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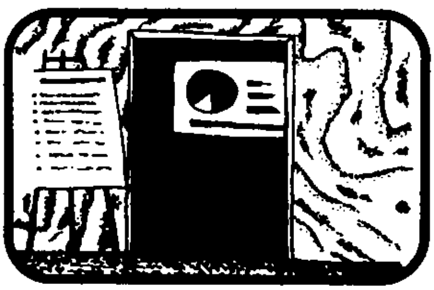
Conference Report



New Mineral Deposit Models of the Cordillera

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A two day short course on "New Mineral Deposit Models of the Cordillera" was presented first in Vancouver prior to the 1996 Cordilleran Roundup and then in December of the same year in Spokane in conjunction with the Northwest Mining Association meeting. The objective was to provide industry participants with new ideas and models to assist them with exploration. A spectrum of ore deposit models was discussed, from deposit types with proven economic potential to styles of mineralization that remain to be evaluated. Both sessions were well attended by geologists from Canada and the United States. The first course was organized by the British Columbia Geological Survey (BCGS) in collaboration with the Mineral Deposit Research Unit (MDRU) of The University of British Columbia and the Geological Survey of Canada (GSC), while the second was a joint venture between the BCGS and the Northwest Mining Association. Most speakers participated in both workshops.

SHORT COURSE NOTES AND ABSTRACTS

The Northwest Mining Association is selling the notes for the second short course for $85 US plus $12.50 handling charges.
Northwest Mining Association
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E-mail: nwma@on-ramp.ior.com

The abstracts for the first short course in Vancouver are posted on the BCGS's web site:
http://natural.gov.bc.ca/geosmin/metalmin/depmodel/rdup-abs.htm

INTRODUCTION

The short course began with a presentation by Michael Etheridge of Etheridge, Henley and Williams on **"Making Models Matter."** He pointed out that exploration geologists increasingly are being asked by non-technical people to explain what they do, why they do it that way, and how to measure program effectiveness. The answers often involve deposit models because even the most "pragmatic" of explorers use them to help justify their decisions and to argue that their approach is effective (*i.e.*, lower risk). The principal deficiency in many models is that they do not incorporate an understanding of the critical geological process responsible for forming a deposit. For example, the critical process in forming a porphyry copper deposit may well be the dilatant deformation that gave rise to the stockwork vein system, rather than the petrogenesis of the intrusive host rock, or even the associated alteration. Effective exploration models should maintain relevance by continual modification, and be presentable in map form to focus effort on the most favorable areas.

> *"Even the most 'pragmatic' of explorers use models to help justify their decisions."*

David Lefebure (BCGS) discussed **British Columbia deposit profiles** that are being developed for Cordilleran-type settings. More than 140 metal, coal and industrial mineral deposit models are relevant to British Columbia. The deposit profiles are two- to five-page descriptions used to classify known deposits and occurrences, to estimate undiscovered mineral resources, and to group deposits to allow compilation of representative grade and tonnage data.

GOLD SKARNS AND CARLIN DEPOSITS

During a comprehensive review of **gold skarns**, Gerry Ray of the BCGS highlighted the need to assay all mineral assemblages in skarns because micron-sized gold may be associated with barren sulphides or even sulphide-poor assemblages. Most gold skarns have low metal ratios (Cu/Au <2000; Cu/Ag <1000; Zn/Au <100, Ag/Au <1) compared to other types of skarns. The oxidation state of the hydrothermal fluids and the oxidizing or reducing capacity of the hostrocks influences the skarn mineralogy and metal chemistry. "Reduced" gold skarns are marked by low garnet/pyroxene and pyrite/pyrrhotite ratios and the presence of hedenbergitic pyroxene and Fe-rich biotite. Associated intrusions have low Fe_2O_3/FeO ratios and the ore bodies are developed distal to plutons, in the outer parts of pyroxene-rich exoskarn envelopes (Fig. 1). Examples include Nickel Plate (BC), Fortitude (Nevada) and Buckhorn Mountain (Washington State). Oxidized gold skarns are characterized by

> *"New ore in Carlin trend has come largely from the discovery of high-grade (>6 $g \cdot t^{-1}$) refractory deposits."*

high garnet/pyroxene and pyrite/pyrrhotite ratios, and by the presence of diopsidic pyroxene, pyrite, magnetite and hematite. Ore bodies tend to form proximal to intrusions. Examples include Nambija (Ecuador) and McCoy (Nevada).

Newmont Exploration Limited geologists David Groves and Mac Jackson provided updates on the **Carlin trend**, a 60-kilometre long belt of sedimentary-hosted gold deposits in Nevada with a total current resource of 3100 tonnes of gold. Near-surface oxidation has rendered many of the deposits amenable to bulk tonnage mining and heap-leach processing, which has led to the mistaken impression that all deposits in this class are large tonnage and low grade. In recent years new ore has come largely from the discovery of high-grade (>6 $g \cdot t^{-1}$) refractory deposits. The Hardie Footwall deposit is a stratigraphically controlled, downdip extension of the original Carlin oxide-gold deposit. The deposit contains a drill-indicated, geologic resource of 1,315,000 tonnes grading 16 $g \cdot t^{-1}$ Au. The West Leeville deposit is another stratigraphically controlled deposit located 2 km north of the Carlin mine with drill-indicated reserves of 5.4 million tonnes grading 14.7 $g \cdot t^{-1}$Au. As well, there are breccia bodies, such as Deep Star, Deep Post and Purple Vein, that are located close to the Goldstrike intrusion at the northern end of the Carlin trend. Deep Star has a drill-indicated, geologic resource of 797,000 tonnes at a grade of 32 $g \cdot t^{-1}$ Au. The deposit is located between steeply dipping strands of the Genesis fault zone at depths of 350 m to 500 m and, in plan, measures only 75 m by 100 m. These new deposits show significant variations from the original "Carlin-type" model, which exploration geologists should keep in mind.

The potential to find **Carlin-type deposits in Canada** was addressed by Howard Poulsen (GSC, Ottawa). He noted that the geological and genetic models for Carlin-type deposits (Fig. 2) continue to evolve, in part because for many of the deposits the primary features of hypogene ores are obscured by oxidation. The hypogene aspects of these deposits are the most relevant to Canadian exploration. Western Canada is one area that has exploration potential because of some of the obvious geological similarities with central Nevada. For example, the Paleozoic stratigraphy of the Roberts Mountains Allochthon of Nevada is correlative with that of the Kootenay Arc and Selwyn Basin in Canada, and that of the Golconda Allochthon is correlative with Slide Mountain rocks. Important metallogenetic similarities to the Carlin trend are the presence of sedex barite deposits (Selwyn Basin) and of vein and manto-type Ag–Pb–Zn mineralization (East Kootenay, Cassiar, Keno Hill).

Odin Christensen of Newmont Exploration Ltd. reviewed examples of **Carlin-type deposits from the western Pacific region**, including the Mesel deposit, Indonesia, deposits in southwestern China, and the Bau District in Malaysia. The Mesel and Bau deposits are located in sedimentary sequences within volcanic arcs, clearly a different environment than Nevada. At Mesel, the gold mineralization is hosted by a Middle Miocene limestone immediately beneath and adjacent to an andesitic intrusion. The mineralization, limestone and intrusion all formed between 13-11 Ma. Mesel has mineable reserves of 8.77 million tonnes at an average grade of 7.10 $g \cdot t^{-1}$ Au. The Chinese deposits include Banqi, Getang, Lannigou and others hosted by Permian to Triassic rocks. There are no known igneous rocks in the districts. Orebodies occur as stratabound deposits within carbonates, along faults, and along contacts between carbonate and siliciclastic units.

INTRUSION-RELATED GOLD

Jacob Margolis of Home-stake Mining Company reviewed the gold and copper deposits of the northern **Sulphurets district**, located 60 km northwest of Stewart, British Columbia. These deposits span a spectrum from porphyry to epithermal environments. During the emplacement of the initial porphyry Cu–Au mineralization, quartz stockworks with chalcopyrite containing electrum, such as the Mitchell deposit (~200 million tonnes grading 0.2% Cu and 0.857 $g \cdot t^{-1}$ Au), developed at higher levels within the volcanic and intrusive rocks. An initial stage of phyllic alteration

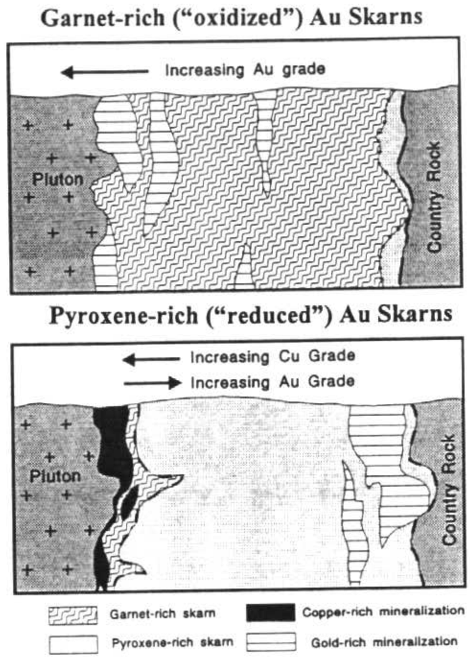

Figure 1 *Schematic sections comparing the main features of "oxidized" and "reduced" gold skarns (from Gerry Ray).*

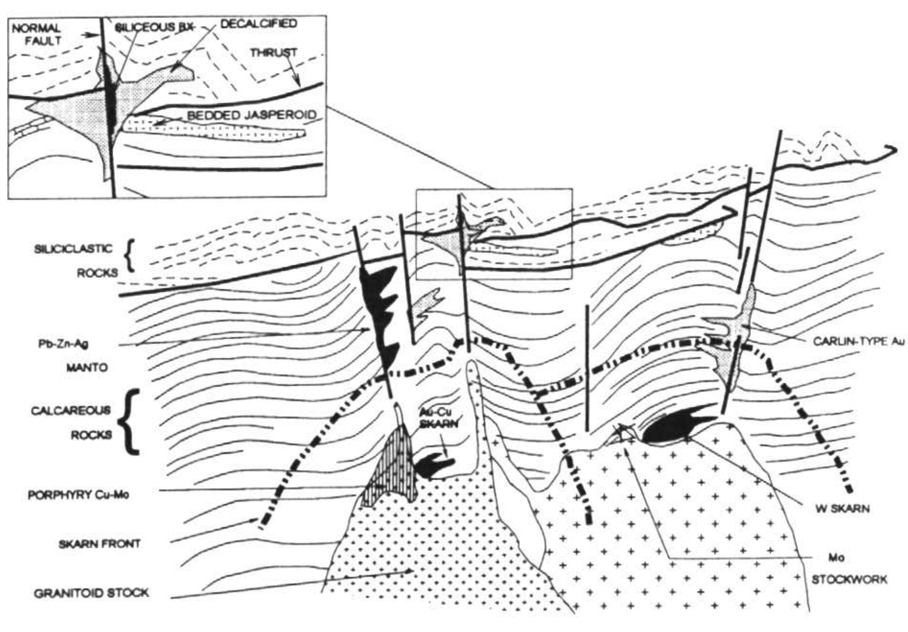

Figure 2 *Occurrence model for Carlin-type deposits (from Howard Poulsen). Adapted from Sillitoe and Bonham (1990,* Geology, *v. 18, p. 157-161), and Berger and Bagby (1991, in Foster, R.P., ed.,* Gold Metallogeny and Exploration: *Blackie, Glasgow and London, UK, p. 210-248).*

hosting quartz–molybdenite veins was followed by argillic alteration and a final stage of precious metal-rich epithermal systems developed in the volcanic rocks. These epithermal systems consist of quartz–barite veins containing galena–sphalerite–tetrahedrite–pyrargyrite–gold–acanthite (West Zone) and a low-grade, disseminated auriferous pyrite zone (Snowfield deposit, >8 million tonnes grading 2.7 g·t⁻¹ Au). Margolis concluded by pointing out that porphyry molybdenum systems can have associated gold mineralization and that calc–alkaline intrusives are as prospective for the yellow metal as alkaline suites.

"Porphyry molybdenum systems can have associated gold."

Dani Alldrick and Trgyve Höy (BCGS) described a newly differentiated deposit type, **intrusion-related gold-bearing pyrrhotite veins**. The veins are commonly emplaced in en echelon fracture sets around the periphery of subvolcanic plutons in a transitional setting between porphyry and epithermal systems (Fig. 3). These veins are composed of massive fine-grained pyrrhotite and pyrite and/or massive bull quartz with minor calcite. They are attractive exploration targets because of their high grades, continuity due to strong structural controls, and predictable relationships to intrusions and genetically related deposits. Examples include the Scottie Gold, Snip, Johnny Mountain, Le Roi, War Eagle and Centre Star mines in British Columbia and some of the main veins (Copper Rand, Portage, Merrill, Main and Chib-Kayrand mines) in the Chibougamau Camp, Quebec. The Snip and Johnny Mountain deposits were described in a presentation by David Rhys, consulting geologist. High-grade gold–silver mineralization occurs in thick, semi-tabular pyrite+pyrrhotite stockworks with intense sericitic alteration.

Rhys also described the **Red Mountain** precious metal deposit, located 15 kilometres east of Stewart, British Columbia, which occurs within several zones within a folded sequence of Mesozoic sedimentary rocks, volcaniclastic and intrusive rocks. Several shallow-dipping alteration zones are developed sequentially above a propylitic zone with a quartz stockwork carrying molybdenum. These include sericite–quartz–pyrite alteration, chlorite–K–feldspar–sericite–titanite alteration with disseminated and vein pyrrhotite and brown to black tourmaline veins and K–feldspar–pyrite–titanite–actinolite alteration. Anomalous gold (>0.3 g·t⁻¹) mineralization is developed at the transition from pyrite to pyrrhotite dominant alteration over a >1 km² area. Within this anomalous zone, high-grade gold–silver mineralization (3-20 g·t⁻¹ Au) occurs in 5-29 m thick, semi-tabular pyrite+pyrrhotite stockworks (1992 resource of 2.5 million tonnes grading 12.8 g·t⁻¹ Au and 38.1 g·t⁻¹ Ag) with intense sericitic alteration and surrounding disseminated sphalerite+pyrrhotite. The alteration zoning, molybdenum–copper quartz stockworks, extensive K–silicate and tourmaline alteration, and the relationship with a hypabyssal porphyritic intrusion show similarities to many porphyry systems.

"High-grade gold–silver mineralization occurs in thick, semi-tabular pyrite±pyrrhotite stockworks with intense sericitic alteration."

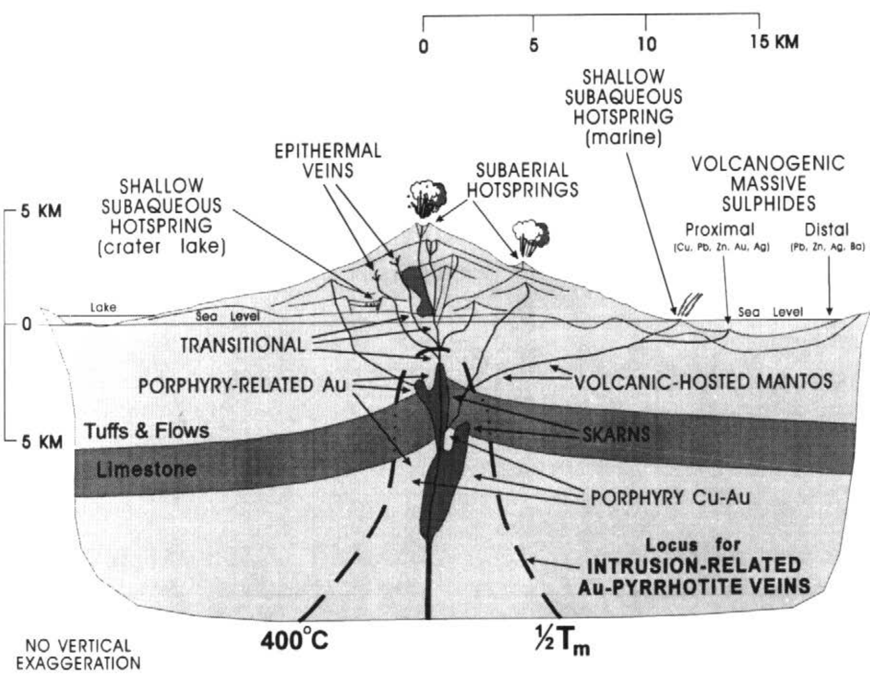

Figure 3 *Island arc model for intrusion-related gold-bearing pyrrhotite veins (from Dani Alldrick and Trygve Höy).*

FORT KNOX-TYPE GOLD MINERALIZATION

Jim Mortensen of The University of British Columbia described the host **Tombstone Plutonic Suite**, a lithologically diverse belt of mid-Cretaceous plutons that intrude miogeoclinal strata. The belt has been offset along the Tintina Fault and extends west to the Fairbanks mining district in Alaska. Mineralization spatially associated with Tombstone Plutonic Suite ranges from intrusion-hosted porphyry Au-(Bi-W-Mo) deposits (*e.g.,* Fort Knox, Dublin Gulch, Emerald Lake, Pukelman), to intrusion- and wallrock-hosted Au-bearing quartz-arsenopyrite veins and breccias (*e.g.,* Ryan Lode, Dublin Gulch), to proximal W-(Au) skarns (*e.g.,* Mar/Ray Gulch, Scheelite Dome, Rhosgobel, Tungsten Hill), to distal (?) Au- and/or Sb-rich replacement/manto deposits (*e.g.,* Scrafford, Wayne). Relatively late, lower-temperature, Ag- and base metal-rich veins locally both overprint the intrusion-centred systems (*e.g.,* Dublin Gulch) and occur distal to the intrusion (*e.g.,* Keno Hill, Peso, Rex, Wayne). Intrusion- and country rock-hosted, possibly Carlin-like, disseminated/stockwork Au–As–Sb mineralization is also developed in several areas (*e.g.,* Brewery Creek, Neve/Brick, True North).

The **Dublin Gulch deposit**, located near Mayo in the Yukon Territory, was discussed by Hans Smit of New Millenium Mining Limited. The deposit area is underlain by Late Proterozoic to Early Cambrian Hyland Group clastic rocks of the Selwyn Basin. These rocks have been deformed by Early Cretaceous thrusting and later regional scale gentle folding. Subsequent to this deformation, the clastic rocks were intruded by Cretaceous Tombstone Suite intrusions, including the Dublin Gulch stock. Fort Knox-type mineralization within the stock consists of sheeted, low-sulphide gold quartz veins with very limited wallrock alteration. Ore veins grade into veins possessing distinct sericite selvages, lower gold and bismuth contents, and minor arsenopyrite, pyrite and pyrrhotite. Gold occurs as native gold, associated with bismuth minerals or less commonly encapsulated in arsenopyrite. Individual veins are thin and grade in the range of 10-30 g·t⁻¹ Au. However, the ore zone, encompassing both the vein and granodiorite host material, typically grades between 0.8 to 2.0 g·t⁻¹. In 1995, drilling defined a mineable reserve of 36 million tonnes grading 0.92 g·t⁻¹ Au.

> *"Dublin Gulch ore typically grades between 0.8 to 2.0 g·t⁻¹ gold."*

OPHIOLITE-HOSTED MESOTHERMAL GOLD-QUARTZ VEINS

A tectonic model describing the origin of **mesothermal gold-quartz veins** associated with ophiolitic sequences was presented by Chris Ash (BCGS). He pointed out that the deposits are hosted within, or marginal to, collisional suture zones where large volumes of CO_2-rich fluids have been channeled to produce carbonate-altered ultramafic rocks or "listwanites." These veins appear to form during periods of metamorphism and partial melting due to tectonic crustal thickening in response to arc-continent collision. They are typically associated with late syn-collisional intermediate to felsic magmatism. Mineralizing hydrothermal fluids are interpreted to be derived, at least in part, from tectonically thickened, hydrated oceanic lithosphere that undergoes metamorphic dehydration and partial melting during and after faulting.

TRANSITIONS FROM PORPHYRY TO EPITHERMAL ENVIRONMENTS

Andre Panteleyev (BCGS) pointed out that porphyry and epithermal characteristics may blend in volcano-plutonic arcs with "telescoped" hydrothermal systems. This commonly occurs as an overprinting of earlier mineralization by lower temperature, more oxidized, advanced argillic alteration assemblages. The telescoping may be due to rapid erosion of volcanic edifices by tropical weathering or glacial erosion, swift degradation of hydrothermally damaged volcanic structures, or cataclysmic decompressional events such as gravitational sector collapse. Transitional mineralization is a closely related variant of high-sulphidation deposits as the hydrothermal fluids involved are derived from the same, or similar intrusions. The **transitional deposits** can have similar advanced argillic or acid sulphate alteration and mineralization (covellite and tennantite–tetrahedrite, enargite–luzonite), but these minerals are generally subordinate and restricted to late, localized acidic fluid flow. For transitional deposits, the dominant alteration is quartz–sericite–pyrite derived from relatively high temperature and pressure and highly saline solutions that are more akin to those that form porphyry deposits. Pyrite is the dominant sulphide mineral; chalcopyrite, tetrahedrite/tennantite are common; and enargite is rare or absent. The Kori Kollo mine, Bolivia and Equity Silver mine, British Columbia exemplify this deposit type.

OLYMPIC DAM-TYPE DEPOSITS

Olympic Dam-type iron oxide deposits form from volatile-rich igneous-hydrothermal systems. Olympic Dam-type iron oxide deposits currently attract exploration attention for their associated copper, gold, uranium and LREE. Murray Hitzman of the Colorado School of Mines pointed out they constitute a distinct class of ore deposits characterized by iron-rich, low-titanium rocks formed in extensional tectonic environments. They form primarily in cratonic or continental margin environments and are expressions of deeper-seated, volatile-rich igneous-hydrothermal systems, tapped by deep crustal structures. The majority of known deposits, particularly the larger examples, are found within Early to mid-Proterozoic host rocks (1.1-1.8 Ga). Most districts occur along major structural zones and many of the deposits are elongated parallel to local structural trends. The ores are generally dominated by iron oxides, either magnetite or hematite. The host rocks are generally intensely altered with a general trend from sodic alteration at deep levels, to potassic alteration at intermediate to shallow levels, to sericitic alteration and silicification at very shallow levels. Locally, the host rocks are intensely Fe-metasomatized. Individual deposits occur both as strongly discordant veins or breccias and massive concordant bodies. Current exploration interest is focussed on copper- and gold-bearing occurrences in Australia and the Yukon.

> *"Olympic Dam-type iron oxide deposits form from volatile-rich igneous-hydrothermal systems."*

Michael Etheridge provided a description of an Olympic Dam-type deposit, the **Ernest Henry** that is located within early Proterozoic rocks of the eastern Mount Isa Inlier, Australia. The deposit contains 167 million tonnes at 1.1% Cu and 0.54 g·t⁻¹ Au. Osborne (~15 million tonnes at 3.0% Cu+1.3 g·t⁻¹ Au), Selwyn (~5 million tonnes at 1.0% Cu+5.0 g·t⁻¹ Au), Eloise (~3 million tonnes at 5.8% Cu+1.5 g·t⁻¹ Au), and Elliot (~2 million tonnes at 3.0% Cu and 1.3 g·t⁻¹ Au) are other deposits that are being mined in the region. Most of the deposits are associated with "ironstones" and coincide with moderate-to-large amplitude magnetic anomalies. Etheridge pointed out that the key factors in developing exploration models for this type of deposit are the granitoid and structural associations. A genetic link between the Cu–Au deposits and the I-type granitoids (dominantly granodiorite) of the Williams Batholith is well established. As well, strong structural control is evident in most deposits of this type. The most common structural association is with dilational breccias on ductile to brittle shear/fault zones of a range of orientations.

SEDIMENT-HOSTED DEPOSITS

Sediment-hosted stratiform copper deposits include some of the richest and largest copper deposits in the world. Rod Kirkham (GSC, Vancouver) explained that they are also an important source of silver and cobalt. Most sediment-hosted stratiform copper deposits form during diagenesis of sediments deposited in low-latitude arid and semi-arid areas. A variety of processes are involved in different districts, but metals are characteristically deposited at redox boundaries where oxic, evaporite-derived brines containing metals extracted from redbed aquifers encounter reducing conditions. The reducing environments are either those with stratigraphically controlled fixed reductants (Kupferschiefer) or those with mobile reductants, such as H_2S-bearing waters and hydrocarbons (Dzhezkazgan). Occurrences are known in Proterozoic sequences (*e.g.*, Grinnell Formation, Montana and Redstone River area, Mackenzie mountains) in the eastern Cordillera. Possible occurrences also are found in Triassic and Early Jurassic sequences in the western Cordillera. Kirkham pointed out that these occurrences offer signifi-

> *"Sediment-hosted stratiform copper deposits include some of the richest and largest copper deposits."*

cant exploration potential in British Columbia and the Yukon.

The alteration, and its relationship to host lithologies of **sedex Pb–Zn deposits** was described by Bob Turner (GSC, Vancouver). Deposits in siliceous rocks tend to have poorly developed alteration zones; silicification is dominant and ferroan carbonate alteration (Fig. 4) can be important (*e.g.*, Tom-Jason, Yukon; Cirque and Driftpile, BC). Calcareous sediment-hosted deposits tend to have more extensive alteration which includes silicification, dolomite or ferroan carbonate alteration (*e.g.*, Sheep Creek, Montana; Isa and Century, Australia). Feldspathic sediment-hosted deposits display the best developed alteration zones and most diverse alteration assemblages. These include potassic (muscovite, k-spar), tourmalinite, chloritic and albitic assemblages (*e.g.*, Sullivan, BC; Broken Hill and Cannington, Australia; Zincgruven, Sweden). These alteration assemblages are similar to alteration associated with feldspathic sediment-hosted Besshi deposits and modern sedimented rift-hosted deposits. Since host lithologies reflect tectonic controls on the sedimentation, the style of alteration typically varies between the syn-rift and rift sag phases. Syn-rift stratiform deposits occur in feldspathic clastic rocks associated with high heat flow and magmatism (*e.g.*, Sullivan, Broken Hill, Cannington, Aggenays–Gamsberg), while rift-sag stratiform deposits typically occur in siliceous or calcareous strata and are associated with lower heat flow extensional basins (*e.g.*, Mt. Isa, Hilton, Century, McArthur River, Tom-Jason, Cirque, Rammelsberg, Meggen).

Wayne Goodfellow (GSC, Ottawa) described unusual **Ni–Mo–PGE sulphide occurrences**, stratiform mineralization hosted by carbonaceous shale and chert within Phanerozoic sedimentary basins. The two most important districts occur in Middle Devonian and earliest Cambrian basinal facies in the Yukon and southern China, respectively. The deposits are typically thin (<20 cm) but extend over distances of hundreds of kilometres. The sulphides consist of combinations of pyrite, marcasite, vaesite, gersdorffite, millerite, sphalerite, wurtzite, molybdenite, chalcopyrite, and tennantite. These deposits have high metal grades, including up to 10% Ni, 2% Zn, 4% Mo, 50 g·t-1 Ag, and 0.7 g·t-1 Au, but no accumulations that are thick enough to mine in a free market economy have been found. Goodfellow advocated that this unusual mineral assemblage formed following the impact and volatilization of a major chondritic meteorite. This led to the raining of Ni–PGE-rich quenched droplets to the sea floor of an anoxic ocean. The association of Ni–PGE mineralization with high organic-matter contents and related carbonate concretions could reflect higher rates of organic matter sedimentation following a related mass extinction event. In Spokane, Raymond Coveney Jr. of the University of Missouri at Kansas City summarized some of the characteristics of the Chinese deposits (marine platform depositional setting, polymictic textures, fluid inclusions) that support a hydrothermal origin for these deposits. Certainly if economic deposits are to be found, a hydrothermal genesis seems more likely to produce thicker local accumulations.

> *"These deposits have high metal grades, including up to 10% Ni, 2% Zn, 4% Mo, 50 g·t-1 Ag and 0.7 g·t-1 Au, but no accumulations that are thick enough to mine in a free market economy have been found."*

Godfrey Walton of Hemlo Gold Mines Inc. discussed **Irish-style carbonate-hosted Pb–Zn deposits**. He pointed out that strong structural controls are documented in the deposits, mineralization is stratabound with some local sections that cross cut stratigraphy, and replacement and breccia mineralization textures are common. Isotopes indicate two fluids were involved in the process, one hydrothermal and the other Carboniferous sea water. Walton argued that the deposits formed primarily below the sea floor and are diagenetic to epigenetic in origin. There is evidence that an early portion of the min-

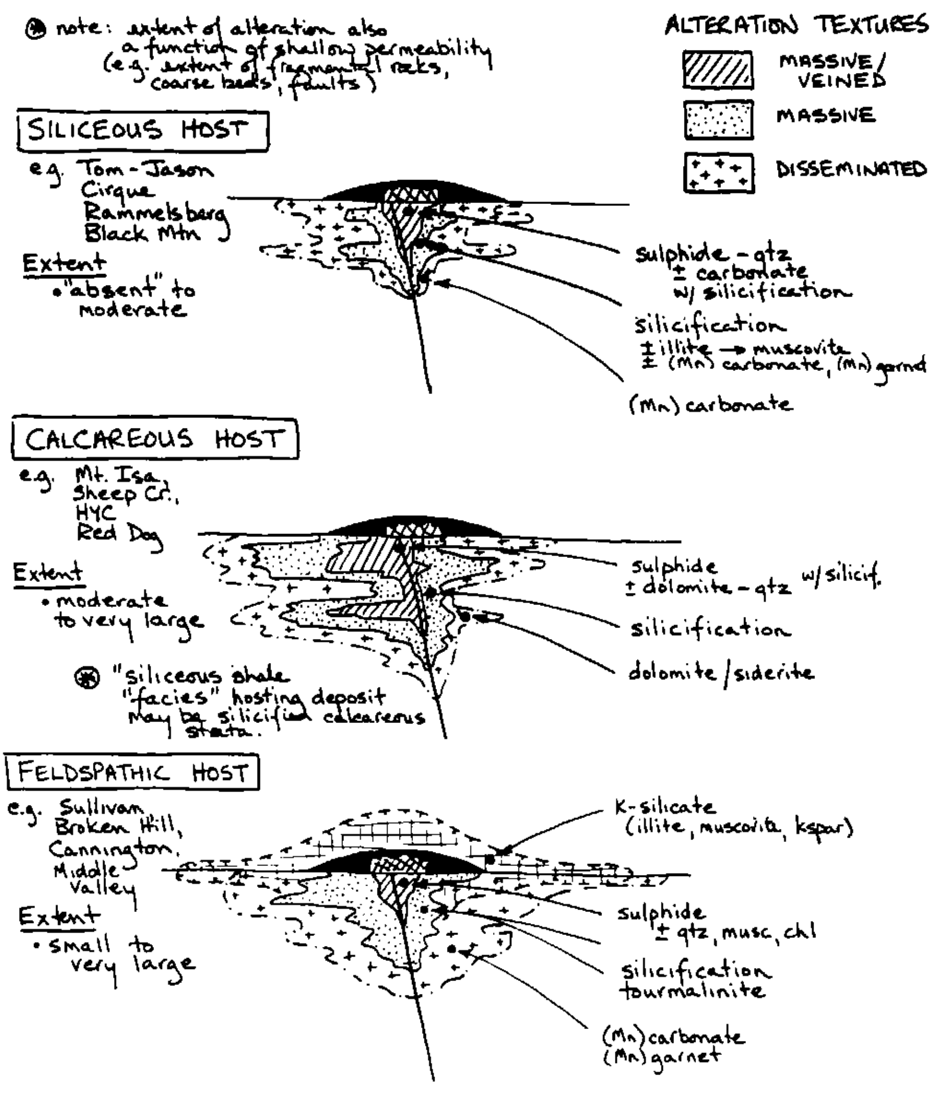

Figure 4 *Alteration styles associated with sedex deposits and their relationship to host lithologies (from Bob Turner).*

eralization formed on the sea floor, while the bulk of the mineralization is later. Therefore, Irish deposits have some characteristics in common with both sedex and MVT deposit types. He closed by endorsing the Cordillera as a prospective region to explore for Irish-type carbonate-hosted Pb–Zn deposits.

Hugh Abercrombie (GSC, Calgary) spoke about the discovery of **microscopic disseminated Au–Ag–Cu** (Prairie-type gold) in basement and sedimentary rocks of the Western Canada Sedimentary Basin. These recently recognized occurrences consist of low-temperature, native and intergrown or alloyed Au–Ag–Cu and associated alteration, including native S and pyrite. The metals and alteration are inferred to be related to metal transport in oxygenated brines originating in halite evaporites. Downward, density-driven flow of these brines into red bed-evaporite sequences and fractured Precambrian basement, followed by updip migration and eventual discharge at the eastern margin of the basin provides the mechanism for mobilization and transport of metals. Microbially mediated redox reactions involving coupled oxidation of organic material and hydrocarbons and reduction of sulphate has produced widespread occurrences of native sulphur and may have localized deposition of gold and other metals by controlling redox conditions. Although no economic grades have been reported, these occurrences could ultimately lead to the identification of a new deposit type.

George Simandl of the BCGS described a number of strata-bound, sparry magnesite deposits hosted by sedimentary rocks of Precambrian to Cambrian age from southeastern British Columbia, including the Mount Brussilof mine. The mineralogy is primarily sparry, pinolitic and zebra-textured magnesite with quartz/chert and dolomite impurities. These deposits form either by replacement of dolomitized, permeable carbonates due to interaction with a metasomatic fluid, or by diagenetic recrystallization of a magnesia-rich protolith of chemical, possibly evaporitic, origin.

SHALLOW SUBMARINE VOLCANOGENIC DEPOSITS

Mark Hannington (GSC, Ottawa) reviewed modern, **shallow submarine hot springs** and their similarities with older volcanogenic gold deposits. Pacific island arc volcanoes host extensive hot spring and fumarolic activity and locally have produced large porphyry copper and epithermal gold deposits (*e.g.*, 40 million ounces gold deposit at Lihir). Within these arcs the submarine volcanoes forming at water depths of less than 1500 m also host mineralization, including gold-rich polymetallic massive sulfides, gold–barite deposits, epithermal vein- and disseminated-stockwork mineralization, and pyritiferous muds and pyrite replacement deposits in volcaniclastic sediments. These occurrences constitute a new type of submarine mineral deposit that resembles deep-sea metalliferous deposits but also has distinctive epithermal characteristics. These deposits occur in a volcano-tectonic setting that is relatively under-explored in older volcanic sequences, although the Eskay Creek and Selbaie mines have highlighted the potential.

> *"A new type of mineral deposit that resembles deep-sea metalliferous deposits but also has distinctive epithermal characteristics."*

Tina Roth of Homestake Canada Ltd. described the high-grade **Eskay Creek deposit** located in northwest British Columbia. The bulk of the sulphide and sulphosalt ore is hosted in the stratiform 21B zone. Production commenced in January 1995 with a proven and probable mining reserve of 1.08 million tonnes grading 65.5 g·t^{-1} Au and 2 931 g·t^{-1} Ag. The 21B zone exhibits many characteristics analogous to Kuroko-type volcanogenic massive sulphide (VMS) deposits, but has a suite of elements and high precious metal content more characteristic of epithermal systems.

John Thompson (MDRU) discussed **high-sulphidation VMS deposits** that formed from hydrothermal systems dominated by magmatic water that were active in submarine settings (Fig. 5). High-sulphidation VMS deposits contain abundant pyrite and several of the following: enargite, chalcocite (hypogene), covellite, bornite, tennantite and tetrahedrite. Alteration associated with high-sulphidation VMS deposits is characterized by the presence of quartz and alunite with important barite, sulphur, kaolinite, pyrophyllite and diaspore. These mineralogical characteristics are similar to epithermal high-sulphidation deposits; however, the sea-floor setting for the VMS type influences the geometry of the deposits, the outer and upper alteration mineralogy (reflecting the involvement of seawater), and the stratigraphic control on deposits. The gold-rich polymetallic massive sulphides on the Palinuro seamount and gold-rich barite–silica–sulphide precipitates at the Hine Hina hydrothermal field in the Lau Basin are two possible modern examples. Older Phanerozoic examples occur in the Green Tuff belt of Japan, on Wetar Island

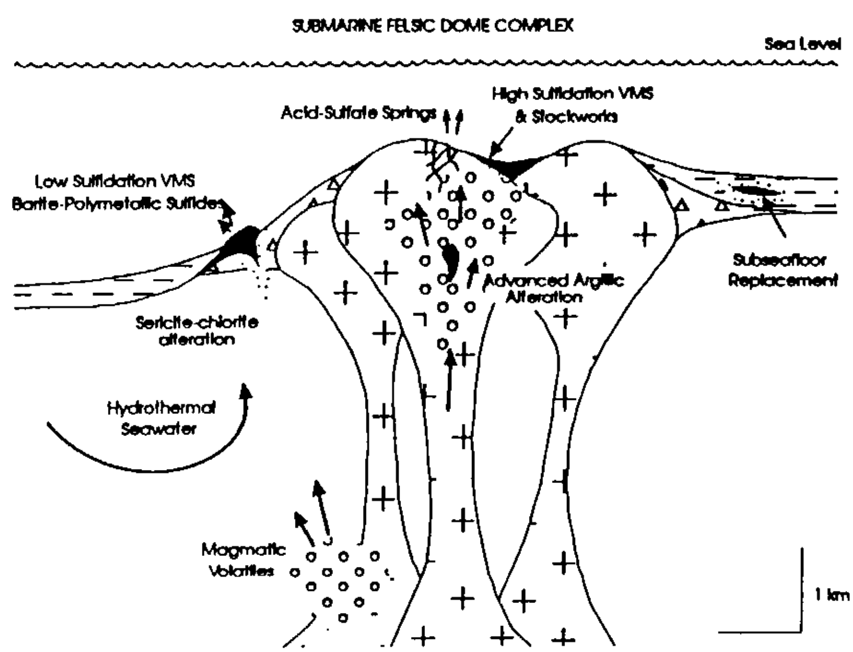

Figure 5 *Schematic section of a high-sulphidation VMS environment in relation to a felsic dome complex, from John Thompson's presentation. Now published in Sillitoe, R.H., Hannington, M.D. and Thompson, J.F.H.,* Economic Geology, *1996, v. 91, p. 204-212.*

in Indonesia, and in the Pontid belt of northeastern Turkey. Precambrian high-sulphidation VMS deposits may also exist, although deformation and metamorphism hinder the interpretation of their mineralogy and geometry.

Mike Rasmussen of Echo Bay Minerals Company described the **Lamefoot gold mine** located in the Republic Graben of northeastern Washington. The crudely stratiform, magnetite–pyrite–chalcopyrite-pyrrhotite ore body occurs at a major turbidite/limestone contact, immediately above felsic tuffaceous sediments, within the Permian Attwood Formation. The magnetite occurs with variably banded assemblages of magnetite and ferruginous quartz and siderite. The massive sulphides occur mostly at the northern end of the deposit and are volumetrically minor. Gold is also recovered from sulphide-quartz veinlets in the volcaniclastic footwall and a quartz breccia with a matrix of dark silica, calcite, chlorite and sulphides at the base of the magnetite-sulphide lens. The magnetite-sulphide lens is similar to some Besshi-type VMS deposits and also exhibits some replacement textures that might be similar to the Tynagh deposit in Ireland. Rasmussen suggested the veinlets and breccia are related to a younger mesothermal vein event (Jurassic?).

WRANGELLIA: A POTENTIALLY IMPORTANT NI–CU–PGE METALLOGENIC TERRANE

Larry Hulbert (GSC, Ottawa) described Triassic mafic-ultramafic intrusive complexes on the eastern margin of Wrangellia that can be traced along strike for at least 600 km from east-central Alaska to northwestern British Columbia. These sill-like intrusive centres acted as subvolcanic magma chambers that fed the thick oceanic plateau basalts of the Nikolai Group. The intrusions host numerous **Ni–Cu–PGE** occurrences and the Wellgreen mine. Although the parental magmas that gave rise to these intrusive and extrusive rocks are clearly of a tholeiitic origin, the intrusive complexes have striking similarities to Archean and Proterozoic komatiitic ultra-mafic bodies that host world-class nickel sulphide deposits.

CONCLUDING REMARKS

Both workshops attracted large audiences of industry geologists who were looking for updates on deposit models to apply in their exploration programs. Collectively, the presentations emphasized the important fact that mines continue to be found in new geological or geographic settings. Another short course titled "**Metallogeny of Volcanic Arcs**" is being organized by the BCGS and will be held in Vancouver in conjunction with the 1998 Cordilleran Roundup and Pathways '98. For more information on mineral deposit models, readers may wish to consult some of the references listed below.

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