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Geology
In All Modesty

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Geology: In All Modesty

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When GAC president Steve Rowins telephoned me on a bright winter's morning in 2013 to invite me to join GAC Council as vice-president, which meant becoming president and then past-president, the initial glow of feeling flattered and flushed with a sense of purpose gave way to trepidation: I would have to deliver a presidential address. What could I possibly say that had not already been covered by Steve himself, or by my other immediate predecessors Stephen Johnston, Peter Bobrowsky and Dick Wardle? All of these presidents, in their own eloquent ways, gave such perceptive epistles on where geology is going in Canada. I knew I could not say anything new in this regard, even though the landscape has changed with the declining job market and worsening research funding. So I thought I might instead talk about… geology, and about how I think as a geologist, and why I find it so fulfilling. For me, geology is the most captivating of the sciences, and I did give the other ones a good try, I really did. Later I learned that geology had been the preeminent and most prestigious science in the 19th century, but over time it has been shouldered aside by other disciplines which have come to prominence. Now, it seems to be portrayed to the general public as a rather modest subject and not terribly relevant to modern society, and even bearing a whiff of guilt in an increasingly environmentally conscious world. When we think about it, however, we realize that geology is a most majestic subject because it incorporates so many things: all the other sciences plus the dimension of Deep Time. But these days, for various reasons I am anxious about the future of geology as we know it, that is, the study of rocks.

I am from Hamilton, Ontario, grew up in the embrace of the Niagara Escarpment, and did my undergraduate degree at McMaster University in the 1970s. Here is a photograph of the Highway 6 roadcut through the Silurian just north of Highway 403 (Fig. 1a). The lower half consists of sandstone and shale, passing upward into dolomite. When we as students measured sections in these roadcuts I remember that we couldn't find any fossils and condemned them as the most boring rocks ever. And yet they must have left a deep impression. I didn't realize then that hardly anyone had studied these units for years. That has changed, but even now every time I go back to the same localities, which I do often, I find new and amazing things. There really is a lot to see when you look.

It was flying by helicopter into the remote canyonlands north of the South Nahanni River after my second year that truly crystallized my passion for geology. The combination of science with outdoor adventure could not be beaten — not to mention the profusion of fossils in the Devonian limestone bedrock there. Yet the Niagara Escarpment of southern Ontario is just as exciting scientifically. Here is the cliff at Mount Nemo (Fig. 1b) between Burlington and Milton, south of Highway 401. It is just 13 km from that Highway 6 roadcut, but those boring thin-bedded dolomites pass into an entirely different facies: a huge shallow-water carbonate sand shoal deposit made of crinoid ossicles, cross-bedded and cut by spectacular scour surfaces. Digital elevation maps suggest that the shoal system was a complex of carbonate sand bars which are seen in cross-section in the cliffs and quarries. Over the past nearly 30 years I have prepared miles of photomosaics to document the internal architecture, ran ground-penetrating radar, collected fossils, studied the porosity under the SEM, and so on. This unit is unique in the Michigan Basin: how could the extremely high energy levels indicated by the sedimentary structures have arisen in a supposedly tranquil epeiric sea? These rocks – under our noses for so long – pose fundamental questions about Silurian oceanography and climatology.

As a budding éminence grise – without the eminence admittedly – I am at the stage in life when I wonder about my own thought processes, asking what geology is in the grand scheme of things scientific, how philosophers of science see us, and how to transmit these notions to students and people in other disciplines. Karl Popper told us that science moves along in a rather ordered way not by proving theories but by trying to falsify them. Does this fit with geology? Not exactly, because ours is an historical science: Mother Nature has already conducted the experiment, and we can't really test our hypotheses – interpretations – in the same way as in the 'hard' sciences like physics and chemistry. Paul Feyerabend felt that science proceeds more chaotically, and I think that is closer to how we practise geology. Thomas Kuhn considered that the slow advance of science was punctuated by sporadic intellectual or technological breakthroughs or revolutions, and in geology we can appreciate that, with plate tectonics as an obvi-

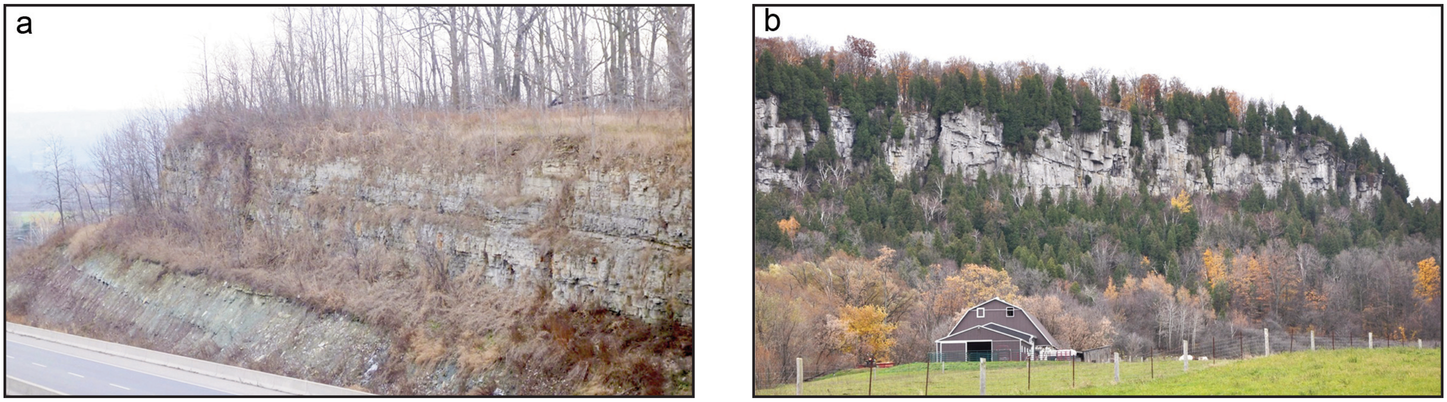


Figure 1. Lower Silurian strata of the Niagara Escarpment in the Hamilton–Burlington area, southern Ontario. (a) Highway 6 roadcut (Clappison's Cut) with Hamilton off to the left. The lower part consists of silty shale and sandstone belonging to the Grimsby and Thorold formations which are overlain by several dolomite formations separated by unconformities. The topmost unit is the Ancaster Member of the (traditional) Lockport Formation, which consists of cherty wackestone. A few hundred metres to the northeast it passes into thin- to medium- and lenticular-bedded crinoidal grainstone traditionally assigned to the Amabel Formation. (b) North-facing cliff face of Mount Nemo, 13 km north of Clappison's Cut. The Amabel Formation has thickened dramatically and consists of thick- and massively cross-bedded crinoidal grainstone with enormous scour surfaces.

ous example. I regard zircon dating and its use for sediment provenance as another one.

When geologists try to philosophize they don't seem to get too far. The 1963 book *The Fabric of Geology*, edited by Claude Albritton, is a collection of still-interesting papers but it does not set out overarching ideas or principles. The Geological Society of America celebrated its 125th anniversary in 2013 by publishing *Rethinking the Fabric of Geology* and two companion books that follow a similar approach. Maybe how we think in geology just can't be distilled into a single simple philosophy. On the other hand, the famous evolutionary biologist Ernst Mayr may have come close with his books in which he articulated a philosophy of biology. These include *Toward a New Philosophy of Biology* (1988), *This is Biology* (1997) and *What Makes Biology Unique* (2004). As a centenarian he witnessed astonishing advances and had plenty of time to ponder how they came about.

However, when most scientists, and journalists, think or talk about science, geology typically recedes from view. The downright pessimistic book *The End of Science,* published by John Horgan in 1996, didn't interview any geologists or even mention geology. It seems that the author forgot, or never knew, that in the 1800s geology was front and centre amongst the sciences. In those days, however, there was no way to measure the age of the Earth. Charles Darwin and Charles Lyell guessed it was in the hundreds of millions of years, based more on intuition and notions about rates of geological and evolutionary processes. Then physics stepped in, and Lord Kelvin famously, or infamously, calculated with great certitude an age of one hundred million years, which he later revised downward. But physics eventually did lead to the breakthrough that was necessary: the discovery of radioactivity and then radiometric dating.

Science is portrayed to the general public as being rooted in measurement and experiment, and heavy on technological wizardry and mathematics. Geology does all that too, but as Dolf Seilacher, the Sherlock Holmes of paleontology, once reminded me, the eye and the imagination are still valid scientific instruments. The roles of discovery and serendipity are by no means unique to geology but they are especially crucial, and experience and intuition help us make sense of it all. We must not surrender our rightful place because otherwise our special perspectives and contributions are easily overlooked. Unfortunately, research funding organizations seem to struggle with this legitimacy.

In what other ways are geologists different? We have a few basic stratigraphic principles but don't have scientific laws; if we did, they would be made to be broken. We continually return to the field, to make new or more observations of geological attributes and relationships. If we don't get these right, then all that follows is spurious. Every new student, then, needs to acquire basic field skills, and understand the strengths and limitations of field-based data — our version of 'experiential learning.' This can only be done by one-on-one mentoring, which is somewhat at odds with the pressure in universities to strive for ever higher student enrolment. Several years ago Chevron was running an advertisement in venues like *GSA Today* that showed geology students at an outcrop somewhere like in Utah or Arizona. It was aimed to attract new employees, but it should have been in magazines for the general public too: a perfect opportunity for putting a human, and geological, face on petroleum exploration. Instead, Chevron unleashed their 'We Agree' advertising campaign to showcase its concern for the environment, local communities and so forth — what is referred to, with some elasticity these days, as 'social licence.' It was immediately parodied by activists, and in advertising circles it is considered to have been an expensive flop. I would be curious to know if the companion advertising campaigns by several other oil companies managed to quell at least some anti-petroleum and anti-mining fervour.

Geologists engage in lifelong learning. We never stop, be it peering at a granite countertop or watching ripples form at the beach. Geologists are also renowned for getting the interpretation either completely wrong or partially wrong, and that is accepted quite happily as part of how geological problems are solved, as Bob Dott pointed out in his 1998 *GSA Today* essay. By the time Imperial Oil drilled the famous discovery well Leduc #1 in 1947, it had 133 consecutive dry holes to its credit — but we wouldn't really say the exploration geologists were wrong all along, would we? When I worked in Calgary in the early 1980s, a senior geologist once joked to me that, given the vast number of dry holes that riddle the province – now running into the many hundreds of thousands – oil and gas wells could have been drilled on a random basis and exploration would have been just as successful. Yes, it is true that millions of dollars are spent in search of a field, but there is an accumulation of knowledge that ultimately does lead to discovery, which is followed by a dramatic advance in understanding as the field is developed, such as this one in the Cretaceous Glauconite Formation in Alberta (Fig. 2). The intellectual background is therefore integral to a geological advance and that is why the archival literature remains important, perhaps more so than in other disciplines. So, geologists seem to be especially forgiving of making mistakes. Not for us Max Planck's famous (paraphrased) aphorism that "science advances one funeral at a time." At the same time, geologists are not too impressed by dogmatic interpretations about Earth's history or exaggerated predictions of Earth's future.

Geologists also have a unique ability, which they acquire in short order, to move seamlessly and effortlessly across spatial scales from nanometres to thousands of kilometres, and temporal scales from seconds to billions of years. We can all think of geological objects and phenomena to populate a graph of distance or size versus time (Fig. 3a). A meteorite impact crater tens of kilometres across took just seconds to form. A fossil animal like a Cambrian trilobite or archaeocyathan sponge a few centimetres in size (Fig. 3b) may have lived up to a decade or two or three. That would imply that the associated constituents (Fig. 3c) formed in a broadly similar time span, and a rough idea of sedimentation rate, in this case how long it took to build a patch reef, can be estimated. If we find the same species of fossil on another continent, that tells us something about ocean currents, larval biology and so forth, and allows us to correlate the two distant areas. Of course, if we do not find it elsewhere that tells us something too — in geology the absence of something can be as important as its presence.

Another aspect of geology that I find so fascinating is how we approach geological problems using what I like to call the 'interrogative trinity,' asking the questions 'what,' 'how' and 'why.' Different geological tasks or activities involve these questions in different ways and proportions, and they can be plotted on a ternary diagram (Fig. 4). When we make a geological map we are determining factual information: the *what*. An

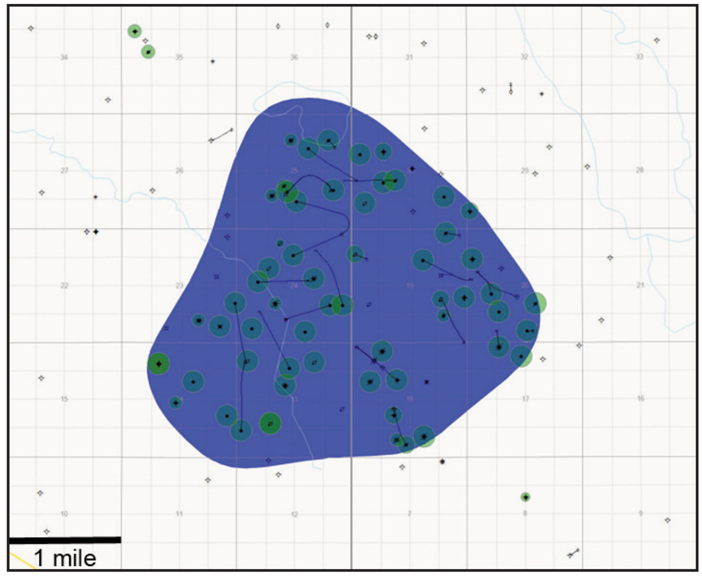


Figure 2. Map of a portion of eastern Alberta showing an oil field in the Lower Cretaceous Glauconite Formation (blue area) and location of oil wells (green circles) and dry holes (most of the uncoloured dots in and around the field). As drilling proceeded, it was revealed that the field is developed in fluvial channel sandstone and development became more precise. Map courtesy of J. Weissenberger, Husky Energy.

experiment might tell us *how* something formed. If we do a facies analysis we describe *what* the rocks consist of, but then we want to know what they mean: the *how* and the *why*. Geology can be quite numerical, and occasionally it lends itself to mathematical modelling. A model is a simplification of a complex system and cannot be taken as fact or proof, but it may help support interpretation of *how* and *why* based on observation and experiment.

After a few years working in the Calgary oil patch I decided to embark on PhD studies on paleontology in order to round out my grasp of geology, which had hitherto been mainly sedimentological. I discovered that fossils capture well the essence of geological thinking, and far from being a stale exercise in stamp collecting, there is a wealth of questions to ask. After all, life is the only creative force in the Universe, and fossils represent 3.5 billion years of that creativity, and thus they are the

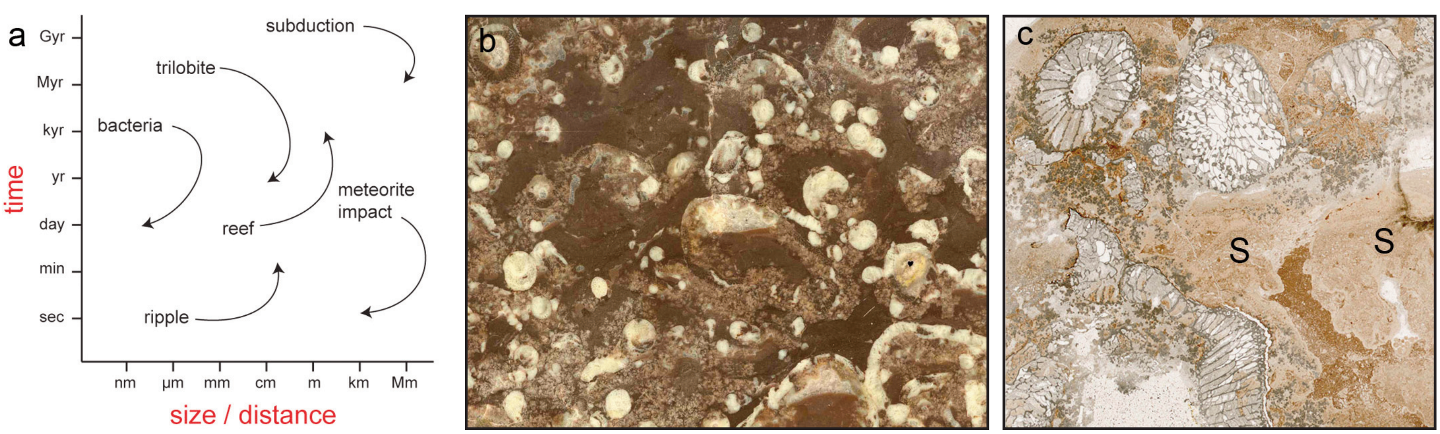


Figure 3. (a) Graph of temporal (y-axis) versus spatial (x-axis) scales as a framework for geological phenomena, such as meteorite impacts, formation of ripples, growth of bacteria and fossils, reef accretion, and the development of a subduction zone. (b) Polished slab of lower Cambrian reef rock (Forteau Formation, southern Labrador). Archaeocyathan sponges are the white domes and sticks; the calcimicrobe *Renalcis* forms pinkish masses that bind the archaeocyaths together. The matrix is red lime mudstone. Field of view is 15 cm wide. (c) Thin section photomicrograph of the same reef rock. The archaeocyaths are intricate skeletons, whereas *Renalcis* appears as dark-grey clusters. The matrix turns out to be mostly microbial here, i.e. weakly laminated stromatolites (S). Field of view is 2.5 cm wide. We can imagine these framebuilding elements formed in a matter of a decade or so and the overall reef might have taken tens of thousands of years to accrete — perhaps faster than usually thought.

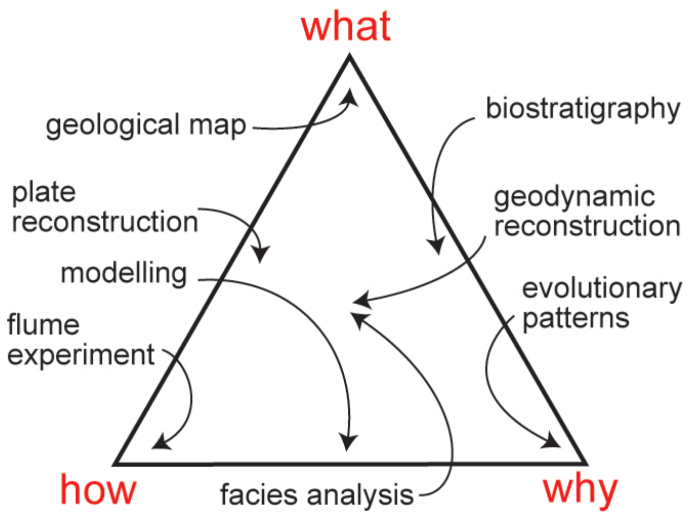


Figure 4. Geological subject matter in the context of an 'interrogative trinity' expressed as a ternary diagram. The geologist inherently knows the domains occupied by the various activities. For example, a geological map aims to be a purely factual rendition, whereas creating sedimentary structures in a flume is determining how they formed. Reconstructing the positions of ancient continental plates is an attempt to identify what they are and then account for how they got to there. Modelling is more a combination of trying to understand certain phenomena and why they took place. Study of fossils might be combinations of asking what and why, depending on what one wants out of the fossils. Efforts like facies analysis and understanding an orogenic belt occupy the central domain because they incorporate all three questions.

evidence for biological evolution. You have to understand the rocks that contain them and their stratigraphic relationships. Fossils tell you the time. You learn something about depositional processes because they were sedimentary particles. As they were once living things you can deduce their paleobiology. Traces in the sediment give clues to locomotion and feeding behaviour, and if you find coprolites you know something about nutrition and digestion. Fossils were part of communities and there is a paleoecological story to tell. You try to figure out which fossils were predators and which were prey, which were herbivores and which grubbed around the sediment or benignly filtered food from the water. Depending on the circumstances, there is much room for bold ideas. Two decades ago we realized that we had phosphatized embryos in acid-resistant residues from a Cambrian limestone: a taphonomic miracle if there ever was one, and now we know something about early development. (Initially we speculated they were trilobite embryos, but now we know they belonged to a kind of worm.) There is more: using synchrotron X-ray fluorescence we found geochemical evidence in a Burgess Shale arthropod for Cu-bearing blood called hemocyanin — the circulatory system! While this may seem the epitome of curiosity-driven research – and of course we may be wrong – shale geochemistry has important practical applications.

Doing geology is like having fun solving a puzzle. Virtually every rock sample presents more questions than answers. One of the things I like to tell students or visitors is that they may be holding something in their hand that despite years of study we simply can't explain. My favourite is the striking fossil *Receptaculites*, which is common in Tyndall Stone, Canada's most famous dimension stone (Fig. 5a). This fossil has been all over the taxonomic map, from sponges to algae to pine cones. It's still a mystery. Another puzzle is the bizarre crumpled calcite vein arrays called 'molar-tooth structure,' first observed in Precambrian limestone along the border between Alberta and Montana and so named in 1885 because of its resemblance on bedding planes to the surface of elephant molars. Then it lay dormant for a century, ignored by geologists and absent from textbooks. I first laid eyes on molar-tooth structure while hiking there in 1976. What on earth is this? Nobody knew. The Eureka! moment for me came one evening 15 years later: these veins formed by lime mud fluidization and injection during earthquake-induced shaking of the sea floor. Hundreds of

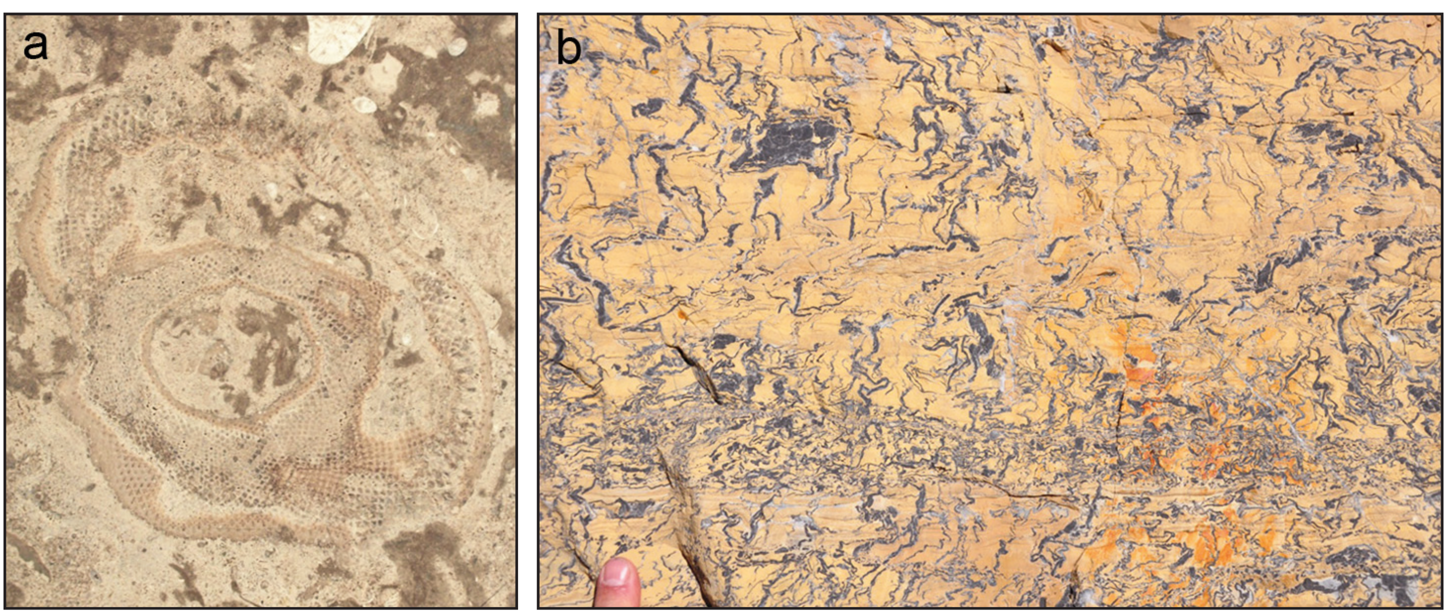
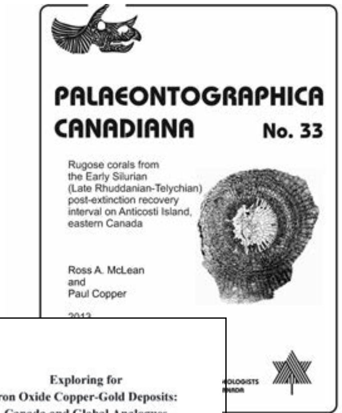


Figure 5. Doing geology can be like solving a puzzle. (a) Polished Tyndall Stone cut parallel to bedding, showing *Receptaculites* fossil [more correctly *Fisherites reticulatus* (Owen 1844)]. This is part of the memorial wall in the Geology Building, University of Saskatchewan. The stone belongs to the Selkirk Member of the Red River Formation (Upper Ordovician), southern Manitoba. Field of view is 27 cm wide. (b) View perpendicular to bedding of the Mesoproterozoic Siyeh Formation (= Helena Formation in Montana) showing dolomitic lime mudstone cut by folded calcite-filled veins. These veins are 'seismites.' This is part of an ornamental block at a viewpoint on Highway 6 just north of the entrance to Waterton Lakes National Park, Alberta. Finger is 18 mm wide.

Figure 6. Important advice in Yosemite National Park, California.

samples and thin sections later: QED. Molar-tooth structure turns out to be a stratigraphic seismograph! Like so much in geology, a seemingly small thing can have big implications in the narrative.

Doing geology is storytelling. Everyone loves a good story. So let's celebrate geology and brag about it — while we follow our passion and keep on having fun! Figure 6 points the way.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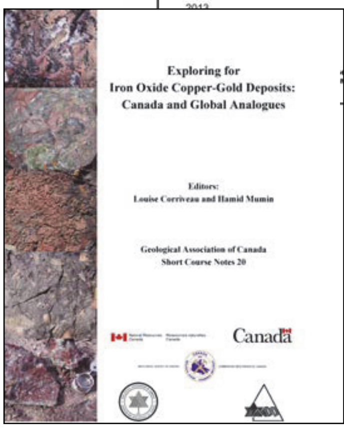
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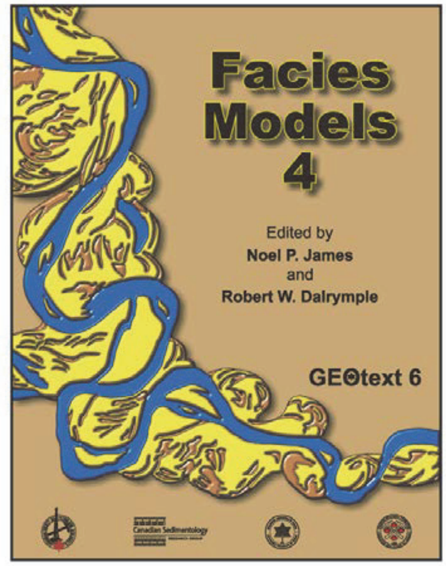
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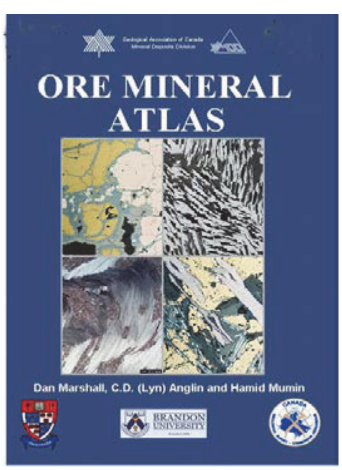
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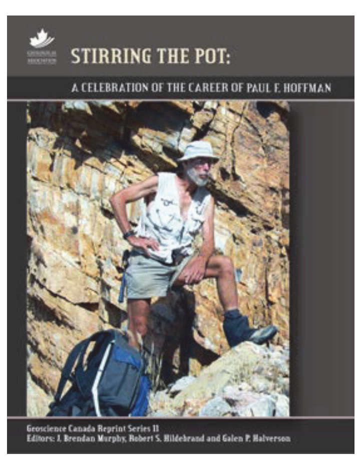
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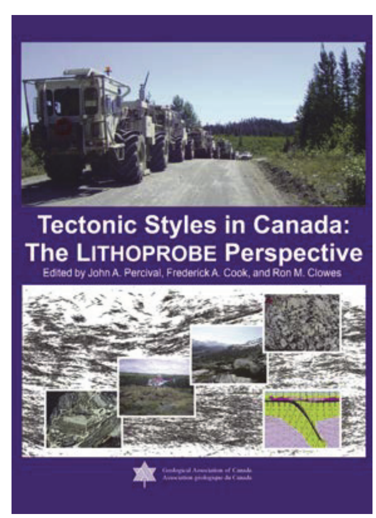
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