New Mineral Deposit Models for the Cordillera

BCGS GeoFile 1996-01

GeoFile 1996-01 is a collection of abstracts for presentation at the 1996 Cordilleran Roundup short course. Each section is prepared by a different set of authors.

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Introduction

A – Making Models Matter

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The exploration business is, like all other businesses, subject to increasing accountability and the requirement for performance measurement and quality assurance. Increasingly, we are being asked by non-technical people to explain in plain language what we do, why we do it that way and how we can measure our effectiveness. Managers and investors require assurance that the exploration programs in which they have a direct interest are being carried out at least as effectively and efficiently as those of your competitors.

What do these issues have to do with the scientific process of exploration and, in particular, with the question of exploration models? Even the most "pragmatic" of explorers use geological models to justify their decisions as to exploration methodology and prospectivity, and to argue that their approach is more efficient/effective (i.e., lower risk) than others.

This paper examines the ways in which we develop and use exploration models. It is particularly concerned with the following questions:

1. Are the models that we use sufficiently specific and useable to be able to support the decision-making process in a practical way?

2. Can they provide real input into the evaluation of exploration risk and the analysis of the cost versus value of information?

3. Do the models enable geoscientific information to be linked in a practical way to an exploration methodology?

In our experience, many of the deposit or exploration models that are widely used by explorers and researchers fail to meet one or more of these criteria. The principal deficiency in such models is that they do not incorporate a sufficiently detailed and precise understanding of the critical geological process that were responsible for forming and localising the deposit. As a result, the models lack the essential predictive capability to become genuinely effective exploration tools. We will briefly examine some of the more widely used models for porphyry, epithermal, VHMS and sediment-hosted deposit styles to demonstrate these points.

The geological process factor that is most commonly overlooked or grossly generalized in hydrothermal deposit/exploration models is the hydrodynamics of the ore-forming system. We will analyse this factor in some detail to illustrate the value of being more disciplined in the development and application of models.

We will demonstrate that the hydrodynamics of most ore-forming systems are largely controlled by fault/shear systems that were active at the time of mineralization. We will also show that certain structures or parts of structures are likely to be more effective in localising fluid flow. These relationships between deposits and key segments of active structures require that models are specific in both spatial and temporal terms with respect to the potential localising structure(s). However, few deposit models include such information, and few exploration programs appear to include acquisition of such information as a priority. For example, the critical process informing a porphyry Cu deposit may well be the dilatant deformation that gives rise to the stock work vein system rather than the petrogenesis of the intrusive host rock or even the associated alteration. Yet how may porphyry models incorporate any explicit structural information?

How then do we "make models matter"? We recommend that deposit/exploration models be developed, applied and continuously revised according to the following principles:

1. The models should be based on a thorough understanding of the dominant geological processes involved in the formation of the deposit type being sought. The emphasis should be on process rather then just product. It is particularly important for hydrothermal deposits that the hydrodynamic and therefore structural controls are carefully specified.

2. The exploration team should develop/refine and 'own' the model(s) relevant to its needs and to the particular geological setting of the exploration area. Generic models taken 'off-the-shelf' are rarely suitable.

3. The models should be linked to the whole process of exploration, including the acquisition and assessment of information, a clear decision-making strategy, the development and implementation of risk-management procedures, and the formulation and budgeting of the exploration program. However, technical decision making should be kept separate from commercial decision making.

4. Models must be translated into map form that is relatable to the geology of the exploration area. Integrated geological, geophysical and geochemical databases can then be compared to the model maps to produce probability maps, enabling exploration dollars to be focused on the areas with the lowest technical risk.

5. Realistic geological process models for most deposit types are complex. They usually incorporate several physical and chemical processes with complex interdependencies. They should therefore incorporate at least some of the 'fuzzy' logic associated with chaotic processes.

In other words, we need to develop, apply and continuously revise our exploration models within the business framework, and not just see them as intellectual or 'academic' exercise that is somehow divorced from the 'real business' of exploration. We should be able to measure the effectiveness and efficiency of exploration programs against the models, and make sensible business decisions on the basis.

B - British Columbia Mineral Deposit Profiles

David V. Lefebure and staff, British Columbia Geological Survey

The British Columbia Geological Survey (BCGS) started a mineral potential assessment project in 1992 utilizing deposit models for defining and characterizing mineral deposits which exist, or could exist, in the province. The deposit models are 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. Initially, the Survey relied on mineral deposit models published by the United States Geological Survey (USGS) in Bulletin 1693 and Open File report 91-11A. As the project proceeded, the BCGS has updated many of these models and creating others. More than 140 deposit models are relevant to British Columbia. This selection of models represents a compromise between very specific classifications with limited variation within a group and very general models which encompass a number of deposit types. The BCGS classification system includes more than 50 deposit types not addressed by the USGS, many of them for industrial minerals. There are also models for a few deposit types that are applied in the Canadian Cordillera, which are not widely accepted elsewhere.

The model descriptions, called mineral deposit profiles, are being developed by BCGS staff in cooperation with experts from the Geological Survey of Canada, industry and universities. They describe deposit types which are found, or could be found, in British Columbia. Wherever possible, they incorporate both provincial and global deposit characteristics. The profiles include information on commodities, tectonic setting, depositional environment, geological setting, age of mineralization, associated rock types, deposit form, texture and structure, mineralogy, ore controls, genetic models, exploration guides, associated deposit types, general references and economic factors. For some of the profiles, the BCGS has generated probability curves based on grade and tonnage data from the province's mineral deposits and mines.

Industry experts have classified over 9,900 of British Columbia's mineral occurrences by BCGS deposit type. The most common deposits in the province are vein, porphyry and skarn deposits. This reflects mainly the abundance of island arc volcanic terranes, but also the levels of erosion of many of these terranes and the mineral industry exploration emphasis over the last century. The single most abundant deposit type is polymetallic silver-lead-zinc veins which comprise 25% of the known occurrences in the province. No other deposit type exceeds 5%; porphyry copper, alkalic porphyry, copper skarn, gold-bearing quartz veins and basaltic copper are the next most common.

The province presents numerous opportunities to pursue traditional base and precious metal and industrial mineral targets. As a complete set of profiles is developed for the province, the potential to find less well known types of orebodies will be better defined. For example, British Columbia is prospective for basaltic copper (volcanic redbed copper), closed basin zeolite, bentonite, sparry magnesite, Broken Hill-type lead-zinc, gold skarn and opal deposits. Furthermore there are several deposit types, which occur in equivalent geological settings, that are not clearly represented by any known deposits in the province, including sediment-hosted copper, iron oxide Cu-Au breccias, carbonate-hosted disseminated Au-Ag (Carlin-type), emeralds and diamonds.

In a few cases deposits within British Columbia have led to deposit models being proposed that are addressed adequately elsewhere. For example, in Mesozoic volcanic sequences throughout the province there is potential for subaqueous hot spring deposits such as Eskay Creek, intrusive-related gold-bearing pyrrhotite veins and alkalic porphyry deposits.

Gold Skarns and Carlin-type Deposits

C - The Characteristics of Gold Skarns

by G.E. Ray, British Columbia Geological Survey

Gold skarns are defined as skarn deposits in which gold is the primary or dominant economic metal present. The following features should be noted about these deposits:

1. They occur worldwide along destructive plate margins and tend to have a spatial and temporal association with Cu porphyry provinces.

2. They are associated with subduction and arc-related plutonic rocks of largely gabbro-diorite-granodiorite composition. These intrusives tend to be undifferentiated, being relatively depleted in LIL-elements such as Rb, Ce, Nb, and La, and enriched in Cr, Sc, Sr and V.

3. They are mostly developed in calcic skarn with exoskarn envelopes dominated by Ca-silicate assemblages (clinopyroxene and garnet). Magnesian Au skarns (with Mg-silicates such as olivine and serpentine) are very rare; one example however, is the Butte Highlands deposit (Montana).

4. The gold in Au skarns is commonly micron-sized; thus, the ore is visually indistinguishable from waste. It may be associated with Bi-tellurides and arsenopyrite, and in some deposits there is an enrichment in Co.

5. Depending on the mineralogy and garnet-pyroxene chemistry of the prograde exoskarn and ore, Au skarns can be separated into reduced and oxidized types.

6. Reduced Au skarns are marked by low garnet/pyroxene and pyrite/pyrrhotite ratios and the presence of hedenbergitic pyroxene and Fe-rich biotite. The intrusives have low Fe_2O_3/FeO ratios and the ore bodies are developed distal to the pluton, in the outer parts of the pyroxene-rich exoskarn envelopes. Examples include Nickel Plate (B.C.), Fortitude (Nevada) and Buckhorn Mountain (Washington State).

7. Oxidized Au skarns are characterized by high garnet/pyroxene and pyrite/pyrrhotite ratios, and by the presence of diopsidic pyroxene, pyrite, magnetite and hematite. Ore bodies tend to form more proximal to the intrusions than those in the reduced Au skarns. Examples include Nambija (Ecuador) and McCoy (Nevada).

8. Compared to the ore in Cu, Fe, Mo, W, Pb-Zn and Sn skarns, ore in most reduced and oxidized Au skarns has distinctly low metal ratios ($Cu/Au < 2000$; $Cu/Ag < 1000$; $Zn/Au < 100$, $Ag/Au < 1$).

9. There is no correlation between Cu and Au in many Au skarns (unlike in Fe and some Cu skarns where a good correlation exists between these metals). Thus, the gold potential of a skarn can be easily overlooked if copper sulphide-rich outcrops are preferentially sampled and other sulphide-bearing or sulphide-lean assemblages ignored.

10. In some Au skarns (e.g. the Nickel Plate and Fortitude deposits) there is a metal and mineralogical zoning throughout the exoskarn envelope. This zoning consists of proximal

garnet-dominant skarn with high Cu/Au ratios and distal pyroxene-dominant skarn with low Cu/Au ratios and the gold ore bodies.

Although most Au skarns have some or most of the above characteristics, individual deposits can have unique features, and it is likely that new types or varieties of Au skarns will be discovered. In exploration, any skarn of any class should be routinely and systematically assayed for gold. Essentially, any calcareous or carbonate rock package intruded by an arc pluton has a potential for hosting Au skarn deposits, although such favorable packages are generally small and relatively rare in typical island arc or back-arc environments. However, primary target areas would include (a) reefs aprons, which often flanked the original island volcanoes (b) carbonate facies formed along the margins of the back-arc basins, and (c) thrust slices of allochthonous platformal carbonates which were subsequently intruded by arc magmatism.

D - End Members of the Deposit Spectrum on the Carlin Trend: Examples from Recent Discoveries

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The Carlin trend is a 60 kilometerlong line of sedimentary-rock-hosted gold deposits located in the Great Basin physiographic province of the western United States. Production of gold from the Carlin trend totals 750 tonnes (24 million troy ounces), and reserves and resources stand at approximately 3100 tonnes (100 million troy ounces).

In recent years, resource additions have come largely from the discovery of high grade (+6 grams per tonne), carbonate-rock-hosted, refractory deposits at depths in excess of 400 meters. These deposits, and their oxidized equivalents, span a spectrum of models between stratigraphically controlled and structurally-controlled end members.
Two recent refractory gold discoveries, the Hardie Footwall and Deep Star deposits, exemplify the end members of the deposit spectrum on the Carlin trend.

The Hardie Footwall deposit lies immediately north of the Carlin mine and represents a down-dip, refractory extension of the original Carlin oxide gold deposit. It was discovered in 1993 as a result of detailed stratigraphic and structural studies of exposures in the Carlin East pit and relogging of a limited number of deep drill holes north of the Carlin mine. At a cut-off of 6 grams/tonne, the deposit contains a drill indicated, geologic resource of 1,315,000 tonnes at an average grade of 16 grams per tonne gold. In plan, the deposit is 500 meters long and 100 to 250 meters wide. In section, ore zones are from 6 to 25 meters thick and confined to dolomitic, silty limestone and lesser calcarenite in the upper 100 meters of the Silurian-Devonian Roberts Mountains Formation. Alteration is stratiform in nature and consists of widespread decalcification, or removal of calcite, within the upper 100 meters of the Roberts Mountains Formation and lower 20 meters of micrite of the Devonian Popovich formation. The gradational contact between these two units is marked by carbon flooding at the top of the alteration zone. Silicification is restricted to replacement of rare calcarenite and debris flow limestone beds and high-angle fault zones within the deposit. Decarbonatization, or the complete removal of all carbonate mineral species, is typically developed below the gold zones near major bounding structures. Highest gold grades are associated with decalcified and dolomitic rock, less-commonly with silicified structures and rarely with decarbonatized zones. High-angle, normal faults form sharp boundaries to the deposit and locally control high gold grades within the larger stratiform mineral system. Veining and brecciation are absent from the deposit, and high grade zones are visually indistinguishable from surrounding waste rock. Sulfide, largely in the form of arsenical pyrite, and organic carbon contents average 1% and 0.5 to 1%, respectively. Narrow dikes of andesitic to latitic composition occupy several structural orientations and, like the faults, either bound or locally upgrade gold zones. Intrusive rocks, however, constitute less than 0.5% of the Carlin and Hardie Footwall deposits.

At the other end of the deposit spectrum are a series of very high grade breccia bodies located in proximity to the Goldstrike intrusion on the northern end of the Carlin trend. Individual deposits include Deep Star, Deep Post and Purple Vein (Barrick Gold Corporation's Meikle mine). Deep Star, which is undergoing underground development via twin decline access from the Genesis open pit, has a drill indicated, geologic resource of 797,000 tonnes at a grade of 32 grams per tonne gold. The deposit is located between steeply dipping strands of the Genesis fault zone at depths of 350 to 500 meters and, in plan, measures only 75 by 100 meters. It consists of quartz-dolomite-kaolinite-sulfide breccia developed in marble, calc-silicate rocks and exoskarn between lobes of propylitized diorite of the Goldstrike intrusion. Ore zones are highlighted by quartz-dolomite-clay alteration and sulfide contents up to 18 weight %. Sulfide species are limited to gold bearing arsenical pyrite, marcasite and minor amounts of arsenopyrite. Carbon, in the form of graphite, is present in minor amounts. Breccia masses are largely matrix supported and monolithic in character and are interpreted to be products of dissolution and replacement of marble, calcsilicate rocks and skarn. Penetrative shear fabric and milling of fragments highlight a structural overprinting in much of the deposit. The hangingwall of the deposit, although barren of gold, displays elevated pyrite, dolomite and siderite contents in calcsilicate rocks and quartz hornfels.

Exploration discoveries on the Carlin trend continue to record variations in the original "Carlin-type" model for sedimentary-rock-hosted deposits in northern Nevada. The contrasting features of newly discovered refractory deposits are, in large part, a function of geometry and lithology of carbonate stratigraphy, diverse structural settings and the relative abundance and type of intrusive rocks.

E - Carlin-type Gold Deposits: Canadian Potential?

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The Carlin-type deposits of Central Nevada occur mainly in finely laminated silty dolomite or carbonate-bearing siltstone and represent a cumulative gold resource estimated at 2300 tonnes. Geological and genetic models for Carlin-type deposits continue to evolve, in part because many deposits of this type in the Great Basin are intensely oxidized so that many of the primary features of hypogene ores are obscured. This oxidation also has rendered the Nevada deposits amenable to bulk tonnage mining and heap-leach processing, an economic artifact that has led to the mistaken impression that all deposits in this class are of large tonnage and low grade. New deep discoveries of hypogene ore, however, are of moderate tonnage, high grade and amenable to underground mining. Geological models that emphasize the hypogene aspects of these deposits (Table 1) will be most relevant to Canadian exploration.

The early genetic interpretation of Carlin-type deposits in the Great Basin was one of epithermal origin and of Miocene age related to basin-and-range extension: this interpretation has been largely refuted on geological grounds. There are however two prominent current views on the origin of these deposits, one intrusion-related and the other a deep-crustal fluid-fault model: the first allows for both Mesozoic and Tertiary deposits, the second demands a sole Oligocene age.

The following points of geological comparison can be made between favourable geological settings in Nevada and those with Canadian potential for Carlin-type deposits:

1) Most deposits of this type in Nevada occur in an area between the Golconda and Roberts Mt. Thrusts but mainly in footwall strata: The Paleozoic stratigraphy of the Roberts Mountains Allochthon 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.

2) Remnants of terranes (i.e. Northern Sierra, Grindstone, Olds Ferry) preserving evidence of Late Devonian- Early Mississipian continental arc magmatism, analogous to Yukon-Tanana terrane, occur outboard of the Carlin gold belt.

3) The Carlin deposits straddle, or mainly occur to the east of the .706 "initial Sr line". This line, which approximately marks the western limit of subsurface continental crust in North America, extends into Canada and
follows the western margin of the Omineca Belt.

4) Apart from Au, there are important metallogenic similarities between the Nevada gold belt and equivalent Canadian segments of the Mesozoic continental margin:

a) the gold belt is coextensive with the "Nevada Ba belt" Sedex deposits which have comparable analogs in Selwyn Basin;
b) the gold belt overlaps with, but occurs mainly east of a significant Mesozoic W+/-Mo skarn belt; comparable to Kootenay, Cantung, MacTung etc.;
c) there is a weak correlation between the Carlin and Cortez gold belts and the occurrence of vein- and manto-type Cretaceous/ Early Tertiary Ag-Pb-Zn mineralization comparable to that in East Kootenay, Cassiar, Keno Hill.

Table 1: Characteristics of Carlin-Type Sediment-hosted Micron Gold Deposits

TYPE EXAMPLE: Carlin, Nevada

OTHER EXAMPLES: Global- Mercur Utah, Golden Reward, S.D., Guizhou, China
Canadian: Golden Bear, B.C. (?); Brewery Creek, YT (in part ?)

DIAGNOSTIC FEATURES:
-stratabound low-sulphide replacement of carbonate rocks
- micron sized Au with As, Sb, Hg but negligible to low base metals
- structurally and stratigraphically controlled zones of silicification and brecciation
- commonly near hornfels, skarn or calcsilicate rocks but outward of contact aureoles

SIZE AND GRADE:
-up to 500 tonnes Au; commonly 1 to 10 million tonnes ore grading 1 to 20 g/t Au

OREBODIES:
- irregular discordant breccia bodies and concordant stratabound disseminated zones confined to particular stratigraphic members; controlled by normal faults

GEOLOGICAL SETTING:

- in carbonate and impure carbonate-argillite facies of continental platforms and shelves that have been overprinted by regional thrusting, extension faulting, felsic plutonism and zones of contact metamorphism

HOST ROCKS:
- mostly in impure sedimentary carbonate rocks but also rarely in granitoid rocks, clastic sedimentary rocks and greenstones

ORE AND GANGUE MINERALS:
- pyrite with overgrown arsenian pyrite rims containing gold inclusions; orpiment, realgar, cinnabar and stibnite common accessories at deposit scale

METAL SIGNATURE
- Ag:Au highly variable but typically less than 1
- locally high concentrations of As, Sb, Hg

HYDROTHERMAL ALTERATION:
- decalcification and silicification (jasperoid) of carbonate rocks most commonly associated with ore but may be enveloped by zones of argillic and sericitic alteration
- Nevada deposits deeply oxidized to produce supergene zones favourable for bulk mining and heap-leach processing

Sediment-hosted Mineralization

F – Sediment-hosted Stratiform Copper Deposits: An Overview

Kirkham, R.V., Geological Survey of Canada

Sediment-hosted stratiform copper (SSC) or "diagenetic sedimentary" copper deposits are a large, diverse class of deposits that include some of the richest and largest copper deposits in the world. They are also important sources of silver and from the central Africa Copperbelt of Zambia and Zaire are the world's most important source of cobalt.

Analysis of many deposits and districts indicates that most SSC deposits formed during diagenesis in sediments deposited in low-latitude arid and semi-arid areas. A variety of processes were involved in different districts but metals were characteristically deposited at redox boundaries where oxic, evaporite-derived brines containing metals extracted from redbed aquifers encountered reducing conditions. The reducing environments were fundamentally of two types: 1) those with stratigraphically-controlled fixed reductants (Kupferschiefer and some redbed-type deposits), and 2) those with mobile reductants, such as H2S-bearing waters and hydrocarbons (Dzhezkazgan-type). Outward and upward away from the oxidized zone is the complete or partial following sequence of minerals: hematite, native copper, chalcocite, bornite, chalcopyrite, galena, sphalerite and pyrite. Recent studies also support the concept that similar ore-forming processes continue into higher temperature metamorphic environments and were aided by regional tectonic processes.

Models can be constructed for several districts based on an appreciation of the above features and basinal fluid-flow characteristics. For the Kupferschiefer, many major deposits in the central African Copperbelt, White Pine in Michigan and several other deposits and occurrences, metalliferous brines in underlying redbeds, possibly mobilized as a result of basinal compaction, were forced upward and outward into overlying anoxic sediments in which the metals were precipitated. In many redbed or continental environments the oxic cupriferous brines migrated through arenaceous aquifers where metals were deposited in roll-front-type redox reaction zones between oxidized and originally reduced sediments with wood trash and early diagenetic pyrite. In the Dzhezkazgan area in Kazakhstan and possibly the Revett Formation of the Belt Supergroup in western Montana and Idaho, oxic metalliferous brines in arenaceous aquifers in redbed sequences migrated up dip until they encountered mobile reductants, derived from underlying anoxic formations, that were trapped in closed regional anticlines or actively migrating up fault systems. Metal precipitation occurred at stratigraphically crosscutting regional redox boundaries. In the Graviisk area of Russia possibly both fixed and mobile reductants controlled metal precipitation. In other areas, such as the Lisbon Valley, Utah, evidence indicates that heated cupriferous brines derived from redbed aquifers, migrated up fault zones until they encountered reducing environments where the metals were precipitated. Possibly in the central African Copperbelt ore fluid flow was controlled by large-scale, gravity-driven systems created by orogenic activity and uplift in the Zambezi and/or Damaran belt to the south and west. Evaluation of many areas thus indicates several important variations on a theme for the formation of SSC deposits where oxic brines derived from evaporites migrated though and extracted metals from, redbed aquifers at different times and precipitated them at redox boundaries of diverse nature.

SSC occurrences are known in meso- and neo-Proterozoic sequences in the Rocky and Mackenzie mountains in the eastern Canadian Cordillera (e.g. Grinnell Formation and Redstone

River area). Possible SCC and volcanic redbed copper (VRC) occurrences, the analogues of SSC deposits in volcanic sequences, are widely distributed in Triassic and Lower Jurassic sequences in the western Cordillera. Although in many localities they are offset by numerous faults, these occurrences offer significant exploration potential in British Columbia and Yukon Territory.

G – Sedex Pb-Zn Deposits: Creating a Framework for Understanding and Using Hydrothermal Alteration as an Exploration Guide

Robert Turner, Geological Survey of Canada

Careful scrutiny over the last 20 years of hydrothermal alteration associated with volcanogenic massive sulphide (VMS) deposits has led to exploration models based on the geochemical and mineralogic zoning around VMS deposits. Such models have not been forthcoming for sedimentary exhalative (SEDEX) deposits in spite of striking similarities between the deposit types. The reason for this is at least two fold: an undeserved reputation that SEDEX deposits lack associated alteration, or if present the alteration is subtle and not extensive, and a variety of alteration types that prevent formulation of a single model for alteration zoning. The purpose of this talk is to rationalize the diversity of alteration types and identify the geologic settings in which SEDEX alteration is most likely to be a useful exploration guide. To do this we consider the role that host sediment composition and tectonic setting have on controlling the nature of SEDEX alteration and modern analogue hydrothermal systems.

Strata hosting stratiform deposits can be divided into three imprint types: siliceous, calcareous and feldspathic. Siliceous rocks include siliceous shale, chert and quartz-chert rich sandstone and siltstone that are dominated by a quartz-clay mineralogy (e.g. Earn Group, Selwyn Basin; Gunsteel Fm, Kechika Trough). Calcareous strata such as dolomitic or calcareous siltstone and limestone and are a carbonate-quartz-clay assemblage (e.g. Road River Fm, Selwyn Basin; Mt. Isa Group and Barney Creek Fm., Australia). Feldspathic strata include feldspathic sandstone and siltstone and are composed of feldspar-quartz-clay assemblage (e.g. Aldridge Fm., B.C.; Broken Hill Group; Australia; Vangorda Fm., Yukon; Salton Sea, California; Middle Valley, NE Pacific).

Hydrothermal alteration associated with stratiform deposits differs according to host rock type. Deposits in siliceous rocks tend to have poorly developed alteration zones; where present silicification is dominant, ferroan carbonate alteration can be important (e.g. Tom-Jason, Yukon; Cirque and Driftpile, B.C.). Calcareous sediment-hosted deposits tend to have more extensive alteration that includes silicification, dolomite or ferroan carbonate alteration (e.g. Sheep Creek, Montana; Mt. Isa and Century, Australia; Jason End, Yukon). Feldspathic sediment-hosted deposits display the best developed alteration zones and most diverse alteration assemblages. These include potassic (muscovite, kspar), tourmalinite, chloritic and albitic assemblages (e.g. Sullivan, B.C.; Broken Hill and Cannington, Australia; Zincgruven, Sweden; Anvil, Yukon). These alteration assemblages are similar to alteration associated with feldspathic sediment-hosted Besshi deposits (e.g. Ducktown, USA) and modem sedimented rift-hosted deposits (e.g. Middle Valley).

It is worth considering how variation in sediment composition could be understood in light of the tectonic setting of the basin. Stratiform deposits are associated with continental rift basins. Continental rift basins evolve from an early synrift phase (mechanical subsidence) involving faulting, lithospheric thinning, high heat flow and magmatism, to a riftsag phase (thermal subsidence) continental platform environment. Synrift basins are characterized by feldspathic sediments: locally sourced basement-derived arkoses during early rift stages (e.g. Salton Sea, California) or feldspathic turbidites derived from continental scale drainages during later continental margin formation. However, riftsag basins are characterized by more mature (i.e. quartzose) recycled siliciclastic sediment as well as platformal carbonate and their off shelf calcareous shale equivalents.

Stratiform deposits are associated with both the synrift phase and extensional reactivation during rift sag phase. Synrift stratiform deposits occur in feldspathic clastic rocks associated with high heat flow and magmatism (e.g. Sullivan, Broken Hill, Cannington, AggenaysGamsberg). Such deposits commonly display diverse and extensive alteration types because of their feldspathic host but also possibly due to higher temperature hydrothermal fluids. Using somewhat different criteria, synrift deposits are described as Broken Hill type by Parr and Plimer (1995). Synrift deposits are transitional to Besshi type deposits which share similar stratal composition and alteration mineralogy. Riftsag 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). Extent and nature of alteration is dependent on whether it is a siliceous or calcareous host.

H – Genesis of Carbonaceous Shale-hosted Ni-Mo-PGE Deposits

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Nickel-Mo-PGE sulphide deposits are hosted typically by carbonaceous shale and chert within sedimentary basins. The age of these deposits is highly variable and ranges from Cambrian to Cretaceous. The two most important examples occur in Middle Devonian and earliest Cambrian basinal facies of the Yukon, Canada, and southern China, respectively. The deposits are typically thin (<20 cm) but extend over distances greater than 1000 km. The thickness, stratigraphy, sedimentology, mineralogy and bulk and isotope compositions are also remarkably uniform laterally. The Yukon deposits are underlain by a 3m-thick unit that consists of carbonate concretions up to one metre in diameter. The Chinese deposits are underlain by a black phosphorite up to 34 cm thick. The sulphides display sedimentary textures that appear to have been disrupted by dewatering of organic-rich sediments during compaction. The sulphide assemblage is variable between deposits of different ages but remarkably uniform between deposits of the same age. The sulphides consist of combinations of pyrite, marcasite, vaesite, gersdorffite, millerite, sphalerite, wurtzite, molybdenite, chalcopyrite, and tennantite. Micro-framboidal to euhedral pyrite grains occur disseminated throughout the organic-rich host rock or are clustered along bedding planes. Most of the other sulphides are finely intergrown with pyrite or form secondary veinlets.

Maximum metal values are as follows: Yukon - Ni (7.0 %), Cu (660 ppm), Zn (2.3 %), Mo (0.33 %), V (2400 ppm), Cr (280 ppm), Ga (27 ppm), Tl (390 ppm), Ag (8 ppm), Pt (511 ppb), Pd (202 ppb), Ru (12 ppb) and Ir (10.9 ppb); China - Ni (2.3 %), Cu (0.38 %), Zn (0.36 %), Mo (4.4 %), V (3900 ppm), Cr (2500 ppm), Ga (23 ppm), Tl (290 ppm), Ag (35 ppm), Pt (391 ppb), Pd (87 ppb), Ru (8.4 ppb) and Ir (2.9 ppb). Ru/Ir ratios are chondritic. 34S values for sulphides in both Yukon and China sections show a sharp decrease at the Ni-PGE horizon. 13C values for carbonates in China also decrease sharply at this time, consistent with a major biomass drop. The thickness uniformity and lateral extent of the mineralization, the absence of a hydrothermal vent complex and associated alteration, and the difficulty of transporting relatively immobile elements such as Ir and Ru by hydrothermal fluids argues against an origin by seafloor hydrothermal or other endogenic processes (e.g., anoxic ocean turnover). However, these attributes, combined with chondritic Ru/Ir ratios and the association of this mineralization with mass extinction boundaries, are consistent with the formation of this unusual mineral assemblage by the raining of Ni-PGE-rich quenched droplets to the seafloor of an anoxic ocean following the volatilization of a major chondritic meteorite and the lofting of this material into the stratosphere after impact with the earth's surface. The association of Ni-PGE mineralization with high organic matter contents (7.3 and 17.1 % maximum in the Yukon and China, respectively) and related carbonate concretions probably reflects higher rates of organic matter sedimentation following the mass extinction event. The unusual occurrence of Ni-sulphides as sedimentary minerals most likely reflects the limiting effect of H_2S on the buildup of dissolved iron in the ambient reduced water column and the seeding of this column with metals (Ni, Mo, Fe, Zn, Pb, Ag, Ga, Tl, etc.) of meteoritic and crustal origin following meteoritic impact. Only then could Ni^{2+} compete with Fe^{2+} for reduced sulphur under seafloor sedimentary conditions and form sedimentary Ni-sulphides. Although the carrier phases for PGEs have not been identified, they probably occur with other meteoritic components (e.g., Cr, Fe, V) in microtektites that have been highly altered.

I – Irish Style Carbonate-hosted Lead-Zinc Deposits

Godfrey J. Walton, Hemlo Gold Mines Inc.

How do we classify these deposits? Are they unique to Ireland or can we find them in other localities such as British Columbia or the Yukon? Are they syngenetic, epigenetic or diagenetic? Are they similar to MVT, sedex or in a class of their own? These are some of the questions that we need to answer so that we can define the deposits. We need to understand them so that we can be more effective in our exploration for them.

People have spent years looking at these deposits, but the recent discoveries, Galmoy and Lisheen have helped to provide some excitement and encouraged the geological community to revisit the models for these deposits. I want to review some of the recent published data which I think provides some insights into the deposits. I will emphasize certain characteristic that will be useful for exploration of these deposits. The areas that I will focus on are: (1) Tectonic setting; (2) Geology; (3) Structural setting; (4) Morphology; (5) Metal ratios; (6) Isotopes; and (7) Fluid inclusions.

The characteristics that I consider important are:

1) Active tectonics during sedimentation and some of the mineralization,

2) Deposits are hosted by Carboniferous carbonates, basal section of the Waulsortian mud mound complex and Navan beds,

3) Strong structural control seen in the deposits,

4) Mineralization is stratabound with some local sections which cross cut,

5) Mineralization textures are generally replacive and brecciated but locally banding is evident,

6) Iron and Magnesium carbonates seen in and around the mineralization,

7) Zinc, Lead, Iron, Copper and Silver are known in the deposits and have some zoning laterally and vertically,

8) Isotopes point to two fluids being involved in the process, one hydrothermal and the other Carboniferous sea water,

9) Fluid inclusions indicate that the temperature ranges from 100C to 300C.

Some of these characteristics are similar to MVT deposits and some are similar to sedex deposits. It is these differences and similarities that have caused a lot of discussion over the genesis of these deposits.

My own bias is that the deposits formed primarily below the sea floor and are therefore diagenetic to epigenetic in origin. There is some evidence for an early portion of the mineralization to have formed on the sea floor, but the bulk of the mineralization is later. The alteration seen with the mineralization has also documented above the mineralized horizons.

In comparing, the characteristics of sedex and MVT deposits to Irish deposits we can see that they have some common characteristics to both deposit types. The Irish deposits probably represent a deposit type that is in between the two end members. In evaluating the deposits in detail we can see that there are numerous differences within the Irish style deposits.

The Cordillera does have the environment to host these types of deposits, although they may not look exactly like the Irish deposits.

J – Prairie-Type Sedimentary Au-Ag-Cu

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The discovery of micro-disseminated Au-Ag-Cu and related mineralization in basement and sedimentary rocks of the Western Canada Sedimentary Basin (WCSB) at Fort MacKay, northeastern Alberta, has led to the recognition of a new and potentially important occurrence of low temperature sedimentary mineralization. Prairie-type mineralization consists of native and intergrown or alloyed Au-Ag-Cu and related metals and associated alteration including me-oxide, -chloride, -carbonate, native S, and pyrite. Mineralization and alteration are inferred to be related to metal transport in oxygenated brines originating in halite evaporites of the Prairie Formation, Elk Point Group. Downward, density driven flow of these brines into red bed-evaporite sequences and fractured Precambrian basement, followed by up-dip 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 Au and other metals by controlling redox conditions.

Fort MacKay is located in the Athabasca River valley near the eastern margin of the WCSB and is perhaps best known for the nearby Athabasca tar sands mining operations. Basement rocks in northeastern Alberta range from Archean to Paleoproterozoic in age and predominantly are highly metamorphosed granitoid gneisses. They are unconformably overlain by a Paleozoic passive margin sequence comprising Middle Devonian Elk Point Group regolith, red bed-evaporites, dolostone, and shale, and Upper Devonian Beaverhill Lake Group massive to argillaceous limestone with minor evaporites. The passive margin sequence is unconformably overlain by Lower Cretaceous siliciclastics of the Mannville Group, part of a Middle Jurassic to Tertiary foreland basin succession, which host to the tar sands deposits. Reconstructed burial depths and estimated paleogeothermal gradients indicate that temperatures attained during maximum Laramide age burial did not exceed 90°C in this part of northeastern Alberta. Structure is relatively simple, although the combined effects of uplift on the Peace River-Athabasca Arch in the late Paleozoic, collapse due to salt dissolution in the Prairie Formation, and karsting related to exposure at the sub-Cretaceous unconformity, have produced a network of small scale horst and graben structures and a number of northerly trending normal faults with west-side-down displacement. The Athabasca river valley is the discharge point for three distinct aquifer systems: the Cretaceous-Quaternary (TDS <10 g/l) aquifer which is recharged by meteoric waters in highland areas, an upper Devonian (TDS <50 g/l) aquifer, and a lower, sub-salt Devonian (TDS >200 g/l) aquifer.

Prairie-type mineralization has been observed from basement to Cretaceous age rocks at Fort MacKay, although the most abundant Au and related mineralization occurs in argillaceous limestones of the Upper Devonian Waterways Formation. Here Au occurs in association with Ag, Cu, Zn, Pb, Cd, Fe, Cr, Ni, Sb, Bi, Cl, Ca, Al, and Si. Gold is next most abundant in basement rocks where it is associated with Ag, Cu, Pb, Sb, Sn, W, and Cl. Other workers have shown that transport of copper and Au-PGE mineralization is possible in saline brines at oxidation potentials set by equilibration of the brine with hematite-anhydrite. The presence of native copper in silty carbonates of the Waterways Formation in the Fort MacKay region is indicative of oxidation potentials exceeding the minimum oxidation potential set by equilibrium with hematite-anhydrite, further enhancing the capability of these brines to scavenge and transport Cu and Au-PGE metals.

Alteration is complex and reflects variable redox states. Native sulphur has been observed at a number of stratigraphic levels where it marks the boundary between relatively oxidized and reduced environments. The origin of native sulphur is under investigation, but similar occurrences elsewhere have been linked to reactions between microbially produced H2S(g) and sulphate-bearing formation waters in the presence of liquid hydrocarbons or immature organic material. Native sulphur occurs regionally at the base of the Beaverhill Lake Group at the interface between reduced, pyrite-bitumen bearing limestones of the Waterways Formation and oxidized, hematite-anhydrite red bed-evaporites of the Elk Point Group. Native sulphur also is visible in fractures cutting organic-rich laminites which occur near the base of the Winnipegosis Formation, Elk Point Group, and has been observed microscopically in basement rocks. Further studies of the relations between mineralization, alteration type (redox state), hydrocarbons, and organic matter are underway.

Intrusive and Porphyry-related Gold

K – The Dublin Gulch Intrusive-hosted Gold Deposit

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The Dublin Gulch Project is an advanced exploration project on an intrusive-hosted gold deposit located near Mayo, Yukon Territory, Canada. The project is 100% owned by First Dynasty Mines Ltd., a Yukon incorporated, Denver based, resource development company. The company is currently completing a pre-feasibility and Initial Environmental Evaluation (IEE) on the property.

The project area is underlain by Upper Proterozoic to Lower 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.

Alteration and mineralization on the property are related to the Dublin Gulch Stock, a granodiorite intrusive dated at 92.8 +/- 0.5 ma. Country rocks have been hornfelsed, and skarns occur locally. A pervasive fabric related to the Cretaceous thrusting event is still visible, but is no longer a plane of weakness. Mineralization associated with the Dublin Gulch Stock includes:

Sheeted, low-sulphide quartz veins within the intrusion, containing gold and bismuth ('Fort Knox' style of mineralization) along the north side of the intrusion.

Pyroxene-scheelite skarn zones, notably the Mar Tungsten Deposit on the southeast side of the stock, which contains an estimated resource of 5.4 million tonnes grading 0.82% WO_3.

Structurally controlled, auriferous quartz-arsenopyrite veins within both the intrusion and surrounding sediments, especially proximal to the northern contact.

Cassiterite in a tourmalized breccia zone on 'Tin Dome', situated north of Dublin Gulch.

High Silver quartz-sulphide veins (e.g., Peso Silver and Rex) found distal to, but on trend with, the stock.

The potential of the Dublin Gulch Stock to host an intrusive-hosted, bulk mineable, deposit was first tested in 1991. Four mineralized zones were identified: the Eagle, Olive, Shamrock, and Steiner zones. In 1993, an inferred plus potential resource of 98.6 million tonnes grading 1.19 g/T Au (0.035 opt) was calculated solely based on the Eagle zone. All 1995 work was focused on this zone.

In the Eagle Zone, alteration and mineralization changed character as the magma cooled. A transition from magmatic fluids in equilibrium with the host stock; to hydrothermal fluids, no longer in equilibrium, resulted in increased alteration. A corresponding shift from feldspar-dominant to sericite-dominant alteration, an increase in sulphide mineralization, and a decrease in gold deposition, is observed.

Earliest mineralization ranges from fracture fill and wallrock impregnations consisting of kspar +/- quartz +/- albite to veins containing quartz +/- kspar with very weak alteration or narrow feldspar +/- sericite selvages. These stages are characterized by gold-bismuth deposition, low sulphide mineralization, and the absence of wallrock fabric.

Earlier veins grade into veins possessing distinct sericite selvages, lower Au+Bi precipitation, and more abundant but still low sulphide content (arsenopyrite, pyrite-pyrrhotite). Narrow zones of deformation occur along selvages.

Late veins have wide zones of sericite alteration, very little gold, and contain up to 1% sulphide in the wallrock. Brittle deformation and narrow cataclasite zones are commonly associated. Clay in the deposit is probably due to weathering, especially along structures, and not due to hydrothermal fluids.

Gold occurs as native gold liberated in gangue or associated with bismuth minerals. Grains are relatively large, with an average size of 120-150 microns. Lesser amounts of gold appear encapsulated in arsenopyrite. Individual veins grade in the range of 10-30 g/T (0.29-0.87 opt) Au, however sample intervals of 1.5m (5 feet), encompassing both the vein and granodiorite host material, typically grade between 0.8 to 2.0 g/T (0.023-0.058 opt) in the ore zone. Silver values are generally lower than gold values.

First Dynasty Mines Ltd. spent $US 3.2 million on the Dublin Gulch Project in 1995. Work included 14,000m (46,000 ft) of reverse circulation and diamond drilling. The goal was to delineate 30-40 million tonnes of mineable reserve centered within the larger Eagle Zone 'inferred and potential resource' at a similar or higher grade. In conjunction, engineering, economic, environmental, and social aspects of the project were studied. Pre-feasibility and IEE reports are expected to be completed in January 1996. Plans include a 20,000-25,000 tonnes per day open pit mine with an approximate 1:1 ore to waste stripping ratio, coupled with a cyanide heap-leach extraction process.

In fulfilling its mission statement to undertake ethical and socially responsible resource development, First Dynasty Mines has followed the highest environmental guidelines and proactively shared the planning and concerns of the Dublin Gulch Project with the local people and communities.

So far, everything looks favorable for the continued advancement of the Dublin Gulch Project. If economics and permitting allow, First Dynasty Mines foresees the commencement of mine production in 1997.

L – Intrusion-related Gold and Base Metal Mineralization Associated with the Early Cretaceous Tombstone Plutonic Suite, Yukon and East-central Alaska

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The Tombstone Plutonic Suite (TPS) is a lithologically and metallogenetically diverse suite of mid-Cretaceous (95-90 Ma) plutons that intrude miogeoclinal strata of the northern Cordillera in central Yukon and westernmost Northwest Territories. These intrusions form an east-west trending belt more than 550 km long and up to 100 km wide that stretches from the Mackenzie Mountains southeast of Macmillan Pass to the Tintina Fault in the Dawson area of western

Yukon. A western continuation of the belt has been dextrally offset approximately 450 km along the Tintina Fault, and extends a further 200 km southwest from the central Circle quadrangle in east-central Alaska at least as far as the Fairbanks mining district. Three Au deposits that are directly hosted by, or are spatially closely associated with TPS intrusions are in advanced feasibility to pre-development stages (Fort Knox: ~4M oz. contained Au; Dublin Gulch, ~2M oz. contained Au, and Brewery Creek (~800K oz. contained Au). The TPS is presently being actively explored for additional economic Au and base metal deposits.

Intrusions of the TPS range from isolated dykes and sills to multiphase batholiths up to 250 km2 in area. The TPS in Yukon displays an extended compositional range, from rare clinopyroxenite, gabbro and tinguite through more typical diorite, syenite, quartz syenite, monzonite, granodiorite and granite. TPS intrusions in Alaska appear to be more restricted in composition, consisting mainly of tonalite, granodiorite and granite. The plutons are commonly weakly porphyritic, and observed field relations and preliminary geobarometric studies indicate emplacement depths from near-surface to 5 km. Wall rocks to the TPS intrusions range in metamorphic grade from essentially unmetamorphosed to upper greenschist facies, and a pronounced contact aureole up to several hundred metres wide is developed around most intrusions. The timing of intrusion was immediately post-tectonic with respect to craton-directed thrust faults that affected the northern Cordilleran miogeocline in this area.

Mineralization spatially associated with TPS intrusions ranges from intrusion-hosted "Fort Knox-style" porphyry Au-(Bi-W-Mo) deposits (e.g., Ft. 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 TPS offers a unique opportunity to investigate the factors controlling a wide range of styles of intrusion-related mineralization. A transition from late miarolitic cavities containing Au, native Bi, bismuthinite, and a variety of Au-tellurides to sheeted, "pegmatitic", Au-bearing quartz-(K-feldspar) veins similar to those at Fort Knox is observed at the Emerald Lake occurrence, clearly demonstrating that at least some of the Au-bearing fluids responsible for mineralization associated with the TPS are of magmatic origin. Other factors, such as the specific differentiation history of the magmas, depth of emplacement, composition and metamorphic grade of country rocks, and nature and extent of structural preparation, all vary widely along the length of the Tombstone belt; and on-going research is directed at evaluating the relative importance of these factors in controlling the genesis and nature of intrusion-related mineralization.

M – Porphyry Copper and Related Gold Mineralization in the Sulphurets District of Northwestern British Columbia – Implications for Intrusion-related Gold Exploration

***Jacob Margolis**, Homestake Mining Company, Reno, Nevada*

The Sulphurets district, 60 km northwest of Stewart and 20 km southeast of the Eskay Creek mine, contains at least four significant Cu-Au deposits: the Kerr Cu-Au (148 million tons [MT], .76% Cu, .01 opt Au), West zone Au-Ag (.71MT, .43 opt Au, 20 opt Ag), Snowfield Au (8 MT, .08 opt Au), and Mitchell Cu-Au (geologic resource of ±200 MT, .2% Cu, .025 opt Au). This report concerns the northern portion of the district on the flanks of Mitchell Valley, the area of the Mitchell and Snowfield deposits. Host rocks, apparently correlative with the Lower Jurassic Hazelton Group, include submarine hydroclastic basaltic lava flows, dioritic intrusive rocks, and volcaniclastics. Calc-alkaline granitoid (commonly quartz-syenite) stocks occur at the base of the alteration system, are altered and mineralized by stage 1 (see below), and are believed to have driven the hydrothermal activity. Fluorite (post stage 1) is common proximal to the syenites. Ar-Ar and U-Pb dating of hydrothermal tourmaline and quartz-syenite, respectively, indicate an Early Jurassic (about 192 Ma) mineralization age. A Middle Cretaceous (110 Ma) thermal event is also recognized and is probably coincident with post-mineralization low-grade greenschist metamorphism and thrusting.

Excellent exposures and high relief have facilitated the recognition of four superimposed hydrothermal/mineralization events representing a gold-enriched porphyry-epithermal transition. From earliest to latest these are:

(1) porphyry-style Cu-Au stage consisting of pervasive potassic alteration (K-feldspar-magnetite-biotite-specularite) of deep-level, intrusive quartz-syenite and surrounding volcanic rocks; Cu-Au-bearing quartz stockworks (e.g., Mitchell deposit) developed at high levels within country-rock volcanic and intrusive rocks; electrum occurs within chalcopyrite, and there is a strong positive correlation between Cu and Au;

(2) relatively high-level quartz-sericite-chlorite-pyrite alteration hosting quartz-molybdenite veins and tourmaline, both of which were introduced at this time;

(3) unmineralized, blanket-like, advanced-argillic alteration (pyrophyllite-kaolinite-woodhouseite-pyrite-barite) at high levels; and underlying massive pyrite veins enriched in Bi-Te-Sn;

(4) gold-rich, quartz-barite veins containing galena-sphalerite-tetrahedrite-pyrargyrite-gold-acanthite (Pb-Zn-Au-Ag-Sb-Cu-Cd-Hg±Te) best developed at high and peripheral positions (West zone style); and a high-grade, basalt-hosted disseminated Au zone (Snowfield deposit) with a similar mineral assemblage. This disseminated gold mineralization occurs proximal to a high-level, stage-1 stockwork zone and beneath and laterally adjacent to an advanced-argillic cap. Gold precipitation at Snowfield apparently resulted from sulfidation of previously altered (stages 1 and 2) basaltic andesite which was highly permeable due to a coarse hydroclastic texture. Within the stage-4 veins, abundant barite and absence of adularia are evidence that fluid mixing as opposed to boiling led to precipitation of gold and metal sulfides. Although stage-3 massive pyrite veins may contain high but erratic gold grades, textural relations indicate that gold (with galena-sphalerite-tetrahedrite) was introduced by the stage-4 fluid.

Two gold environments are present at Sulphurets:

(1) earliest, central (within or above granitoid), porphyry-Cu stage, with gold apparently carried as a chloride complex at relatively high temperature in a dominantly magmatic fluid of high salinity;

(2) latest, typically high-level and distal (to granitoid and stage-1 system), base-metal related, gold mineralization akin to adularia-sericite type epithermal systems, with gold apparently

carried as a sulfide complex at lower temperatures in a relatively alkaline and reduced fluid with a larger component of meteoric water. Stable isotope data provide evidence for these two fluid types and temperatures.

Exploration in porphyry-style systems must be geared to recognize and target these two settings, as both may be economically viable. In addition, a third, rarer setting, not present at Sulphurets is the acid-sulfate-related enargite-gold (high sulfidation) style of mineralization; such deposits typically occur in a high-level and central position relative to underlying causative porphyry intrusions and potassic Cu-rich mineralization. It is possible that such a system existed in the advanced-argillic zone at Sulphurets but was eroded. However, the temporal transition from the acidic stage-3 system to the more alkaline and gold-rich stage 4 system at Sulphurets is an emerging characteristic of at least some high sulfidation gold deposits. Although the early, high-temperature Cu-Au environment is similar in most districts, the late, generally peripheral, lower-temperature gold system may assume a variety of deposit styles, chiefly dependent upon host-rock type, precipitation mechanisms, and hydrothermal flow regimes. The distinctive transition from Cu precipitation to Mo-B-F precipitation is consistent with the protracted exsolution of magmatic aqueous fluids from the crystallizing silicic melt, as demonstrated in experimental studies of other workers.

N – Red Mountain, Northwestern British Columbia: Auriferous Pyrite Stockworks in a Zoned, Porphyry-like System

David A. Rhys, Consultant and former Lac Minerals staff

Gold-silver mineralization at Red Mountain (1992 resource of 2.5 million tonnes grading 12.8 g/t Au and 38.1 g/t Ag) occurs within several discrete zones within a folded sequence of Middle to Late Triassic sedimentary rocks, Early Jurassic volcaniclastic and pyroclastic rocks, and Early Jurassic intrusions. Three phases of Early Jurassic sills and stocks collectively comprise the Goldslide intrusions: (i) irregular bodies of medium-grained hornblende monzodiorite (Hillside porphyry), (ii) hornblende-biotite + quartz porphyritic monzodiorite to quartz monzodiorite (Goldslide porphyry; U-Pb zircon ages of 197.1 $\pm$ 1.9 Ma), and (iii) biotite porphyritic hornblende monzodiorite sills (Biotite porphyry). Contact breccias and igneous breccia dikes are common features of the Goldslide intrusions. Chemical similarities and equivalent ages of volcanic rocks and intrusions, and the presence of intrusive clasts in volcanic rocks suggest that the intrusions are feeders to overlying volcanic units.

Hydrothermal alteration affects all pre-Tertiary rocks on Red Mountain, including all phases of the Goldslide intrusions. Several shallow-dipping alteration zones are developed sequentially above a propylitic quartz stockwork/molybdenum zone. These include: (i) sericite-quartz-pyrite alteration (pyrite- dominant alteration), (ii) chlorite-K-feldspar-sericite-titanite alteration with disseminated and vein pyrrhotite (pyrrhotite-dominant alteration) and (iii) brown to black tourmaline veins and K-feldspar-pyrite-titanite-actinolite alteration. Anomalous gold (>0.3 g/t) mineralization is developed at the transition from the pyrite to the pyrrhotite dominant alteration over a >1 km2 area. Within this anomalous zone, high grade (3-20 g/t Au) gold-silver mineralization occurs in 5 to 29 m thick, semi-tabular pyrite $\pm$ pyrrhotite stockworks with intense sericitic alteration and surrounding disseminated sphalerite + pyrrhotite.

Stratigraphic, spatial and geochronologic relations and alteration zoning indicate that mineralization formed in a subvolcanic environment at the top of the Goldslide intrusions and at the base of the Early Jurassic volcanic pile. The Goldslide porphyry is interpreted to be the mineralizing intrusion. The alteration zoning, molybdenum-copper mineralized quartz stockworks, extensive K-silicate and tourmaline alteration, and the relationship with a hypabyssal porphyritic intrusion show similarities to many porphyry systems.

Gold Veins

O – Mesothermal Gold-Quartz Vein Deposits in British Columbia Oceanic Terranes

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Mesothermal gold quartz vein deposits in British Columbia (eg. Bralorne-Pioneer and Cassiar) and gold placer deposits derived from such veins (eg. Atlin, Cariboo, Dease Lake and Manson Creek) are, or were hosted within or marginal to collisional suture zones where large volumes of CO2-rich fluids have been channeled. These zones represent major crustal breaks between diverse assemblages of island arcs, subduction complexes and continental margin clastic wedges. They are delineated by the presence of obducted remnants of ancient oceanic lithosphere, i.e. dismembered ophiolitic rocks.

Deposits are intimately associated with carbonate altered ultramafic rocks "listwanite" derived from oceanic lower crustal plutonic or upper mantle metamorphic protoliths. The presence of such ultramafic rocks at surface, in essence characterize the trans-crustal nature of these major fault zones. Listwanite is therefore significant in that it delineates such suture zones and, more importantly marks areas where the sutures have channeled potential mineralizing fluids.

Gold mineralization is characterized by silicification, pyritization and potassic metasomatism localized along fracture zones within broader carbonate alteration halos. Economic concentrations, due to the likelihood of vein continuity and definable reserves are most likely hosted by the more competent lithologies of the obducted oceanic lithosphere, which form relatively large tectonic blocks. The differentiated mafic plutonic oceanic crustal segment of the East Lisa Complex (*"Bralorne Intrusion"* or *"Bralorne Diorite"*) hosting the Bralorne gold veins and the upper crustal volcanic rocks of the Sylvester allochthon hosting the Erickson gold veins are British Columbia examples. The Grass Valley district in the Motherlode Belt was the richest and most famous gold mining district in California, with practically all the gold recovered from lodes. As at Bralorne, the veins are hosted in a mafic plutonic-volcanic section of obducted crust, the Smartville Complex.

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.

Ar39/Ar40 ages of hydrothermal vein mica from the Cache Creek and Bridge River Terrane define temporally restricted mineralizing events which closely follow a collisional episode. In contrast, published K/Ar data for deposits associated with the Slide Mountain Terrane suggest that mineralization was temporally much less restrictive and formed during a period of uplift and extension in Early Cretaceous.

The available age data suggest that either:

* There are two distinct tectonic regimes of mesothermal gold-quartz vein formation in the Cordillera, one involving a collisional event and the other produced during extension and uplift, or that

* All these vein deposits are late-syncollisional and the K-Ar systematics of mesothermal vein deposits occurring in association with oceanic lithosphere above the American continental margin have been reset by later thermal events.

Mesothermal gold quartz vein deposits are found along suture zones where affected by intense and pervasive carbonate alteration that is closely associated with late syn-collisional, structurally controlled intermediate to felsic magmatism. They are potentially economic where hosted by relatively large, competent tectonic blocks of obducted oceanic crust.

P – The Snip and Johhny Mountain Gold Mines: Early Jurassic Intrusive-related Vein Deposits, Iskut River Area, Northwestern British Columbia

***David A. Rhys**, Consulting Geologist*

The Snip and Johnny Mountain gold mines occur five kilometres apart on Johnny Mountain in northwestern British Columbia. The area is underlain by in a folded sequence of Upper Triassic turbiditic and volcaniclastic rocks, which host the Snip mine. The Triassic rocks are unconformably overlain by flat lying Early Jurassic volcanic rocks at the Johnny Mountain mine.

Ore at the Snip mine occurs in two southwest-dipping shear veins, the Twin zone and its splay, the 150 vein, which together contain >30 tonnes Au. The deposit comprises interlayered (i) laminated calcite and chlorite-biotite-pyrite replacement shear veins and (ii) dilatant quartz and pyrite-pyrrhotite veins. Veins were emplaced progressively during normally-directed simple shear that accompanied a period of semi-brittle deformation.

The Johnny Mountain mine (Stonehouse deposit, 3 tonnes Au production) located south of Snip, consists of a set of steep north-dipping dilatant quartz-pyrite veins with K-feldspar alteration envelopes. The veins are superimposed on flat lying Early Jurassic volcaniclastic rocks that are intruded by a series of Early Jurassic feldspar porphyry dykes. Structural relations suggest that the Stonehouse veins represent a higher level, more brittle response to the same deformational event that formed the stratigraphically deeper Snip orebodies.

The Early Jurassic Red Bluff K-feldspar megacrystic quartz diorite stock intrudes Triassic rocks 300-800 metres northeast of the Twin zone. The intrusion is affected by (i) early intense quartz-magnetite-sericite-K-feldspar-biotite (potassic) alteration associated with abundant quartz-magnetite-hematite veins and Au-Cu-Mo mineralization, overprinted by (ii) sericite-pyrite-quartz (phyllic) alteration characterised by pyrite veining. Geologic relations, including similarities in alteration and structural style, geochronology, and camp-scale mineralogic and alteration zoning, indicate that intrusion, deformation, initiation of the porphyry hydrothermal system, and formation of the structurally hosted Au and base metal deposits are closely related spatially, temporally and probably genetically.

Q – Intrusion-related Au-(Ag-Cu) Pyrrhotite Veins

***Dani Alldrick**, British Columbia Geological Survey*

Intrusion-related gold-bearing pyrrhotite veins occur as a series of parallel, tabular to cymoid veins of massive iron sulphide and/or bull quartz. These moderate tonnage, high-grade veins are emplaced in en echelon fracture sets around the periphery of subvolcanic plutons. Examples of this newly-recognized deposit-type include some of the historic gold camps of British Columbia. These deposits are attractive exploration targets because of their high profit potential (high grades), ease of mining (strong, regular, structural control), relative ease of exploration (predictable restricted geologic setting; characteristic geophysical response) and high exploration potential (deposits occur in clusters or sets of veins and also have close genetic associations with other important mineral deposit types).

Veins may be composed of (i) massive fine-grained pyrrhotite and/or pyrite, or (ii) massive bull quartz with minor calcite and minor to accessory disseminations, knots and crystal aggregates of sulphides. These two dominant vein types may occur independently or together. The two mineralization styles may grade into each other along a vein, may form parallel to each other in a compound vein, or they may occur in adjacent but separate veins within an en echelon set.

The subvolcanic setting for these deposits is transitional between the setting for porphyry copper systems and the setting for epithermal systems. Mineralization is synvolcanic and syn-intrusive and formed along the thermally "brittle-ductile transition envelope" that surrounds subvolcanic intrusions. Late magma movement generated localized shearing which opened en echelon vein sets. Circulating hydrothermal fluid precipitated gold-rich iron sulphides and gangue.

All examples of this deposit type are emplaced in volcanic arc environments in oceanic or continental margin settings. These deposits have close associations with other ore deposits that are typical of arc environments. Consequently intrusion-related Au-(Ag-Cu) pyrrhotite veins should provide new exploration targets within established arc-related porphyry and epithermal camps. Conversely, discovery of these high-grade gold veins in frontier areas should spur exploration for additional deposits of this type, and for all the associated mineral deposit types of the volcanic arc environment.

Shallow Subaqueous VMS and Epithermals

R – The Eskay Creek Mine: A precious Metal Rich, Clastic Sulphide-sulfosalt Deposit

Tina Roth, Mineral Deposit Research Unit - The University of British Columbia, and Homestake Canada Inc.

The Eskay Creek Mine is a high-grade precious and base metal-rich sulphide and sulphosalt deposit located 80 km northwest of Stewart, British Columbia. A number of mineralized zones identified on the property can be distinguished by varying mineralogy, textures and grade. Economic concentrations of precious and base metals are contained in the 21 zone, which contains a number of distinct sub-zones. The bulk of the ore is hosted in the stratiform 21B zone. Production from the 21B zone commenced in January 1995 with a proven and probable mining reserve of 1.08 million tonnes grading 65.5 grams/tonne Au and 2,931 grams/tonne Ag.

Stratiform mineralization is hosted in marine mudstone at the contact between underlying rhyolite and overlying basalt packages. This succession forms the upper part of the Lower to Middle Jurassic Hazelton Group. At the same stratigraphic horizon as the 21B zone are the 21A zone, characterized by As-Sb-Hg sulphides, and the barite-rich 21C zone. Stratigraphically above the 21B zone, mudstones host a localized body of base-metal-rich, relatively precious metal-poor, massive sulphide (the "hanging wall" zone). Stockwork vein mineralization is hosted in the rhyolite footwall in the Pumphouse, Pathfinder and 109 zones. The Pumphouse and Pathfinder zones are characterized by pyrite, sphalerite, galena and chalcopyrite rich veins and veinlets hosted in strongly sericitized and chloritized rhyolite. The 109 zone comprises gold-rich quartz veins with sphalerite, galena, pyrite, and chalcopyrite associated with abundant carbonaceous material hosted mainly in siliceous rhyolite.

The 21B zone consists of stratiform clastic sulphide-sulphosalt beds. The ore minerals are dominantly sphalerite, tetrahedrite and Pb-sulphosalts with lesser freibergite, galena, pyrite, electrum, amalgam and minor arsenopyrite. Sphalerite in the 21B zone is typically Fe-poor. Stibnite occurs locally in late veins and as a replacement of clastic sulphides. Rare cinnabar is associated with the most abundant accumulations of stibnite. Barite occurs as isolated clasts and in the matrix of bedded sulphides and sulphosalts, or as rare clastic or massive accumulations, mainly in the northern portion of the deposit and in the 21C zone.

The clastic ore beds in the 21B zone show rapid lateral facies variations. Individual beds range from <1 mm to 1 m thick. The thickest beds occur at the core of the deposit and comprise sulphide cobbles and pebbles in a matrix of fine-grained sulphides. These beds have an elongate trend which approximately defines the long axis of the deposit and which probably were deposited in a channel-like depression. Lithic clasts within the beds are mainly chloritized rhyolite and black mudstone. Angular, laminated mudstone rip-up clasts have locally been entrained within the clastic sulphide-sulphosalt beds. Both laterally and vertically, the ore beds become progressively thinner, finer grained and interbedded with increasing proportions of intervening black mudstone. Vertically successive clastic beds, either graded or ungraded, vary from well to poorly sorted. Bedded ore grades outwards from the core of the deposit into areas of very fine grained, disseminated sulphide mineralization.

The 21B zone exhibits many characteristics analagous to Kuroko-type volcanogenic massive sulphide deposits, but is associated with an epithermal element suite and high precious metal content. These features may be explained if the deposit formed in a relatively shallow water environment and significant boiling of the hydrothermal fluids occurred. The variability in textural characteristics of the clastic ore may reflect a variety of mechanisms related to explosive hydrothermal and/or sedimentary processes.

S – Shallow Submarine Hot Spring Deposits

Mark D. Hannington, Geological Survey of Canada

Recent studies of modern, shallow submarine hot springs have established a direct link with volcanogenic gold deposits and identified a number of new deposit types as targets for exploration in Canada. More than 50 sites of shallow submarine hydrothermal activity have been documented world-wide in volcano-tectonic settings ranging from (1) island arc volcanoes and related rifts (Izu-Bonin arc), (2) back-arc spreading centers (Lau Basin, Okinawa Trough, Havre Trough), (3) rifted continental margins (California Borderland), (4) fore-arc rifts and related alkaline volcanic centers (Tabar-Feni Chain, Lihir Island), (5) shallow segments of the mid-ocean ridges (Iceland Plateau, Axial Volcano), and (6) intraplate hot spot volcanoes (Azores). Among these examples, a number of geologic environments have been recognized as important sites for productive shallow submarine mineralization, including (1) the summit areas of large volcanic edifices or seamounts (1500-1000 m depth), (2) the collapsed calderas of submarine volcanoes and young volcanic cones (1000-500 m depth), (3) the flanks of active volcanic islands (500-50 m depth), and (4) near-shore environments adjacent to subaerial geothermal systems (<50 m depth). At least seven different styles of mineralization are recognized, including (1) gold-rich polymetallic massive sulfides (Palinuro Seamount), (2) gold-barite deposits (Kita-Bayonnaise Caldera), (3) epithermal vein- and disseminated-stockwork mineralization (Tabar-Feni arc), (4) pyritiferous muds and pyrite replacement deposits in volcaniclastic sediments (Vulcano, Italy), (5) submarine solfataras and acid-sulfate springs (Lau Basin, Desmons Cauldron), (6) carbonate hot springs (Piip Volcano), and (7) low-temperature Fe & Mn oxide deposits (Santorini).

Shallow submarine hot springs are particularly common on the submerged volcanoes of Pacific island arcs (Aleutians, Kuriles, Japanese Islands, Izu-Bonin arc, Marianas Islands, Papua New Guinea, Solomons, New Hebrides, Fiji, Tonga-Kermadec, Taupo Volcanic Zone off New Zealand). Volcanic islands throughout this region host extensive hot spring and fumarolic activity and locally have produced large porphyry copper and epithermal gold deposits (e.g., 40 million oz. megadeposit at Lihir). A number of known submarine hot springs occur in close proximity to active gold-depositing systems (e.g., in the harbour at Lihir). Widespread hot spring activity near sea level at these sites suggests extensive submarine venting may also occur on the submerged flanks of many of the volcanic islands. Mineral deposits forming at these hot springs resemble deep-sea metalliferous deposits but also have distinctive epithermal characteristics similar to gold deposits on the adjacent volcanic islands. Examples are known from submerged caldera environments in the Kuriles, S. Kyushu, PNG, and off White Island NZ. Massive barite-sphalerite-galena deposits are currently forming in the shallow calderas of submerged volcanoes of the Izu Bonin arc, and these containup to 2300 ppm As, 670 ppm Sb, 350 ppm Ag, and 2.7 ppm Au (Iizasa et al., 1992). At Fushime, on the shores of Kagoshima Bay (S. Kyushu), hydrothermal precipitates are presently forming below sea level as mineral scales in geothermal wells, and these consist of massive sphalerite and galena with up to 12,000 ppm Sb, 2200 ppm Ag, and 1.4 ppm Au (Akaku, 1988), closely resembling the mineral assemblage at Eskay Creek. Similar deposits are well-known at Palinuro Seamount in the Aeolian Arc (Tyrrhenian Sea), where barite-polymetallic sulfides are forming at 600 m water depth and contain up to 4800 ppm As, 2000 ppm Sb, 6600 ppm Hg, 420 ppm Ag, and 7.1 ppm Au

(Puchelt, 1986). These examples represent a continuum from subaerial, volcanogenic epithermal gold deposits to submarine polymetallic massive sulfides and occur in a variety of shallow-water volcanic settings that previously were considered non-prospective for VMS. Although examples from island arc settings are among the best documented, shallow submarine volcanism and epithermal-style gold-base metal mineralization are not limited to emerging volcanic arcs. The diverse volcanic and tectonic environments which host shallow submarine hot springs indicate that a wide range of geologic settings may be important for this type of mineralization (e.g., mid-ocean ridges, hot spot volcanoes, rifted continental margins, rifted fore-arcs, near-trench volcanoes associated with ridge subduction).

In the geologic record, shallow submarine hot spring deposits are represented by stratiform Au-Ag barite deposits, pyritic Cu-Au stockworks, and auriferous polymetallic sulfides. Examples include the Au-Ag barite deposits of Wetar Island, Indonesia (Lerokis, Kali-Kuning) and similar deposits in the Sunda-Banda arc (Flores, Sumbawa Islands) and in the Philippines (Binebase and Sarangani Islands). Examples of gold-rich pyritic stockwork deposits with barite-rich caps occur in Miocene volcanic belts of Japan (Yoshino mine) and also in Fiji (Undu deposit). Gold-rich barite deposits and epithermal gold-base metal deposits are known in the Pontides mineral belt (Koprubasi, Turkey), in the Yunnan Prov. of China (Laochang), and possibly in Eastern Australia (Mt. Chalmers). Examples from the Skellefte district, Sweden, include the Asen stratiform barite-pyrite deposit, located 20 km from Boliden, and similar emergent volcanic settings may be represented in the Bergslagen district. In Canada, Archean examples in shallow-water volcanics include the Selbaie deposit (NW, Quebec) and mineralization at Onaman Lake (NW Ontario). Deposits with Kuroko-type affinities and distinctive epithermal characteristics also occur in eastern Canada (Tulks Volcanic Belt, Nfld., Mindamar, NS). Important examples from the Cordillera, in addition to Eskay Creek, may include the gold-rich pyritic stockworks at Johnson River and the high-grade Ag deposits at Samatosum and Rea Gold. Many of these deposits may be hybrids (e.g., high-level epithermal-style mineralization superimposed on pre-existing polymetallic massive sulfides) but further illustrate the wide range of potential exploration targets.

T – Magmatic Contributions to Sea Floor Deposits: Exploration Implications of a High Sulphidation VMS Environment

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Over the last ten years, two types of fundamentally different precious metal epithermal deposits have been recognized. Although several names have been used for these types, the terms now in favour are high and low sulphidation. The two deposit types differ in their ore and alteration mineralogy, their geometry and ore controls, and the composition and origin of the ore forming fluids. There is strong evidence for a major magmatic contribution to the fluids that form high sulphidation deposits while low sulphidation fluids are dominated by meteoric water with some evidence for local and transient magmatic input. High sulphidation deposits form in magmatic-hydrothermal systems, an environment characterized the upper part of many strato volcanoes.

Based on the mineralogical classification used for epithermal deposits, the majority of volcanogenic massive sulphide (VMS) deposits could be classified as low sulphidation. These VMS deposits formed from an ore fluid that was dominated by modified seawater, and as with low sulphidation epithermal deposits, evidence for magmatic contributions to these systems is limited. There are also, however, VMS deposits and seafloor occurrences whose mineralogy suggests that a high sulphidation classification is appropriate. These high sulphidation VMS deposits probably formed from magmatic hydrothermal systems that were active in submarine settings.

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 seafloor 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.

Examples of high sulphidation VMS deposits occur on the modern seafloor. The mineralogy of the gold-rich polymetallic massive sulphides on the Palinuro seamount suggests a high sulphidation affiliation. Of more significance are the gold-rich barite-silica-sulphide precipitates and associated alunite-rich advanced argillic alteration that have been discovered at the Hine Hina hydrothermal field in the Lau Basin. This alteration is forming at a water depth of 18502000 m, well below the depth at which normal seawater will boil, and thus the alteration mineralogy probably reflects the direct input of magmatic volatiles. There are several Cenozoic to Mesozoic deposits with high sulphidation mineralogy that formed in a probable submarine environment. Examples occur in the Green Tuff belt of Japan, on Wetar Island in Indonesia, in the Pontid belt of northeastern Turkey, and in Haiti and adjoining parts of the Dominican Republic. These deposits are typically characterized by copper-gold-rich, enargite-pyrite stringer mineralization associated with silicification and advanced argillic alteration. Some deposits are capped by barite-rich zones which probably formed at or close to the seafloor. In the case of the Lerokis and Kali Kuning deposits on Wetar Island, sulphide in the baritic zones has been oxidized (either on the seafloor or post uplift) resulting in gold-bearing iron oxidebarite sand which constitutes the ore. Older high sulphidation VMS deposits may also exist, although deformation and metamorphism hinder the interpretation of their mineralogy and geometry. Possible examples include the latest Proterozoic-Early Cambrian Carolina Slate Belt gold deposits, the mid-Proterozoic Boliden deposit in the Skellefte VMS district of northern Sweden, and the Archean Bousquet deposits of Quebec.

The recognition of high sulphidation VMS mineralization has implications for exploration:

1. Deposits will be goldrich, and if oxidized, the gold may be easily recovered.

2. Unlike high sulphidation epithermal deposits, the VMS equivalent will show a strong stratigraphic control. Recognition of volcanic breaks and chemical sediments will be important.

3. High sulphidation VMS deposits may occur in camps dominated by traditional VMS deposits, particularly those that formed in arc settings, and conversely, VMS deposits may occur in areas where high sulphidation systems exist and have been assumed to be subaerial.

In the Cordillera, a possible example is the Treaty Glacier prospect in the Iskut area. Geological and geochronological data suggest that advanced argillic alteration in this area formed in a magmatic hydrothermal system at more or less the same time as the unusual Eskay Creek VMS deposit. There are also indications that the Treaty Glacier system was submarine, part of the alteration being superimposed on roughly coeval pillow basalts. The Treaty Glacier prospect suggests that there is potential for high sulphidation VMS mineralization in the Cordillera.

U – Subvolcanic Au-Ag-Cu: Transitions from Porphyry to Epithermal Environments

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Transitions from high level magmatic to hydrothermal conditions account for a variety of mineralization styles. Henley (1990) noted: 'magmatic vapour from crystallizing plutons is critical to (mineralization in) the epithermal environment much as described for porphyry copper-molybdenum-gold deposits' and ' in volcanic terrains the distinction of epithermal from porphyry-type environments of mineralization becomes largely one of convenience for exploration than one of reality'. The recognition that epithermal mineralization occurs in shallow parts of porphyry systems has been known for many years. The high-sulphidation epithermal deposits are generally considered to be intrusion-related. Low-sulphidation deposits are less convincingly so and, if intrusions are present, the deposits tend to occur well away from them.

Lateral and vertical zoning of deposit types and metals centred on intrusive bodies, and their overlying stratovolcanoes, is amply documented. These relationships, and other related styles of mineralization, are particularly well documented in Southwestern Pacific and Andean magmatic arcs. The superimposition, blending and blurring of porphyry and epithermal characteristics can take place in volcano-plutonic arcs when "telescoping" of hydrothermal systems occurs. This is commonly evident as an overprinting of earlier mineralization by lower temperature, more oxidized, advanced argillic alteration assemblages. The telescoping that take place during the late life of the mineralizing hydrothermal systems is commonly 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 can be regarded to be a closely related variant of high-sulphidation systems. The mineralizations are genetically related in as much as the hydrothermal fluids involved are derived from the same, or similar intrusions. However, there are enough significant differences to warrant a separate identity for a 'transitional' deposit type. The high-sulphidation deposits have characteristic copper sulphide (covellite) and Cu-As-Sb minerals (tennantite-tetrahedrite, enargite-luzonite) and advanced argillic (acid sulphate) alteration derived from highly oxidized and highly acidic fluids. The transitional deposits can have similar alteration and mineralization as well but it is generally subordinate and restricted to late, localized acidic fluid flow. The dominant mineralization is by quartz-sericite-pyrite derived from less oxidized, neutral-pH to weakly acidic, relatively high temperature and pressure and highly saline solutions that are more akin to porphyry than epithermal deposits.

The main characteristics of transitional deposits are summarized as follows:

Mineralization is intrusion-related; (sub-economic) porphyry copper-molybdenum deposits can occur nearby

The intrusions are emplaced as high-level, subvolcanic stocks; coeval volcanic rocks may, or may not, be present. Quartz-feldspar porphyry domes and flow dome complexes can be mineralized in their interior parts but, overall, they most commonly host typical epithermal and vein deposits

Cu-Au-Ag and/or Au-Ag ore is associated with polymetallic mineralization, typically with abundant As and Sb

Pyrite is the dominant sulphide mineral. Chalcopyrite, tetrahedrite/tennantite are common, enargite is rare or absent

Structural and lithologic permeabilities are the main ore controls

Sulphide minerals are present in stockworks, veins, breccias and local massive replacement to disseminated zones. The ore stockworks and vein sets are composed of sulphide-bearing fractures; they contain only minor quartz

Quartz-sericite-pyrite is the dominant alteration, mainly as a pervasive replacement of the ore hostrocks. Advanced argillic alteration forms a locally developed overprint with pervasive kaolinite and veins with quartz-alunite-(jarosite) assemblages. Higher-temperature zones contain andalusite, pyrophyllite, zunyite, diaspore and rare corundum; tourmaline is abundant in some deposits. Propylitic alteration is widespread in the hostrocks surrounding the ore zones

Vertical zoning is evident and lateral zoning of ore metals may be developed in deposits. From shallow to greater depth there is a progression from Au, Ag with increasing Cu, Zn and Pb, locally Mo, Bi and W and, rarely, Sn

Mineralization is related to 'robust' high temperature and relatively high pressure fluids emanating from porphyritic intrusions. The ore solutions are highly saline, moderately oxidized and less-acidic than those in high-sulphidation epithermal deposits

Deposits that will be discussed to exemplify this deposit type are the Kori Kollo mine, Bolivia, and Equity Silver mine, British Columbia.

Linkages between porphyry and epithermal deposits (and probably even Carlin-type jasperoid Au-Ag ores) are now recognized, but are poorly documented. In order to fully define an intrusion-related transitional deposit type, detailed geological deposit studies and careful investigations of alteration, ore and hostrock geochemistry, fluid inclusions and isotopes need to be conducted.

Cordilleran Exploration Targets

V – Wrangellia – A New Ni-Cu-PGE Metallogenic Terrane

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Triassic mafic-ultramafic intrusive complexes along the eastern margin of "Wrangellia", adjacent the Denali fault from east-central Alaska to northem British Columbia, constitutes a newly recognized Ni-Cu-PGE metallogenic terrane that can be traced along strike for at least 600 km. These sill-like intrusive centres acted as subvolcanic magma chambers that fed the thick overlying, oceanic plateau basalts of the Nikolai Group. Confinement of these olivine-rich ultramafic sills, Ni-Cu-PGE mineralization, more olivine normative and primitive coeval basalts exclusively to the eastern portion of Wrangellia is believed to be a product of melts forming in closer proximity to the hotter axial "jet" of the mantle plume that initiated melting, relative to the cooler more distal portions. 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 Proterozic komatiitic ultramafic bodies that host world class nickel sulphide deposits.

Detailed compositional investigations of silicates and oxides, from both the intrusive and extrusive Triassic magmatic environments, has provided valuable information allowing one to constrain the nature of the parental magmas, the influence of crustal contamination, the degree of communication with magmatic sulphides, and noteworthy spinel elemental associations only observed elsewhere in other major nickel deposits or promising prospects.

U-Pb dating of zircon from a consanguineous hypabyssal, gabbroic sill that intrudes the upper portion of a mineralized mafic-ultramafic complex, end feeds the proximal Nikolai basalts, provides a minimum age for these complexes and associated mineralization, and a precise age for the onset of Triassic volcanism in Wrangellia (232.3 + 1.0 Ma).

Geochemical and isotopic studies indicate that crustal contamination of the parental magmas that gave rise to the intrusive lithologies and ores has taken place. However, these studies in conjunction with magma mixing models, also suggest that there is an optimum amount of crustal contamination beyond which the quality of the mineralization decreases with respect to its Ni, Cu, Se, and PGE+Au grades. Selective emplacement of these subvolcanic intrusions at or near the interface of a major stratigraphic transition, where the chemical nature and the lithological competency of the strata changes, facilitates not only regional exploration, but also quantification of crustal contamination magma mixing models to explain grade variations at certain localities.

Examination of base and noble metal concentrations, in apparently un-mineralized mafic and ultramafic lithologies with comparable sulphur contents and degree of fractionation, throughout the eastern Wrangellia allows distinction between mineralized and un-mineralized intrusions. Cryptic chemical differences in the chalcophile element concentrations, normative olivine content and primativeness of the Triassic basalts have also been recognized between western and eastern Wrangellia. These differences have profound exploration, petrogenetic and metallogenic implications.

Prior to this study only the regional geology of the study area was available, knowledge pertaining to the tectonostratigraphic and tectonomagmatic setting was vague at best, and little if any appreciation existed for the significance of the mafic-ultramafic complexes. Because of the potential economic significance of this newly recognized Ni-Cu-PGE metallogenic terrane, and the general absence of vital information pertaining to the intrusions, sulphide deposits and mineralized occurrences, and the surrounding local geology; the author has attempted to provide a detailed documentation pertaining to this much needed information. In addition, an attempt has been made to provide a better understanding of the tectonostratigraphic and magmatic setting of Wrangellia and Ni-Cu-PGE metallogenic processes during the Triassic.

W – Sediment-hosted Sparry Magnesite Deposits

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Magnesium is a light metal, commonly produced from magnesite, that play increasingly important role in aerospace and automotive industries. Calcined magnesite has a broad range of industrial, chemical, environmental and agricultural applications. Dead-burned and fused magnesia are used mainly in high-performance refractories. Worldwide, most of economic magnesite deposits are associated either with ultramafic or sedimentary rocks. Sediment-hosted magnesite deposits are either fine-grained with well-preserved sedimentary textures or sparry. The origin of sparry magnesite deposits is controversial.

In British Columbia, the large sparry magnesite deposits are hosted by sedimentary rocks of Precambrian to Cambrian age. They are stratabound, occur in belts, and are associated with paleobathymetric highs of probable tectonic origin. The Mount Brussilof deposit is the only magnesite mine in Canada. The magnesite occurs within the Cambrian Cathedral Formation that is comprised of shallow-marine platform carbonates at the edge of the Cathedral escarpment and capped by an unconformity. The Brisco - Driftwood Creek deposits occur along the Windermere high, a paleobathymetric feature. They are hosted by carbonates of the Precambrian (Helikian) Mount Nelson Formation and associated with redbeds containing carbonate pseudomorphs after halite as well as stromatolite horizons, that indicate a shallow marine or lacustrine depositional environment. Magnesite deposits in the Cranbrook area are special because they occur in quartzites of the Cambrian Cranbrook Formation and may not be directly associated with a major paleotopographic high and are possibly reworked.

All, but Botts Lake deposit which is located in the Brisco area, consists mainly of magnesite characterized by sparry, pinolitic and zebra textures that can be interpreted as diagenetic or metasomatic replacement. Typical impurities are quartz or chert and dolomite; typical minor impurities commonly occurring as fracture fillings, in vugs or along bedding lanes are pyrite, calcite, clay and iron oxides, chlorite, calcite, mica, palygorskite and aragonite. Dolomite is either of planar or sparry variety. Where clear age relationship is observed, sparry dolomite post-dates sparry magnesite.
There are two preferred theories regarding the origin of sparry magnesite deposits:

1. Replacement of dolomitized, permeable carbonates by magnesite due to interaction with a metasomatic fluid, assuming an appropriate aCa2+/ aMg2+ ratio, salinity, temperature, high fluid/rock ratio etc.
2. Diagenetic recrystallisation of a magnesia-rich protolith of chemical, possibly evaporitic origin that may consist of fine-grained magnesite, hydromagnesite, huntite or other low temperature magnesia-bearing minerals.

The main difference between these hypotheses is the source of magnesia. It is external in case of metasomatic replacement and *insitu* in the case of diagenetic recrystalisation of magnesia-rich protolith.

Temperatures of homogenisation of inclusions constrain the temperature of magnesite formation or recrystalization to 110 to 240oC depending on the deposit and are in agreement with late-diagenetic or low temperature metasomatic origin or overprint. Both hypotheses are consistent with field and petrographic observations. Currently the diagenetic recrystalization theory is preferred, largely because of the stratigraphic association of carbonate-hosted sparry magnesite with paleotopographic highs, unconformities, hot Cambrian paleoclimate that prevailed in the area encompassed by British Columbia, shallow marine depositional features of the magnesite protoliths and the older age of magnesite than that of cross-cutting sparry dolomite that is commonly associated with MVT, Pb-Zn deposits.

A number of recent cryptocrystalline sedimentary magnesite deposits of exploitable size and grade are known, such as Salda Lake in Turkey and the Kunwarara deposit in Quensland, Australia. These cryptocrystaline deposits, as well as, huntite-magnesite-hydromagnesite deposits of Kozani Basin, Northern Greece, and the magnesite- or hydromagnesite- bearing evaporitic occurrences from Sebkha el Melah in Tunesia may be recent analogs to a pre-diagenetic protolith of British Columbia sparry magnesite deposits.

The model involving diagenetic recrystalisation of a primary magnesia-rich protolith restricts potential exploration areas in comparaison to the metasomatic replacement model. It imposes stratigraphic, paleoclimatic, paleotopographic and shallow depositional environment controls on the most favourable areas targeted for exploration. Nevertheless it is possible that some deposits, such as those of Cranbrook area, may represent reworked (secondary) deposits outside, but nearby, the expected prime exploration areas.

X – Ernest Henry-type Cu-Au-Magnetite Deposits in the Proterozoic

Michael Etheridge, Etheridge Henley Williams

The Ernest Henry Cu-Au deposit was discovered by Western Mining Corporation Ltd. and Hunter Resources Ltd. in 1991 within early Proterozoic rocks of the eastern Mount Isa Inlier (Cloncurry Belt), about 130 km ENE of Mount Isa (35 km NE of Cloncurry), Queensland, Australia. The deposit contains measured and indicated resources of 167 Mt at 1.1% Cu and 0.54 g/t Au.

Ernest Henry is the largest of a number of Cu-Au deposits in the eastern part of the Mount Isa Inlier. The Osborne (~15Mt at 3.0% Cu + 1.3g/t Au), Selwyn (~5Mt at 1.0% Cu + 5.0g/t Au), Eloise (~3Mt at 5.8% Cu + 1.5g/t Au) and Mt. Elliot (~2Mt at 3.0% Cu and 1.3g/t Au) deposits are currently being mined. Most of the deposits and numerous smaller occurrences) are associated with 'ironstones' and coincide with moderate to large amplitude magnetic anomalies. Ernest Henry and other deposits of the Cloncurry Belt have a number of similarities (and some obvious differences) to a variety of iron-rich Cu-Au deposits in middle Proterozoic and possibly the Kiruna-type deposits of Scandinavia).

Geological Setting of Ernest Henry-Type Deposits

The Cloncurry Belt comprises early to middle Proterozoic meta-sedimentary and meta-igneous rocks intruded by at least two quite distinct suites of granitoids. The metamorphic rocks range in depositional age from about 1800 Ma to as young as 1630 Ma and were derived from two or three principal tectonostratigraphic sequences that occur throughout northern Australia. Metamorphic grade ranges from mid-greenschist to upper amphibolite facies, and all of the supracrustal rocks have been subject to a complex compressional to transpressional deformational history during the Isan Orogeny between about 1600 and 1500 Ma.

The older granitoid suite was intruded during a widespread extensional event dated at about 1740Ma, and has consequently been overprinted by the Isan orogeny. The younger and more voluminous granitoids of the Williams Batholith intruded near the close of the Isan Orogeny at about 1500 Ma, and are spatially and temporally associated with a regional hydrothermal alteration event of spectacular scale and intensity.

Deposit Characteristics

All of the significant Cu-Au deposits in the Cloncurry Belt share the following characteristics:

1. They postdate the principal regional metamorphism and associated foliation(s) of the Isan orogeny.

2. They are spatially and temporally associated with the Williams Batholith granitoids.

3. They are structurally controlled by fault/shear zones, commonly with a complex brittle-ductile character: breccias and kink-folds are common in ore zones.

4. They occur in a wide variety of host rocks, including felsic to mafic meta-volcanics, granitoids, (meta)-diabase, and meta-sedimentary rocks ranging from carbonaceous slates to calc-silicates.

5. They are associated with iron-rich, high temperature alteration assemblages, most commonly magnetite-bearing (ironstones), although massive pyrrhotite-pyrite-chalcopyrite mineralisation occurs at Osborne and Eloise.

6. Cu:Au ratios range from about 4:1 (Eloise and other sulphide-rich, magnetite-poor deposits) to less than 1:5 (parts of the Selwyn deposit). Mineralised systems range from very low grades of both CU and AU to quite high grade ores (e.g. Selwyn and Eloise).

The key factors in developing exploration models for this type of deposits are the granitoid association and the structural association.

The Granitoid Association

A genetic link between the Cu-Au deposits of the Cloncurry district and the granitoids of the Williams Batholith is now well established and broadly accepted. Middle Proterozoic Cu-Au mineralisation, including the Olympic Dam deposit, in the Gawler craton of southern Australia is associated with a distinctive suite of similar post orogenic granitoids (Hiltaba Suite).

The characteristics of the Williams-type granitoids of the Cloncurry district are as follows:

1. They are I-type and dominantly granodiorite or more felsic in composition (mostly >60% SiO_2; as such, they differ significantly from the generally more mafic suites generally associated with porphyry Cu-Au mineralisation in modern and ancient arc settings.

2. They commonly show evidence in their chemistry of significant crystal fractionation.

3. Widespread metasomatic alteration of the granitoids and their county rocks; both high K/Na and low K/Na alteration styles are common.

The Structural Association

A 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. In the Cloncurry district, Cu-Au deposits occur in dilational sites on reverse, oblique-reverse and strike-slip faults of a range of orientations.

Ernest Henry appears to have formed on a reverse shear/fault zone where it shallowed in dip as it passed through a more competent meta-volcanic unit within calc-silicates. Ore grade mineralisation corresponds closely to through-going dilational brecciation of the meta-volcanics.

Deformation accompanying mineralisation, although locally significant, is regionally minor and related largely to limited reactivation of a structures formed earlier in the deformation history.

Exploration Criteria

The principal regional to local exploration criteria which follow from our current understanding of Ernest Henry-type mineralisation are as follows:

1. Proximity, preferably in the roof zones, to a distinctive suite of middle Proterozoic post-orogenic, fractionated granitoids.

2. Dilational sites on active shear/fault zones in the aureoles of the prospective granitoids.

3. More competent rock units, but otherwise little host-rock control.

4. Iron-rich alteration, most of the known mineralisation is associated with magnetite-bearing alteration, and magnetics is therefore a widely used prospecting tool. However, Cu/Au-poor magnetite ironstones are widespread and some deposits contain little or no magnetite.

Y – Olympic Dam-type Iron Oxide (Cu-U-Au-LREE) Deposits

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Olympic Dam-type iron oxide (Cu-U-Au-LREE) constitute a distinct class of ore deposits characterized by iron-rich, low-titanium rocks formed in extensional tectonic environments. These deposits formed primarily in shallow crustal environments (<4-6 km) and are expressions of deeper-seated, volatile-rich igneous-hydrothermal systems, tapped by deep crustal structures. Salient characteristics of this class are:

(1) *Age.* The majority of known deposits, particularly the larger examples, are found within Early to mid-Proterozoic host rocks (1.1 - 1.8 Ga). However, examples are recognized into the Tertiary.

(2) *Tectonic setting.* The deposits are located in areas that were cratonic or continental margin environments; in many cases there is a definite spatial and temporal association with extensional tectonics. Most of the districts occur along major structural zones, and many of the deposits are elongated parallel to regional or local structural trends. The host rocks may be igneous or sedimentary; many of the deposits occur within silicic to intermediate igneous rocks of anorogenic type. However, mineralization in many deposits is not easily related to igneous activity at the structural level of mineralization.

(3) *Mineralogy.* The ores are generally dominated by iron oxides, either magnetite or hematite. Magnetite is found at deeper levels than hematite. CO3, Ba, P, or F minerals are common and often abundant. The deposits contain anomalous to potentially economic concentrations of LREEs, either in apatite, or in distinct LREE mineral phases.

(4) *Alteration.* The host rocks are generally intensely altered. The exact alteration mineralogy depends on host lithology and depth of formation, but there is 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. In addition, the host rocks are locally intensely Fe-metasomatized.

In spite of these similarities, many variations occur between and within individual districts, particularly in deposit morphology. Individual deposits occur as strongly discordant veins and breccias to massive concordant bodies. Both the morphology and extent of alteration and mineralization appear to be largely controlled by permeability along faults, shear zones and intrusive contacts, or by permeable horizons such as poorly welded tuffs. Local variations in mineralogy and geochemistry may be largely attributable to wall-rock composition, and to P, T, and ƒO2 controls related to depth of formation.

Examples of Olympic Dam-type deposits are found in the Wernecke Mountains of eastern Yukon Territory and in the western portion of the Northwest Territories. The Wernecke Mountains contain approximately 90 discrete breccia bodies which are concentrated along the Richardson Fault Array, a major fault zone that controlled block faulting from the mid-Proterozoic to the Tertiary. The breccias cut the Proterozoic Wernecke Supergroup, a >4.5 km thick section of marine sediments. All the breccia bodies contain minor to significant amounts of iron oxide. Sulfide mineralization appears to be a late-stage event in all the breccia bodies. In the deeper breccias, chalcopyrite replaces magnetite and is intergrown with, or replaces pyrite and hematite. In stratigraphically higher breccias, chalcopyrite is veinlet-controlled and disseminated, as either replacements of magnetite or as interstitial grains within carbonate or specular hematite. Uranium minerals and gold commonly occur on the periphery of breccia bodies. LREEs in the Wernecke breccias are concentrated in apatite and monazite. Isotopic studies suggest that the hydrothermal fluids responsible for alteration and mineralization in these breccia bodies had near magmatic compositions.

Though the Olympic Dam-type deposits constitute major sources of iron (Kiruna, Chilean Fe), only two deposits are currently exploited for other metals (Olympic Dam - Cu, Au, U; Bayan Obo - LREE). The variability of Cu-U-Au-LREE contents within this deposit class, combined with potentially difficult metallurgy, makes these deposits a high risk exploration target. However, these factors are partially offset by the large size potential of these deposits.