over time. Low dissolved CH_4 concentrations were observed after 1 month but values were generally below detection thereafter. Thermodynamic modelling indicates conditions favourable to Fe(II)-sulphide precipitation quickly developed and persisted over time, whereas X-ray absorption spectroscopy revealed decreasing Fe(III) and S(VI) contents in cfMFT solids. These results suggest that development of sulphate and iron reducing conditions promoted precipitation of secondary Fe(II)-sulphides, which limited dissolved Fe and H_2S concentrations in cfMFT pore water. This process may have also limited trace element (i.e. As, Se, Mo, Ni, and Zn) concentrations, which remained low within cfMFT pore water over time.

LATE TRIASSIC EPITHERMAL POLYMETALLIC Sb-Au (-Pb-Zn-Co-Ag) VEINS, MEGUMA TERRANE, CANADIAN APPALACHIAN OROGEN; A NEW CRITICAL METAL DEPOSIT TYPE IN NOVA SCOTIA, CANADA

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A multi-analytical approach has been applied to the characterization of a little-known polymetallic (As-Sb-Zn-Pb-Fe-Cu-Co-Au-Ag) vein-hosted occurrence in the Digby area of southwestern Nova Scotia, Canada, called the Lansdowne occurrence. This occurrence has been selected as a case-study to further understand critical metal endowment of the Meguma terrane, the outward-most terrane of the Canadian Appalachian orogen. Detailed petrography along with mineral chemistry and Re–Os geochronology of arsenopyrite in mineralized zones constrain two distinct periods of mineralization: the early stage (composed of arsenopyrite), which formed

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at ~365 Ma, and the more dominant late stage (composed of early sphalerite, chalcopyrite and pyrrhotite, followed by later arsenopyrite, galena, and Sb-Pb sulphosalts boulangerite and jamesonite), which formed at ~214 Ma. These two mineralizing stages coincide temporally with major tectono-magmatic events affecting the Meguma terrane: (i) the waning stages of the Neoacadian orogeny and emplacement of the South Mountain Batholith (early stage), and (ii) rifting of the Bay of Fundy, due to the opening of the Atlantic Ocean from the breakup of Pangea (late stage). Results of Al-in-chlorite thermometry associated with early sphalerite of the late stage indicates chlorite formation at 350 to 390°C. Fluid inclusion petrography, microthermometry, and Raman spectroscopic analyses indicate two mingling fluids during the Sb-Pb sulphosalt stage: a variable salinity (6.16–27.35 wt.% eq. NaCl) aqueous brine and a methane dominated fluid. Isochore calculations suggest epithermal conditions for Sb-Pb mineralization (approximately 165°C and 15 bars). High and positive S isotope values of sulphides ($\delta^{34}S$ = 14.7‰ to 25.1‰) suggest a sulphate source for S. An increase in $\delta^{34}S$ values from early to late stage arsenopyrite (15.30‰ to 23.95‰) suggests recycling and re-precipitation of early stage sulphides (up to 30%) to form the late stage sulphides. Base metals are likely sourced from surrounding country rock (mafic sills and host metasediments) as a result of their alteration to calcite-chlorite, but sources of As and Sb remain unknown. Comparisons can be drawn between the Lansdowne occurrence to other Au deposits in the Meguma terrane (e.g. West Gore Sb-Au deposit), as well as other epithermal Sb-Au vein-type occurrences worldwide, such as those of the Variscan orogen in western Europe (e.g. the Berga Antiform of eastern Germany or the Bournac polymetallic deposit in central France). The results of this project support exploration of this newly classified deposit type for critical metals in Nova Scotia.

UNLOCKING THE GEOLOGIC PAST THROUGH ILLUSTRATION

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Understanding geoscience is becoming increasingly vital for all citizens as it relates to climate change, finding and extracting natural resources safely, and having access to clean air and water. Furthermore, having geoscience knowledge is critical to making informed decisions with respect to land use planning and development. The authors recognize that one of the best ways to engage citizens in the earth sciences is through field trips. When people are able to identify rocks and recognize different geological features on the landscape, it creates a new connection to their environment, which will often spark a new sense of curiosity. However, explaining the concepts of geologic time and the geological history of a local area can often be very challenging to the layperson. For the non-geologist, imagining their surroundings as a landscape that was once covered by a shallow sea is next to impossible. To convey a proper understanding of earth science, it needs to be engaging, interesting and accessible. One method used to communicate such complex subjects in an easily comprehensible way is through scientific illustration – it allows us to 'see the unseeable' – a critical element in the study of geology. Scientific illustration requires a skilled artist who is also familiar with the subject matter. In spring of 2021, work began with an illustrator who is a former project geologist of the Yukon Geological Survey on four large visuals that would depict the typical landscape and local environment of the geologic time periods in question; for the Whitehorse area, this included the Triassic, Jurassic, Cretaceous and Miocene. It was essential to have illustrations that would make the geological concepts more accessible to the non-geologist and give the viewer an opportunity to 'step back in time'. Once completed, the four illustrations are anticipated to be used as interpretive panels in strategic locations around the City of Whitehorse.

LANDSLIDE DATING IN THE KLUANE LAKE AREA, SOUTHWEST YUKON, CANADA

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The Denali Fault system is an intracontinental, dextral strike-slip and thrust system that extends southeast from Alaska, through Yukon, into northwestern British Columbia. The Yakutat terrane is accreting into the North American plate at ~50 mm/yr where strain is accommodated along these fault lines. As the system progresses eastward through southwestern Yukon, strain is prominently displayed as strike slip faults between the St. Elias Mountains and the Shakwak Trench, southwest of Kluane Lake. The Kluane Lake study area is prone to debris flows, rockslides, rockfalls, slumps, and complex landslides due to factors such as steep slopes, sporadic permafrost, fractured bedrock, copious amounts of surficial material available for remobilization, and seismic activity produced along the Eastern Denali and Duke River faults. The purpose of this project is to determine the ages of large rockslides in the area to help resolve which of these contributing factors initiated the landslides. To accomplish this, five rockslide sites were sampled and analyzed using terrestrial cosmogenic nuclides (TCN), radiocarbon dating, dendrochronology, and tephrochronology to determine the ages of these events. Four of the sites were chosen for ^{10}Be and ^{36}Cl TCN analysis, and a fifth site was selected for dendrogeomorphological analysis based on recent scarring and leaning coniferous trees. Previously conducted research on the Sheep Mountain Landslide (SML), examined the composition and timing of events that occurred in this area. This research was expanded upon using structure from motion photogrammetry, drone imagery, and radiocarbon and ^{36}Cl dating to more precisely date the event. Ages were calculated for the five events and correlated to periods of warming and/or paleoseismicity during the Holocene, creating a more comprehensive understanding of landslides in the area. Many landslides throughout this northern system, however, still have not been extensively dated. This project will serve as a basis for future cataloguing of landslide ages in the Kluane Lake area. As well, this project will facilitate future research into the frequency of landslide hazards in this economically viable area.

MICROMECHANICALLY DRIVEN RHEOLOGICAL TRANSITIONS AND TECTONIC RESPONSE

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Notwithstanding the inherent heterogeneity of natural rock deformation, phenomena observed at all scales have as their basis a very limited number of fundamental processes. In the solid state, permanent displacement of material can occur by (1) diffusion of individual atoms, (2) sequential displacement of packets of atoms by dislocation glide, and (3) frictional displacement on free surfaces (microcracks). The latter dissipative processes interact within macroscopic aggregates to characterize normative deformation mechanisms e.g. dislocation creep, grain boundary sliding, fault creep, amongst others. The upscaling of phenomena is essentially an increase in the number of defects over the volume of interest. In the end, there remains the need to break or reorganize individual atomic bonds no matter what the scale of observation. This fact can be lost given the relative size of the fundamental processes versus tectonic features, as well as perceived large differences in time factors – the issues of characteristic dimension and characteristic time. Large tectonic features can themselves be described as fictive defects for which physical properties comprising intensive parameters do not allow elucidation of how the features evolve. Consequently, rheological transitions within Earth's crust are spatially and temporally transient, evidence for which may be routinely lost. As part of the latter, localization of deformation can be viewed as the default state, with macroscopic deformation a result of organization into required dissipative structures. Examples of natural deformed rock (TEM- to field-scale) from near surface to the lower crust are presented in support of this conjecture.

ALONG-STRIKE VARIATIONS IN FURONGIAN THROUGH ORDOVICIAN SEDIMENTATION AND DEFORMATION WITHIN THE NORTHERN APPALACHIANS: ROLE OF INHERITED MARGIN GEOMETRY AND COLLIDING ARCS

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Within the Northern Appalachian orogen, the deformed margin of the Laurentian craton and overlying foreland show lateral variability in basin geometry, sediment provenance, and deformation timing. Neoproterozoic to Cambrian break-up of Rodinia resulted in opening of the Iapetus Ocean and formation of an irregular Laurentian margin, defined by NE-striking rifts offset by NW-striking transfer faults.

Microcontinents, separated from the main Laurentian margin by the Taconic Seaway, were deformed during earliest stages of Taconian arc-continent collision. Later stages closed the seaway, generating a pro-arc foreland basin. Subsequent subduction polarity reversal transitioned the foreland to a retro-arc setting. Although well-studied, inconsistencies in time scales, tectonic nomenclature, and sparse geochronological datasets have rendered it difficult to achieve an orogen-wide synthesis of the margin and overlying forelands' variability. To achieve orogen-scale correlations, biostratigraphic and isotopic data are placed on a common timescale. All available detrital zircon geochronological data are also compiled and replotted using consistent parameters to aid in provenance interpretations. Using these compiled and replotted geological data, we focus on Cambrian through Ordovician orogenic events recorded in the northern Appalachians. Earliest Taconian deformation is associated with arc-continent collision at off-margin microcontinents, confirmed by simultaneous margin deformation (recorded in metamorphosed Laurentian margin rocks of the peri-Laurentian realm) and passive margin sedimentation (recorded in autochthonous and allochthonous rocks of the Laurentian realm). This deformation was strongly diachronous, occurring in the Furongian in Newfoundland and in the Early to Mid Ordovician within the Québec Embayment, as was subsequent closure of the Taconic Seaway. In Newfoundland, closure began at ~470 Ma and resulted in obduction of allochthons above the margin. In Québec, closure began at ~461 Ma and allochthon emplacement continued until ~450 Ma. In New England the seaway closed ~455 Ma. Pro-arc foreland basins developed in the Mid Ordovician in Newfoundland, but not until Late Ordovician in the Québec Embayment. Diachronous subduction polarity reversal, occurring first in Newfoundland (~460 Ma) and later in the Québec Embayment (~450 Ma), resulted in simultaneous westward and eastward subduction at different places along the margin leading to a unique hybrid basin (pro and retro-arc) in Newfoundland, analogous to the current position of the Akimeugah Basin forming on the northern Australian Plate. All major episodes of deformation, attributed to the Taconian orogeny in the northern Appalachians, were diachronous. This resulted from: the irregularity of the Laurentian margin; the distribution of off-margin microcontinents; and/or the geometry of colliding arcs and microcontinents.

ATLAS OF ALTERATION MINERALOGY ASSOCIATED WITH NEWFOUNDLAND AND LABRADOR, CANADA, GOLD OCCURRENCES FROM HYPERSPECTRAL ANALYSIS OF DRILL CORE

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A significant number of gold-bearing deposits have been discovered across the Newfoundland Appalachian orogenic belt over the past forty years in all tectonostratigraphic regions; most have been extensively drilled. The occurrences represent a wide-range of metallogenic types ranging from *sensu stricto* orogenic lode gold (e.g. the Marathon Gold Valentine Lake deposits) to epithermal (e.g. Avalon high alumina) types along with a variety subtypes that exhibit mixed, or unique, geological characteristics. The host rocks for orogenic types range from sedimentary to igneous (including granite, gabbro, and mafic volcanic), and nominally metamorphic, rocks. The epithermal types include both high- and low-sulphidation varieties. Some occurrences (e.g. Rattling Brook) have characteristics similar to Carlin-type gold deposits. The deposits range in age from late Proterozoic (e.g. Hope Brook) to probable Silurian. Using the College of the North Atlantic's multi-camera hyperspectral scanning unit (HSU), and in collaboration with Newfoundland and Labrador Department of Industry, Energy and Technology (DIET), we are developing an atlas of alteration minerals associated with gold mineralization in NL, using core stored at the DIET core libraries. Preliminary results indicate that rock units are readily defined, allowing for a more systematic approach to cross-hole correlation; e.g. pyrophyllite variably developed through drill holes at Hope Brook. Most significantly, the HSU data defines mineral associations that can vector towards gold mineralization. For instance, illite-plagioclase-quartz at Sop's Arm (both shale and felsic volcanic host rocks), illite and chlorite at Rattling Brook (Precambrian granite), muscovite-illite at Lizard Pond (siltstone), chlorite-quartz-illite at Cape Ray (graphitic schist and granite), carbonate at Bett's Cove (mafic volcanic and ultramafic), and quartz-muscovite-illite at Handcamp (tuff). When the atlas is complete, it will be released as an Open File.

HYPERSPECTRAL SCANNING OF DRILL CORE FROM THE LUNDBERG DEPOSIT, BUCHANS CAMP, NEWFOUNDLAND AND LABRADOR, CANADA; PRELIMINARY RESULTS

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The historic Buchans mining camp exploited volcanogenic massive sulphide (VMS) deposits recognized internationally as among the world's highest-grade examples of these base metal deposits. Worked from 1927 to 1984, massive in situ, and brecciated transported ores were historically mined from multiple orebodies, whereas stockwork-style mineralization was not mined as a principal ore type. The latter style is comprised of disseminated and stringer sulphide minerals located in the footwall to the previously mined in situ ore bodies. The Lundberg deposit represents the largest known zone of stockwork mineralization at Buchans and is comprised of stockwork/feeder type mineralization formed beneath the former Lucky Strike in situ massive sulphide orebody. Lundberg is currently being assessed as a potential open pit mineral resource and hosts a pit-constrained Indicated resource of 16.8 million tonnes averaging 2.59% combined metals including 1.53% Zn, 0.64% Pb, 0.42% Cu, 5.69 g/t Ag and 0.07 g/t Au. Using the College of the North Atlantic's multi-camera hyperspectral scanning unit (HSU) we have scanned five diamond drill holes from the Newfoundland and Labrador Department of Industry, Energy and Technology core storage facility at Buchans. Preliminary results show (1) there are definitive variations in kaolinite/dickite, chlorite and carbonate in some holes, (2) that a massive sulphide horizon at the base of the Lucky Strike deposit is underlain by a zone of bladed barite that grades progressively downward through quartz and then carbonate alteration haloes, (3) thrust fault zones are defined by sharp variations in carbonate abundance and chemistry, and (4) lithologic units can be mapped on the basis of definitive alteration mineral absorption bands.

MULTI-CAMERA HYPERSPECTRAL AND MLA-SEM ANALYSES OF GOSSANS IN THE FRANKLIN LARGE IGNEOUS PROVINCE, VICTORIA ISLAND, NORTHWEST TERRITORIES, CANADA

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Gossans are extensively oxidized and altered products derived from Fe-rich protoliths at the Earth's surface. They are composed of quartz, Fe-oxides, Fe-hydroxides and, in some cases sulphates such as gypsum and/or jarosite. Most gossans are small (a few metres to less than 1 to 2 km in length), and they are routinely noted by a single point on geological maps. In the barren Arctic tundra, gossans are highly visible on the landscape because of the yellow-orange colouration of the oxide cap. Gossans are commonly, but not solely, formed from the alteration of sulphide minerals in mafic and ultramafic rocks. Consequently, the observation of these types of gossans is an important indicator of local economic mineralization (e.g. Voisey's Bay, Labrador). In the Canadian Arctic Islands, some gossanous terrains at surface are derived from sulphide mineral occurrences and others are derived from reactive processes in permafrost, for instance active gypsum diapirs. The geological quandary lies in how to distinguish one type from the other, and ultimately, in understanding the processes that lead to the formation of barren vs. fertile gossans. We analyzed gossanous soil sampled at two localities on Victoria Island, NT, using (1) MLA-SEM analysis, and (2) the College of the North Atlantic's multi-camera hyperspectral scanning unit (HSU). The MLA-SEM provided quantitative mineral data which readily identified the protolith of the particular gossan. The HSU also distinguished gypsum-bearing gossan material from the others, and in some of these other samples, an Al-OH absorption typical of white micas was detected. The hyperspectral results suggest that an HSU-mounted drone system could readily distinguish between gossans derived from sulphide mineral occurrences, and others derived from reactive processes in permafrost.

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WOMEN GEOSCIENTISTS IN CANADA - RETENTION IN GEOSCIENCE, SURVEY RESULTS

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A number of studies have shown that while there is reasonable gender balance upon graduation from university in geosciences, within 10 years out, the number of women still in the field has markedly declined. The Women Geoscientists of Canada (WGC) felt this was an important issue and worthy of better understanding what others have termed this 'leaky pipeline' issue. In mid-2021 the WGC began designing a survey and in September of 2021, the survey was administered online so as to better understand employee retention in the geoscience professions, and to generate information that could be used by regulatory bodies, industry and professional organizations to encourage people to stay in the geoscience professions. The survey was designed to be as inclusive as possible, with the hope of eliciting as broad a response from the geoscience community as possible, regardless of gender or location. With over 300 respondents, the results of this survey give a glimpse into the reasons why employees take a hiatus–a temporary period spent away from the geoscience profession–and the reasons motivating their departure from the profession and their return from a hiatus. The results of the survey shed light on feelings of inclusivity, barriers felt to one's own opportunity to advance, as well as the day-to-day workplace environment experienced within the geoscience profession. One clear response is that there is a strong motivation from all genders to work in a corporate culture that values its employees. The WGC is a not-for-profit organization incorporated in 2018, which is focused on providing encouragement and support to reach gender balance within the geosciences. This presentation is a first-pass review of the retention survey's results, in which we hope to generate discussion and partner with other advocacy groups to create change.

HOW DO SOIL-FREEZING CHARACTERISTIC CURVES AFFECT CRYOHYDROGEOLOGIC MODEL RESULTS?

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In cold regions, the unfrozen water content plays an important role in a number of processes, including permafrost thaw, groundwater-surface water exchange, and heat and solute transport. The relationship between unfrozen water content and sub-freezing temperatures (or suction at the ice-water interface) is known as the soil-freezing characteristic curve (SFCC). Previous studies have shown that considering the unfrozen water content can significantly improve accuracy in heat and water transport modelling. However, the differences in how various soil-freezing functions and parameterizations affect hydrogeologic properties and thermal regimes are not well understood. We use SUTRA-ice, a numerical model that couples groundwater flow and energy transport with dynamic freeze-thaw processes, to simulate and compare the performance and parameterization of widely-used SFCC functions (e.g. exponential, piecewise linear, etc.). The shape of the SFCC is dependent on parameters such as the residual unfrozen water content, temperature range of freezing, or empirical constants characteristic of a given soil. We use a two-dimensional homogeneous model with time-dependent thermal and hydrological surface boundary conditions. Results show that the function and parameterization of the SFCC significantly affects permafrost evolution, active zone dynamics, and stream discharge in coupled heat and water transfer modelling of frozen soil.

A CA. 270–260 MA MULTI-COMPONENT ARC PLUTONIC COMPLEX IN THE SOUTHERN AREA OF THE BEISHAN OROGENIC COLLAGE, NW CHINA: A GEOCHRONOLOGICAL, GEOCHEMICAL, AND PETROGENETIC ANALYSIS

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Along the southern edge of the Central Asian Orogenic Belt (CAOB) lies the Beishan Orogenic Collage (BOC), bridging the Tianshan Orogen (west) to the Mongolia-Xing'anling Orogen (east). However, its relationships to the terranes and cratons to the south are poorly understood. The BOC is thought to represent the final stages of closure of the Paleo-Asian Ocean, and consequently the last tectonic events in the CAOB. The tectonic setting of the region has been a long-standing point of contention, and timing of final ocean closure and terrane amalgamation is highly debated. Some researchers suggest a continental rift setting for the BOC in the late Paleozoic while others suggest it formed as a series of amalgamated terranes with arc affinity at the time. The Liuyuan Complex (LC) is an ophiolitic terrane and is thought to be the youngest part of the BOC. Recent research indicates the LC formed between 290–282 Ma in a back-arc basin. Seafloor spreading ceased by 282 Ma, which is interpreted to be the time of closure of the Paleo-Asian Ocean. This study focuses on the geochemistry, geochronology, and petrogenesis of a multi-component plutonic complex located at the southernmost edge of the BOC, providing new insight into the controversial and poorly understood tectonic history of the region. The plutonic complex consists of mingled quartz-diorite and quartz-monzonite bodies, which are intruded by granodiorite. The quartz-diorite and quartz-monzonite both have geochemical signatures indicative of an arc setting, and the granodiorite has an adakite-like signature. The mingled mixture of quartz-diorite and quartz-monzonite yielded a SHRIMP U–Pb ages of ca. 270 Ma, while the granodiorite yielded a SHRIMP U–Pb age of ca. 260 Ma. This new data suggests subduction was still active in the BOC between 270–260 Ma, ca. 10 Myr later than suggested by previous models. This study provides new information about the most recent tectonic stage of the Paleo-Asian Ocean and could help better define the history of the CAOB.

IMPACTS OF THAW-ACTIVATED GROUNDWATER FLOW ON WATER RESOURCES IN DISCONTINUOUS PERMAFROST OF NORTHWESTERN CANADA

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Rising air temperatures, intensifying wildfire activity, and human disturbance are driving rapid permafrost thaw across the subarctic, particularly for thaw-sensitive discontinuous permafrost. The Taiga Plains and Taiga Shield ecozones of northwestern Canada have experienced rapid and widespread permafrost thaw over recent decades, creating significant community concerns and uncertainties for water resources. In direct response, we reviewed the thaw-induced impacts to water quantity and quality in the discontinuous permafrost zone of the Taiga Plains and Shield to guide future research in this region. In the wetland-dominated terrain of the Taiga Plains, thaw-induced landcover change enhances the hydrological connectivity between landcovers and between surface water and groundwater systems. Annual and winter streamflow are consequently rising across much of the Taiga Plains with winter becoming a more hydrologically active season. The thawing of peatlands will likely increase the transport and concentrations of dissolved organic carbon, ions, metals bound to organic compounds, and methylmercury. The largest knowledge gap, however, surrounds how permafrost thaw will impact groundwater environments and the associated changes in biogeochemistry, particularly for deeper groundwater and larger river systems. To address these knowledge gaps, water isotopes and environmental tracers are being used to investigate how thaw-induced groundwater flow is impacting water quantity and quality at local and regional scales in the Taiga Plains. Seasonal geochemical groundwater and surface water data are compared to similar data collected over 20 years ago when streamflow in Scotty Creek, Northwest Territories began to steadily rise due to permafrost thaw. The study aims to reveal how thaw has altered the integration of groundwater and surface water systems over the last 20 years and the impacts to overall water quality. Additionally, winter-time groundwater sampling will provide greater insights into the processes of thaw-activated groundwater flow and transport, particularly in poorly studied winter months. The hydrogeologic changes observed within the southern fringe of permafrost will inform anticipated changes at higher latitudes under continued climate warming. Preliminary results from this work are presented and future research directions for cold regions hydrogeology in the Taiga Plains and Taiga Shield are discussed.

EVALUATION OF PALEOMAGNETIC BIAS IN EDIACARAN GLOBAL PALEOGEOGRAPHIC RECONSTRUCTIONS

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Paleogeographic reconstructions, often presented as a black-box model of paleo-locations of continents, are typically constructed by minimizing paleomagnetic bias while satisfying geologic constraints. Fundamentally, these paleogeographic models are created to fit some informed selection of paleomagnetic data (the only quantitative measure of continental paleo-position) so that the resulting models can precisely determine the paleo-locations of the geographic poles consistent with other paleomagnetic data sets. However, underfitting of paleogeographic models to often sparse paleomagnetic data is potentially problematic as models may not capture ancient geomagnetic variations. Geologic observations such as paleoenvironmental, biogeographic and sedimentary provenance tracers are commonly used to justify such underfitting issues of ignoring specific paleopoles, but can inadvertently result in over-simplified paleogeographic models with large paleomagnetic bias. Furthermore, interpretations of geologic constraints are often equivocal or controversial, yielding multiple plausible continental paleo-positions. This study examines the large variance between different Ediacaran paleogeographic models, each purported to satisfy first-order paleomagnetic and geologic (typically paleoenvironmental and tectonostratigraphic) constraints which are often derived by a subjective trade-off between paleomagnetic error and geological plausibility. Here we quantify the extent of compliance with the paleomagnetic database by determining spherical arc distances between the reconstructed coordinates of paleopoles and the present-day geographic South Pole. A reconstructed location of a continent is questionable if arc distances of the majority of high-quality paleopoles with reliable age constraints lie beyond their paleomagnetic errors. In this study, we utilize a recent compilation of a reliable Precambrian paleomagnetic dataset to quantify irreconcilable paleomagnetic bias in competing Ediacaran global reconstruction models, which is a critical period in Earth's evolution. Our intent is to provide a quantifiable measure of paleogeographic bias that would allow researchers to make informed decisions when choosing among existing global models as a foundation for interpreting their geologic data.

EFFECT OF FAULT LOCATION RELEVANT TO UNCONFORMITY ON THE FORMATION OF UNCONFORMITY-RELATED DEPOSITS: INSIGHTS FROM REACTIVE MASS TRANSPORT MODELLING

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Reactive mass transport modelling is conducted using the software package TOUGHREACT to evaluate the effect of fault location relevant to the unconformity on uranium ore genesis. A layered 2-D conceptual model is constructed based on some common features of typical unconformity-related uranium deposits in the Athabasca Basin, Canada. Numerical results indicate that the fault extension above and below the unconformity determines the fluid flow pattern, which in turn governs the temperature distribution, the transport of aqueous components, and the uranium deposition. For all the numerical cases investigated in this study, early uraninite precipitation initially occurs immediately beneath the unconformity, but with a very low grade. At a later time, however, different fault locations lead to diverse results. When the fault zone is located predominantly in the basement with a limited extension above the unconformity, almost all the reducing basal brine is focused into the footwall of the fault zone, driving deep aqueous uranium up to react with the shallow oxidizing fluid being percolated into the basement from the overlying sandstone layer via the downwelling flow zones and the fault zone. As a result, uranium deposits are formed in the footwall area beneath the unconformity. When the fault zone is mainly in the sandstone layer with a limited extension below the unconformity, the focusing extent of ore-forming fluids is considerably lessened. Consequently, no significant deposits can be formed, except some minor uranium mineralization occurring in the footwall and other areas that are spatially associated with the upwelling flow zones in the sandstone layer. The footwall area below the unconformity is an ideal structural trap since it is in favour of focusing fluids for uranium deposition, and therefore it should be an exploration target in the field.

NEW INSIGHTS INTO THE CRUSTAL ARCHITECTURE AND PLATE KINEMATICS OF THE FLEMISH CAP, OFFSHORE NEWFOUNDLAND MARGIN, CANADA

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The role of pre-existing lithospheric weaknesses on extensional processes associated with the formation of continental crustal fragments like the Flemish Cap, offshore Newfoundland remain enigmatic. The first step in investigating how structural inheritance influences continental rifting requires careful mapping of the crustal architecture of the Flemish Cap, which until recently has been poorly constrained due to insufficient seismic data coverage. In this study, we present 13 newly acquired deep seismic reflection profiles over the Flemish Cap, from which the rift-related sedimentary successions from the Jurassic–Cretaceous are identified through correlation with the adjacent Orphan Basin, and deeper crustal reflectivity is assessed. In addition to expected extensional fault systems with fault-bounded blocks, flower structures are also observed, implying that the Flemish Cap was affected by transtension during the Mesozoic. Combined with vintage seismic data, crustal architectural domains (the proximal, necking, hyperextended, exhumed, and oceanic domains included) over the Flemish Cap are remapped based on the new seismic constraints. These reveal along-strike variations for each rift domain, in which the basement ridges in the exhumed mantle domain display similarities with the conjugate Irish Atlantic margin. In addition, continuous strong-amplitude reflection packages beneath the top basement along with basement structures (e.g. detachment faults and a possible shear zone) on the edges of the Flemish Cap may be revealing an important deformation stage resulting from the progression from Variscan orogenic collapse to initial pre-Jurassic rifting. These inferred structures are possibly related to reactivation of inherited structures from the Appalachian orogen and/or the rearrangement of rheological structures within the lithosphere. To address the kinematic evolution of the Flemish Cap during the Mesozoic, the newly-mapped edges of the necking and hyperextended domains are used to locally update an existing deformable plate reconstruction model, improving our understanding of the formation of continental fragments during the opening of the North Atlantic.

HYDROLOGIC PARTITIONING ACROSS A DEGRADING PERMAFROST CHRONOSEQUENCE: IMPLICATIONS FOR GROUNDWATER RECHARGE

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In the discontinuous permafrost zone of North America, rising air temperatures and permafrost degradation have enabled the expansion of woody landcover into areas previously characterized as tundra—a process known as 'shrubification'. This process has a number of implications for landscape-scale water partitioning and groundwater recharge, as the expansion of woody landcover has been shown to alter snowpack accumulation and ablation, the surface energy balance, and influences the thickness of the active layer and extent of seasonally frozen ground. To explore how changing landcover influences the aforementioned processes, a series of 1-D numerical models were constructed using the simultaneous heat and water model (SHAW) for three field sites in the Tasiapik Valley, located in Nunavik, Quebec, Canada. The field sites considered three different stages within an ecological chronosequence that describes the landscape evolution of northern tundra: low shrubs, medium shrubs, and trees. Simulation domains were informed by site stratigraphy, and possessed soil horizons ranging in extent from 15 to 60 cm, and were underlain by a largely homogenous, isotropic, fine sand formation. All simulation domains were 210 cm in length, and were refined from 0.5 cm near the soil surface and within the soil zone, to 5 cm in the underlying sand unit. To simulate greater snow entrapment under taller, sturdier landcover, annual snow inputs were increased under the taller landcover to match observations from local snow surveys. The simulations were forced with precipitation and solar radiation data from the period between 2014 and 2018 which were collected from a co-located meteorological station. Results indicate that subsurface temperature and frost penetration depth are strongly controlled by soil moisture, which is in turn controlled by the lower hydraulic conductivities found in the

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more well-developed soil horizons present beneath taller landcover. Recharge volumes computed using SHAW were comparable to those computed with the water table fluctuation method.

PHENOCRYST AND GROUNDMASS COMPOSITIONS OF EAGLE LAKE GRANITE PORPHYRY, SOUTHWESTERN NEW BRUNSWICK, CANADA: IMPLICATIONS FOR THE GENESIS OF Cu-Mo-Au MINERALIZATION

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The 5 km long, NE-trending Late Devonian Eagle Lake Granite is a pluton with associated Cu-Au-Mo mineralization located adjacent to the Belleisle Fault in southwestern New Brunswick. The granitic phases, divided into two categories based on texture (porphyry and equigranular), consist of phenocrysts and microcrystalline groundmass of quartz, K-feldspar, and plagioclase, with minor biotite, magnetite-ilmenite, titanite, apatite, and zircon. Petrographic and geochemical evidence indicate that this composite intrusion has I-type affinities, an A/CNK of 1.0–1.3, and calc-alkaline and alkali-calcic features. The composition of minerals, such as biotite, confirms the calc-alkaline orogenic affinity. Biotites plot in the Fe-biotite field of the Mg–(Al^{VI}+Fe^{3+}+Ti)–(Fe^{2+}+Mn) ternary diagram and the predominant red colour indicates that they are reduced and rich in total Fe and Fe^{2+}. These data point to primary or modified primary igneous biotite compositions and hydrothermally generated compositions. On the (FeO+MnO)-MgO-10TiO_2 ternary diagram, biotite compositions plot around the boundary of primary and re-equilibrated types, thus confirming that both phenocryst and groundmass biotite formed in an evolving magmatic-hydrothermal system. Temperatures yielded, using the Ti-in-biotite geothermometer, range from 670 to 725°C. The Cl content in these biotites is between 0.001 to 0.079 wt.% whereas F contents range between 0.13 to 0.94 wt.%. Compared to other alteration zones, the content of F in the potassic zone is higher than the others. Cl content of both igneous and secondary biotite does not appear to differ between various types of alteration. According to the feldspar ternary diagram, most plagioclase is between albite and oligoclase, and alkali feldspars are also orthoclase. Sericitization of plagioclase and chloritization of biotite are common. On the FeO-Fe_2O_3-TiO_2 ternary diagram, the Fe-Ti oxides plot in the magnetite range, but also range between magnetite and ilmenite. An originally oxidized I-type magma can show features of reduced ilmenite-series intrusions if the magma was emplaced through or into reduced rocks. At reduced conditions, the temperature drops and fH_2S increases in the fluid system. Zircon saturation temperatures in the Eagle Lake rocks yield between 720 to 825°C whereas crystallization pressures estimated from normative quartz contents fall between 383 MPa (low silica) to 163 MPa (high silica) at emplacement depth ranges from 10.3 to 4.4 km. Based on petrographic examination, both potassic and propylitic alteration are evident in these granites. Secondary fine-grained biotite together with fine-grained magnetite are observed as the principle indicator of the potassic alteration, which is coincident with Cu-Mo-Au porphyry mineralization.

MINERALOGICAL CHARACTERIZATION OF A NEW SILVER-BEARING PARAGENESIS IN THE SIDI SAÏD VEIN SYSTEM (UPPER MOULOUYA DISTRICT, MOROCCO)

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The Sidi Saïd vein system of the Upper Moulouya district (Central Morocco) consists of a N160°E array of steeply dipping (70° to ~90°), discontinuous anastomosing veins, veinlets along with breccias and stockworks. The Orefield host rocks consist of a succession of Cambrian to Ordovician spotted textured schists and quartzites with amphibolite intercalations. Economically, the targeted Sidi Saïd system is the most attractive owing to the high silver grade of the ore reaching locally more than 600 g/t. The ductile and/or brittle nature of the host rock predetermined the shape of the mineralized structures. The veins are generally < 2 m wide and extend laterally for more than 40 m along strike. The hydrothermal alteration assemblage comprises sericite, chlorite, and quartz. The silver ± Pb-Zn-bearing mineralized veins display comb, cockade, breccia, and crack-and-seal textures suggesting multiple episodes of dilation, fluid circulation, and provide an epithermal environment for mineral deposition. Three successive stages of ore deposition are recognized. The earliest stage (I) is referred to as Pb-Fe-As-Co stage and is followed by the main silver-rich Pb-Zn ± F ± Ba ± Qz stage (II) which accounts for most of the exploited sulphide ore at Sidi Saïd. The latest stage III is quantitatively minor and forms late fillings veins and therefore is referred to as the cuboctahedral stage and contained predominantly cuboctahedral crystals of galena and a minor quantity of sphalerite associated with euhedral fluorite, bipyramidal quartz and crested barite. Detailed textural analysis, back-scattered electron imaging, and mineral identification based on energy-dispersive spectroscopy, or chemical analyses indicate that the bulk of the identified silver-bearing sulphide and sulphosalt mineralization from stage (II) is dominated by Ag-Hg amalgams, proustite, polybasite, argentiferous tetrahedrite-tennantite, silver-bearing galena, in addition to native silver in the form of wire silver. Our preliminary data suggest that the Sidi Saïd epithermal Ag-Pb-Zn-F-Ba ore system may have been deposited either during the Variscan thermo-magmatic event in Carboniferous times, or during the Permian–Jurassic period, contemporary with Pangea rifting that led to the opening of the Tethys and the central Atlantic oceans.

A UNIQUE SN-BEARING Pb-Cu-Bi-Ag POLYMETALLIC EPITHERMAL DISTRICT IN THE CHILEAN ANDES: ORES HAVE LEAD ISOTOPES INFLUENCED BY THE BELEN METAMORPHIC COMPLEX, AN INLIER OF ACCRETED PROTEROZOIC–PALEOZOIC CRUST WITH GRENVILLE AFFINITIES

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We describe ore from Capitana mine, Tignamar, identified in the 1960s as the only Sn-rich (4.7% Sn) deposit in Chile. This Sn-bearing Pb-Cu-Bi-Ag high-sulphidation epithermal deposit is in the Andes (3200 m amsl., Lat. 18°37.4'S) east of Arica, ca. 250 km west of the Bolivian Tin Belt. Quartz veins occur within a sericite-chlorite-kaolinite alteration zone surrounding a Miocene ($^{40}Ar/^{39}Ar$: 17.1 ± 0.7 Ma) monzodiorite stock, which intruded a sequence of Oligocene–Miocene volcanic rocks (Lupica Fm.). The district is adjacent to the Belen Metamorphic Complex (BMC), a fault-bounded inlier of foliated amphibolites, serpentinites, orthogneisses, schists, and minor quartzites, intruded by gabbro and felsic dykes. Studies by others cite detrital zircon dates of 1930 to 850 Ma; peak metamorphism (ca. 700°C and 700 Mpa; ca. 25 to 30 km depth) dated at 472 Ma. The BMC was thrust upon Miocene ignimbrites along the high-angle, east-dipping Belén-Tignamar fault system; the fault moved from 18 Ma to 12 Ma and again at ca. 4.5 Ma. Capitana ore is unusual for Chilean deposits: besides pyrite (± minor pyrrhotite), its mineralogy consists of Sb-dominated sulphosalts of Cu, Fe, Zn, Pb, Bi, Sn, Ag, and In. No cassiterite is present; Sn occurs as stannite and in solid solution in enargite, tennantite, and particularly in sphalerite. Sphalerite is rich in Indium (mean 0.2%). Ag is contained in tennantite-tetrahedrite and bismuthinite, jamesonite, bournonite, boulangerite, and heyrovskýite. Chemical analysis of pieces of the vein (probably not representative of the deposit) indicated: Sn (0.05%), Pb (10.1%), Cu (8.9%), Bi (4.8%), Ag (0.7%); Zn (0.53%); Sb (3.5%) and As (3.1%). Unusual enrichment in Hg (> 10 ppm), Te (2 ppm), U (57 ppm), and Indium (23 ppm) is noted, but Au, Mo and W are low. The anomalous U content, a very low Th/U value (0.01) and the presence of trace sulphates, carbonates, and the arsenate joëlbruggerite attest to some supergene modification. The age of the mineralization is Miocene, but average common lead: $^{206}Pb/^{204}Pb$ 18.18; $^{207}Pb/^{204}Pb$ 15.61; and $^{208}Pb/^{204}Pb$ 38.53, is much less radiogenic than other Chilean ore deposits. These values suggest a mixture of lead derived from lower Paleozoic oceanic rocks, older basement, and average Andean magmas, and a probable connection of Capitana Pb with the neighbouring BMC. Although debated, the BMC may be linked to the orphaned Arequipa-Antofalla basement block that was close to the Laurentia–Scotland–Greenland promontory ca. 1000 Myr ago and left behind in South America as the Rodinia supercontinent broke up.

TAILINGS GEOCHEMISTRY AND MINERALOGY UNDER A COMPOSITE COVER AT KAM KOTIA MINE, ONTARIO, CANADA

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A composite cover with a geosynthetic clay liner (GCL) was placed over a tailings impoundment at the abandoned Kam Kotia mine, Ontario, Canada, in 2008 to reduce the production of acid mine drainage (AMD) at this site. Pore gas concentrations were measured from multi-depth gas sampling ports from 2018 to 2021. Aqueous samples were collected from multi-depth soil water solution samplers (SWSS) and piezometers at three test pit locations from 2017 to 2021. Analyses of major and trace elements and stable water and carbon isotopes were conducted along with saturation index (SI) calculations to characterize pore water and groundwater geochemistry. The mineralogy of the cover and underlying tailings was determined using core samples collected in 2017, characterized by total carbon and sulphur analysis, X-ray diffraction (XRD), optical microscopy, and scanning electron microscopy/energy dispersive X-ray (SEM/EDX). Five-step non-sequential selective chemical extractions were performed on the tailings samples to determine trace metal(loid) mobility under different geochemical conditions and their sequestration in secondary minerals. Depleted pore gas O_2 concentrations and improvement in pore water and groundwater quality over the sampling period were observed at two test pit locations. However, elevated aqueous concentrations of Fe, SO_4, Zn, Cu, As, Ni, and Pb were present at one test pit location a decade after cover placement. Continued sulphide oxidation of tailings below the composite cover at this location was indicated by the near-atmospheric pore gas O_2 concentrations and elevated dissolved metal(loid)s concentrations. Optical microscopy and SEM/EDX analyses demonstrated progressive oxidation of pyrrhotite, sphalerite, arsenopyrite, pyrite (with trace Pb and As), and chalcopyrite. Mineralogical analyses and selective extractions also revealed the sequestration and potential release of metal(loid)s by secondary covellite, amorphous and crystalline Fe(III) (oxy)hydroxide, and Fe(III) hydroxysulphate phases. Due to the depletion of trace amounts of calcite and dolomite, the dissolution of siderite, Al-hydroxide, Fe(III) (oxy)hydroxide, and aluminosilicate phases was likely the main acid neutralization mechanisms. Continuing research will focus on detailed mineralogical characterization using synchrotron-based X-ray absorption techniques and quantitative assessment of geochemical processes using reactive transport modelling. In addition to filling the research gap on the long-term tailings' geochemical evolution under a composite cover, this study can provide insight into cover design, mine closure, and remediation planning.

MACHINE-LEARNING-BASED EARTHQUAKE ANALYSIS: LOCATION, TOMOGRAPHY, AND FOCAL MECHANISM INVERSION

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The ever-increasing networks and quantity of seismic data drive the need for seamless and automatic workflows for rapid and accurate earthquake analysis including location, tomography, and focal mechanism inversion. In recent years, machine-learning-based algorithms have achieved remarkable accuracy and efficiency with generalization for earthquake analysis. In this presentation, I report on our group's recent efforts to develop machine-learning-based earthquake analysis methods and their applications. For earthquake location, we incorporated a widely used machine-learning phase picker—PhaseNet—with several popular earthquake location methods (e.g. HypoInverse, HypoDD and GrowClust) and developed a "hands-free" end-to-end location workflow (named LOC-FLOW), which can be applied directly to continuous waveforms and build high-precision earthquake catalogs at local and regional scales. For seismic tomography, we combined machine-learning differential times and cross-correlation differential times to construct high-resolution 3-D velocity models using a double-difference tomography method (tomoDD). For focal mechanism inversion, we adopted a machine-learning first motion classifier (i.e. up or down) and a classic focal mechanism inversion algorithm (HASH) to automatically and efficiently solve focal mechanism solutions for small and moderate earthquakes.

SEISMOLOGICAL INVESTIGATION OF TWO SMALL EARTHQUAKES IN DARTMOUTH, NOVA SCOTIA, CANADA, IN MARCH 2020

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A pair of small earthquakes (MN 2.4 and 2.6) hit the city of Dartmouth, Nova Scotia in early March 2020, and were widely felt by local residents. The events were recorded by three seismic stations within 200 km, but only one station (HAL, N 2.0) with known global positioning system coordinates is adopted as a reference for regional velocity model building and location calibration. We first build a half-space velocity model by estimating the P-S travel-time difference of the blast and determine the near-surface velocity through full-waveform modeling (i.e. comparing a set of synthetic waveforms with the observed blast). The velocity model is then used to evaluate the pair of earthquakes, in which waveform fitting and Rg/S amplitude ratios suggest source depths of ~0.7 km. Such a shallow source depth explains the "really loud bang" reported by local residents and unexpected strong ground shaking caused by such low-magnitude events. Whereas single-station template matching finds no similar earthquakes near the hypocenters of the two events in the past decade and only three aftershocks in the following four months. In summary, the epicenters of these two earthquakes are situated in a recently constructed commercial development, which agree well with local felt reports. The occurrence of the two small earthquakes might be attributed to (1) glacial isostatic adjustment like most earthquakes in eastern Canada and/or (2) mass unloading due to rock removal during the construction period.

HOW ARE GEOCHEMICAL REACTIONS IN AQUIFERS CONNECTED TO CLIMATE CHANGE MITIGATION?

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The storage in deep saline aquifers of CO_2 captured at point sources such as coal-fired power plants is a strategy that many regard as critical to limiting global warming to less than 2 degrees Celsius. But is carbon capture and storage (CCS) safe? Might reactions between CO_2, the native brine, and the host rocks modify the reservoir structure within ~10,000 years? Where does the injected CO_2 go and what is its fate? Can CO_2 escape to the overlying drinking water aquifers to cause unwanted reactions and degrade water quality? Our ability to understand and predict geochemical reactions in aquifers is critical for answering these questions. This lecture will give an overview of geological carbon sequestration efforts and of the research advances in reaction kinetics and geochemical modeling necessary to predict the safety of CO_2 storage. Recent innovative research by my students and collaborators on applying non-traditional stable isotope tracers in geochemical kinetics experiments has broken new ground in near-equilibrium reaction kinetics, which is critically relevant to CCS. The Mt. Simon Sandstone in the U.S. Midwest and the Sleipner Project in Norway represent planned and fully operational industrial-scale CO_2 storage projects, respectively. I present examples of numerical simulations of CO_2 fate and geochemical reactions from both projects. The connections among the hydrosphere, lithosphere, and atmosphere as well as the overlap between basic science and pressing societal needs—the hallmark of groundwater sciences—become clear through a tour of the fascinating and intriguing CCS efforts around the world.

CHEMICAL AND BORON ISOTOPIC COMPOSITIONS OF TOURMALINE AT THE BAIYANGHE Be-U DEPOSIT, NORTHWEST CHINA: IMPLICATIONS FOR Be-U MINERALIZATION

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Tourmaline can record the physical and chemical conditions of the crystallization environment through magmatic-hydrothermal processes. Therefore, tourmaline is a

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favourable geochemical tracer and can be used to reveal the metallogenetic process and ore-forming fluid origin of magmatic-hydrothermal deposits. The Baiyanghe deposit, located in the Xiemisitai Mountains, northwest China, is the largest volcanogenic Be-U deposit in Asia. The deposit has three types of ores: U type, Be type, and Be-U type. These ores occur separate or coexisting and have cross-cutting relationships. Major ore bodies occur as fracture fillings along contact zones between the Yangzhuang granite porphyry and the underlying Devonian volcanic rocks (basalt and tuff). Three types of tourmaline (e.g. hosted in the granite porphyry, tuff, and basalt) were identified based on their occurrences. Tourmaline hosted in the granite porphyry are acicular grains, while hosted in the rhyolitic crystal tuff and basalt all show oscillatory zoning. They all belong to the alkali schorl group. There are different composition modes and distribution modes of trace elements between the tourmaline hosted in the granite porphyry (GT) and tourmaline hosted in the tuff (TT) and basalt (BT). GT is rich in Be and U, whereas BT and TT are rich in Be and poor in U. The $\delta^{11}B$ value ranges from -5.94‰ to -4.48‰, from -8.01‰ to -6.93‰, and from -8.31‰ to -4.94% in the tourmalines hosted in the granite porphyry, tuff, and basalt, respectively. These data indicate that the chemical components that have contributed to the growth of tourmaline were derived from granitic magmas essentially. The oscillating zonation and the apparent variations of trace element compositions (e.g. Fe/(Fe+Mg) and Na/(Na+Ca) ratios) and REE patterns of the tourmaline indicate the involvement of periodic fluids from different sources and significant fluid-rock interaction. These are responsible for the precipitation of subtype tourmalines, as well as both coexisting and separate U ores and Be ores. It is proposed that tourmalines at the Baiyanghe deposit are the products of fluids exsolved from either a deep-rooted crystallizing magma chamber or one of the younger intrusions of the hosting composite granitic pluton in addition to crystallizing of the Yangzhuang granitic magma. The chemical and boron isotopic composition of tourmaline can provide a fingerprint to decipher the magmatic-hydrothermal process during the cyclic U-Be mineralization.