



## TWO INTRIGUING MINERAL DEPOSIT PROFILES FOR BRITISH COLUMBIA

By David V. Lefebure

**KEYWORDS:** economic geology, mineral deposits, models, British Columbia, metallic, iron oxide, Kiruna type, Olympic Dam type, shale-hosted sulphides.

### INTRODUCTION

As part of its mineral resource potential assessment process, the British Columbia Geological Survey Branch is utilizing deposit models to define and characterize mineral and coal deposits which exist, or could exist, in the province. A fundamental part of this process is compilation of information about mineral deposits including descriptions, classification and resource data (Lefebure *et al.*, 1995, this volume). The resulting deposit models (called 'PROFILES') are being used to classify known deposits and occurrences, to guide experts in their identification of possible undiscovered mineral deposits, and to group deposits to allow compilation of representative grade and tonnage data.

The profiles may draw attention to deposit types with the potential to occur in British Columbia that may warrant exploration consideration. Two models with no known orebodies in the province, but intriguing exploration potential, are discussed in this article: iron oxide breccias and veins carrying copper, gold, uranium and rare earth elements; and shale-hosted nickel, zinc, molybdenum and platinum group deposits. Iron oxide breccias are now known to occur in southeast British Columbia (Stinson and Brown, 1995, this volume). The current interest in this deposit type stems from the possibility that a major polymetallic orebody similar to the Olympic Dam deposit in South Australia may exist in British Columbia. In the second deposit type, high-grade nickel, zinc, molybdenum and platinum group mineralization is hosted by black shale sequences. Although currently regarded as little more than a geological curiosity because the known deposits are thin (commonly less than 15 cm), there is the possibility that thicker deposits will be found or a new technology developed to mine these deposits.

### IRON OXIDE BRECCIAS AND VEINS

Deposits characterized by high iron oxide contents (generally greater than 20%) that crosscut their hostrocks have been described by Einaudi and Oreskes (1990),

Hauck (1990), Hitzman *et al.* (1992) and Gandhi and Bell (1993) and grouped as Olympic Dam type, Kiruna type, iron oxide rich deposits or Proterozoic iron oxide deposits. The iron oxides may be magnetite, magnetite and hematite, or hematite in breccia zones or veins which form pipes and tabular bodies. The deposits are hosted by continental volcanics and sediments and intrusive rocks and vary from monometallic to polymetallic with significant copper, gold, rare earth element and uranium values.

The profile for iron oxide breccias and veins lists many features of these deposits, including key exploration guides (Table 1). They can be subdivided into Kiruna-type deposits with a magnetite-apatite mineralogy (USGS model 25i, Cox and Singer, 1986) which grade to polymetallic Olympic Dam type hematitic orebodies (USGS 29b). Although magnetite-apatite deposits occur widely through time (post-Archean), the Olympic Dam type deposits may be restricted to the Middle Proterozoic as noted by Hauck (1992) and Hitzman *et al.* (1992).

Iron oxide breccia and vein deposits can be large; average tonnage for the magnetite-apatite iron ore deposits is 40 million tonnes (Cox and Singer, 1986). The Kirunavaara orebody in Sweden contains 2.6 billion tonnes grading 60% iron with significant phosphorus (Hitzman *et al.*, 1992).

Current interest in iron oxide deposits stems from discovery in 1975 of the Olympic Dam hematite-rich orebody within rocks of the Stuart Shelf in Australia. It contains 2 billion tonnes grading 1.6% Cu, 0.6 g/t Au, 0.35 g/t Ag and 0.6 kg/t U<sub>3</sub>O<sub>8</sub> with a total gross value in place of more than US\$110 billion (Siddler and Day, 1993). In recent years there have been a number of other iron oxide deposits with significant copper and gold values found in Australia, including the Ernest Henry and Osborne in northwest Queensland.

The most well known geological environment for iron oxide deposits in Canada is in the southern part of the Great Bear magmatic zone in the Northwest Territories (Hildebrand, 1986). There are occurrences of magnetite, apatite and actinolite veins and fracture fillings and magnetite, hematite and epidote breccias with uranium, copper, gold, cobalt and nickel minerals (Gandhi, 1994). The latter occurrences are similar to Olympic Dam type deposits and include two deposits, the Sue-Dianne and Mar.

In British Columbia, only the Iron Range deposit located northeast of Creston has been identified as an iron oxide breccia deposit (Alldrick, 1993; Stinson and Brown, 1995, this volume) which is possibly analogous

TABLE 1. DEPOSIT PROFILE FOR IRON OXIDE BRECCIAS AND VEINS

## Iron Oxide Cu-Au-Ag-U-P Breccias and Veins D07

### IDENTIFICATION

SYNONYMS: Olympic Dam type, Kiruna type, Apatite iron ore, Porphyrite iron (Yangtze Valley), Iron oxide rich deposits, Proterozoic iron oxide (Cu-U-Au-REE), Volcanic-hosted magnetite.

COMMODITIES (BYPRODUCTS): Fe, P, Cu, Au, Ag, U (potential for REE, Ba, F).

EXAMPLES (British Columbian - Canadian/International): Iron Range (082FSE014 - 028) - *Sue-Dianne, Northwest Territories; Wernecke Breccias, Yukon, Kiruna District, Sweden; Olympic Dam, Australia; Pea Ridge and Boss-Bixby, Missouri; El Romeral, Chile.*

### GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Magnetite and/or hematite breccia zones and veins which form pipes and tabular bodies hosted by continental volcanics and sediments and intrusive rocks. The deposits exhibit a wide range in their nonferrous metal contents. They vary from Kiruna type monometallic (Fe ± P) to Olympic Dam type polymetallic (Fe ± Cu ± U ± Au ± REE).

TECTONIC SETTING: Associated with stable cratons, typically associated with grabens related to rifting. Intracratonic extensional tectonics coeval with hostrock deposition. Upper crustal igneous or sedimentary rocks.

DEPOSITIONAL ENVIRONMENT/ GEOLOGICAL SETTING: Found crosscutting a wide variety of sedimentary and igneous rocks; magnetite-apatite deposits show an affinity for volcanics and associated hypabyssal rocks.

AGE OF MINERALIZATION: Proterozoic to Tertiary and believed to be virtually contemporaneous with associated suite of intrusive and/or volcanic rocks. Polymetallic iron oxide deposits are commonly mid-Proterozoic age varying from 1.2 to 1.9 Ga.

HOST/ASSOCIATED ROCK TYPES: Veins and breccias crosscut, or are conformable with, a wide variety of continental sedimentary and volcanic rocks and intrusive stocks, including felsic volcanic breccia, tuff, clastic sedimentary rocks and granites. There may be a special association with a felsic alkalic rock suite ranging from "red" granite, and rapakivi granite to mangerite and charnockite and various volcanic equivalents. Iron oxides have been reported as common accessories in the associated igneous rocks. In some deposits the iron oxide forms the matrix to heterolithic breccias which are composed of lithic and iron oxide clasts (usually hematite fragments), hematite-quartz microbreccia and fine-grained massive breccia. Some deposits have associated hematite-rich breccias, bedded iron oxides and iron oxide bearing volcanic rocks which are conformable with associated volcanic rocks. Magnetite lavas and feeder dikes exist on the El Laco volcano in Chile.

DEPOSIT FORM: Discordant pod-like zones, veins (dike-like), tabular bodies and stockworks; in some deposits dikes are overlain by iron oxide tuffs and flows. The veins and tabular zones extend horizontally and vertically for kilometres with widths of metres to hundreds of metres.

## Iron Oxide Cu-Au-Ag-U-P Breccias and Veins D07

**TEXTURE/STRUCTURE:** Cu-U-Au mineralization is typically hosted in the iron oxide matrix as disseminations with associated microveinlets and sometimes rare mineralized clasts. Textures indicating replacement and microcavity filling are common. Intergrowths between minerals are common. Hematite and magnetite may display well developed crystal forms, such as interlocking mosaic, tabular or bladed textures. Some of the deposits (typically hematite rich) are characterized by breccias at all scales with iron oxide and hostrock fragments which grade from weakly fractured hostrock on the outside to matrix-supported breccia (sometimes heterolithic) with zones of 100% iron oxide in the core. Breccias may be subtle in hand sample as the same iron oxide phase may comprise both the fragments and matrix. Breccia fragments are generally angular and have been reported to range up to more than 10 m in size, although they are frequently measured in centimetres. Contacts with hostrocks are frequently gradational over scale of centimetres to metres. Hematite breccias may display a diffuse wavy to streaky layered texture of red and black hematite.

**ORE MINERALOGY [Principal and subordinate]:** The deposits vary between magnetite-apatite deposits with actinolite or pyroxene (Kiruna type) and hematite-magnetite deposits with varying amounts of copper sulphides, Au, Ag, uranium minerals and REE (Olympic Dam type). Hematite (variety of forms), specularite, magnetite, bornite, chalcopyrite, chalcocite, pyrite, digenite, covellite, native copper, carrollite, cobaltite, Cu-Ni-Co arsenates, pitchblende, coffinite, brannerite, bastnaesite, monazite, xenotime, florencite, native silver and gold and silver tellurides. At Olympic Dam, copper is zoned from a predominantly hematite core (minor chalcocite-bornite) to chalcocite-bornite zone then bornite-chalcopyrite to chalcopyrite-pyrite in the outermost breccia. Uraninite and coffinite occur as fine-grained disseminations with sulphides; native gold forms fine grains disseminated in matrix and inclusions in sulphides. Bastnaesite and florencite are very fine grained and occur in matrix as grains, crystals and crystal aggregates.

**GANGUE MINERALOGY [Principal and subordinate]:** Gangue occurs intergrown with ore minerals as veins or as clasts in breccias. Sericite, carbonate, chlorite, quartz, fluorite, barite, and sometimes minor rutile and epidote. Apatite and actinolite or pyroxene with magnetite ores (Kiruna type). Hematite breccias are frequently cut by 1 to 10 cm veins with fluorite, barite, siderite, hematite and sulphides.

**ALTERATION MINERALOGY [Principal and subordinate]:** A variety of alteration assemblages with differing levels of intensity are associated with these deposits, often with broad lateral extent. **Olympic Dam type:** Intense sericite and hematite alteration with increasing hematite towards the centre of the breccia bodies at higher levels. Close to the deposit the sericitized feldspars are rimmed by hematite and cut by hematite veinlets. Adjacent to hematite breccias the feldspar, rock flour and sericite are totally replaced by hematite. Chlorite or potassium feldspar alteration predominates at depth. **Kiruna type:** Scapolite and albite?; there may also be actinolite-epidote alteration in mafic wallrocks. With both types of deposits quartz, fluorite, barite, carbonate, rutile, orthoclase ± epidote and garnet alteration are also reported.

**WEATHERING:** Supergene enrichment of Cu and U, for example, the pitchblende veins in the Great Bear magmatic zone.

**ORE CONTROLS :** Strong structural control with emplacement along faults or contacts, particularly narrow grabens. Mid-Proterozoic rocks particularly favourable hosts. Hydrothermal activity on faults with extensive brecciation. May be associated with felsic volcanic and alkalic igneous rocks. In some deposits calderas and maars have been identified or postulated. Deposits may form linear arrays more than 100 km long and 40 km wide with known deposits spaced 10-30 km along trend.

## Iron Oxide Cu-Au-Ag-U-P Breccias and Veins D07

ASSOCIATED DEPOSIT TYPES: Volcanic-hosted U (D06)?; alkaline porphyry Cu-Au deposits (L03); supergene uranium veins.

COMMENTS: Hitzman *et al.* (1992) emphasize that these are low-titanium iron deposits, generally less than 0.5% TiO<sub>2</sub> and rarely above 2% TiO<sub>2</sub> which allows distinction from iron oxides associated with anorthosites, gabbros and layered mafic intrusions. Iron and copper sulphides may be more common with hematite iron oxides.

### EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Anomalously high values for Cu, U, Au, Ag, Ce, La, Co, ± P, ± F, and ± Ba in associated rocks and in stream sediments.

GEOPHYSICAL SIGNATURE: Large positive gravity anomalies because of iron oxides. Regional aeromagnetic anomalies related to magnetite and/or coeval igneous rocks. Radiometric anomaly (such as airborne gamma-ray spectrometer survey) expected with polymetallic deposits containing uranium.

OTHER EXPLORATION GUIDES: Proterozoic faulting with associated iron oxides (particularly breccias), possibly related to intracratonic rifting. Widespread hematite, sericite or chlorite alteration related to faults. Possibly form linear arrays 100 or more kilometres long and up to tens of kilometres wide.

### ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE : Deposits may exceed 1 billion tonnes grading greater than 20 % Fe and frequently are in 100 to 500 Mt range. Olympic Dam deposit has estimated reserves of 2.0 billion tonnes grading 1.6% Cu, 0.06% U<sub>3</sub>O<sub>8</sub>, 3.5 g/t Ag and 0.6 g/t Au with a measured and indicated resource in a large number of different ore zones of 450 million tonnes grading 2.5% Cu, 0.08 % U<sub>3</sub>O<sub>8</sub>, 6 g/t Ag and 0.6 g/t Au with ~5,000 ppm REE. The Eastern Henry deposit in Australia contains 100 Mt at 1.6% Cu and 0.8 g/t Au. Sue-Dianne deposit in the the Northwest Territories contains 8 million tonnes averaging 0.8% Cu and 1000 ppm U and locally significant gold. The Kiruna district contains 3.4 billion tons of iron oxide apatite ore grading 50-60% iron and 0.5 -5 % phosphorus. The largest orebody at Bayan Obo deposit in Inner Mongolia, China contains 20 Mt of 35 % Fe and 6.19% REE.

ECONOMIC LIMITATIONS: Larger iron oxide deposits may be mined for iron only; however, polymetallic deposits are more attractive.

IMPORTANCE: These deposits continue to be important producers of iron and represent an important deposit type for producing Cu, U and possibly REE.

### REFERENCES

Einaudi and Oreskes (1990); Gandhi and Bell (1993); Hauck (1990); Hitzman *et al.* (1992); Oreskes and Einaudi (1990); Parak (1975); Reeve *et al.* (1990); Research Group of Porphyrite Iron Ore (1977); Roberts and Hudson (1983); Sidder and Day (1993).

to the Olympic Dam type deposits. However, there are other iron oxide breccias in rocks of equivalent age in the Wernecke Supergroup in the Yukon (Laznicka and Gaboury, 1988) with copper and uranium mineralization (Thorkelson and Wallace, 1992). The Igor deposit in the Wernecke Mountains contains 0.5 million tonnes grading 1% Cu (Hitzman *et al.*, 1992).

Recent work on the age and provenance of zircons from Belt Supergroup rocks in the northwest United States by Ross *et al.* (1992) supports a continental reconstruction that places the Stuart Shelf of south Australia offshore of the west coast of ancient North America in the Middle to Late Proterozoic. This idea was proposed initially by Bell and Jefferson (1987). Ross has found zircons in Belt sediments, derived from an unknown western source, that yield 1590 Ma dates. These dates are consistent with Bell and Jefferson's hypothesis, as the Gawler volcanics on the Stuart Shelf are virtually the same age. This has led Ross to suggest that there is potential for Olympic Dam type deposits in the Belt-Purcell Supergroup (G.M. Ross, personal communication, 1994).

Therefore, the best possibility for finding a polymetallic iron oxide deposit in British Columbia would appear to be in the Proterozoic Purcell Supergroup or the equivalent Muskwa assemblage in the northeastern part of the province (Figure 1).

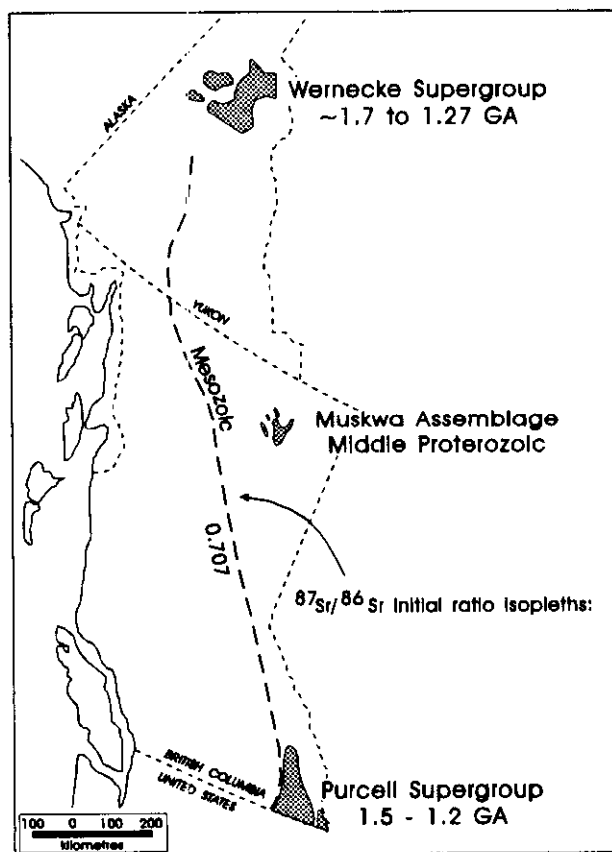


Figure 1. Mid-Proterozoic Sequences in British Columbia with Potential for Polymetallic Iron Oxide Breccias and Veins.

## SHALE-HOSTED Ni-Zn-Mo-PGE DEPOSITS

The discovery of the Nick deposit in the Selwyn Basin in 1981 (Hulbert *et al.*, 1992) has drawn attention to the potential of Cordilleran black shales to host nickel, zinc and platinum group element mineralization. Subsequent reports on similar deposits in China (Nansheng and Coveney, 1989; Coveney and Nansheng, 1991) provided more information about these deposits, including the potential for high molybdenum contents.

These shale-hosted sulphide deposits consist of thin layers of pyrite, vaesite ( $\text{NiS}_2$ ), amorphous molybdenite and sphalerite in black shale with associated phosphatic chert and carbonate rocks. The horizons have formed in anoxic basins within clastic sedimentary sequences containing black shales. As these deposits occur in the same settings as sedex lead-zinc-silver-barite deposits, there is an opportunity to discover them as well. The profile for these unusual deposits lists many of their features, including key exploration guides (Table 2).

The only production from these deposits has been from small tonnage mines in southeast China relying on labour-intensive methods. Currently only the Zunyi mine in southeast China is in operation. It is producing approximately 2000 tonnes of molybdenum ore annually with a cutoff of 4.1% Mo and grades between 4.1 and 7.1% Mo with up to 7.1% Ni, 2% Zn, 2.5% As, 0.57 g/t Pt, 0.66 g/t Pd and 0.55 g/t Au in ore samples (Coveney *et al.*, 1992, 1993). Currently the Chinese are only recovering molybdenum by roasting followed by caustic leaching to produce ammonium molybdate (Coveney *et al.*, 1992). The Nick mineralized layer in the Yukon contains, on average, 5.7% Ni, 1.2% Zn, 0.24% Mo, 0.39 g/t Pt, 0.24 g/t Pd and 0.15 g/t Au (Hulbert *et al.*, 1992).

The known deposits of this type are too thin to be economic at current metal prices, except where labour costs are very low. However, these deposits contain enormous tonnages of nickel, zinc and molybdenum because of their remarkable lateral extent and high grades. For example, the Nick horizon is believed to contain 0.9 million tonnes of nickel assuming a 3-centimetre horizon (Hulbert *et al.*, 1992). Such material will be exploited if thicker deposits can be found or a relevant new technology is developed.

Regional geochemistry is the most effective exploration tool for these deposits because the mineralized horizons are so laterally extensive and the contained metals contrast strongly with background values in the sedimentary succession. For example, the Nick occurrence was found as the result of anomalous stream sediment samples collected by the Geological Survey of Canada during a regional survey. Shale-hosted nickel-zinc-molybdenum-platinum group mineralization is characterized by elevated abundances of Ni, Mo, Au, PGE, C, P, Ba, Zn, Re, Se, As, U and S. Increased organic content appears to correlate with higher Ni, Mo and Zn values (Maughan, 1976). There is a strong spatial correlation with phosphatic horizons; mineralized layers are typically enriched in phosphate.

TABLE 2. PROFILE FOR SHALE-HOSTED Ni-Zn-Mo-PGE DEPOSITS

## SHALE-HOSTED Ni-Zn-Mo-PGE

E16

### IDENTIFICATION

SYNONYMS: Sediment-hosted Ni-Mo-PGE, Stratiform Ni-Zn-PGE.

COMMODITIES (POSSIBLE BYPRODUCTS): Ni, Mo (stone coal, P, Zn, Pt, Pd, Au).

EXAMPLES (British Columbia - Canada/International): *Nick, Yukon; large number of deposits in southeastern China including mining camps of Tianshan, Xintuguo, Tuansabao and Jinzhuwain, north central Guizhou Province and Zunyi Mo deposits, Dayong-Cili District.*

### GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Thin layers of pyrite, vaesite ( $\text{NiS}_2$ ), jordisite (amorphous  $\text{MoS}_2$ ) and sphalerite in black shale sub-basins with associated phosphatic chert and carbonate rocks.

TECTONIC SETTING(S): Continental platform sedimentary sequences and possibly successor basins. All known deposits associated with orogenic belts, however, strongly anomalous shales overlying the North American craton may point to as yet undiscovered deposits over the stable craton.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Anoxic basins within clastic sedimentary (flysch) sequences containing black shales.

AGE OF MINERALIZATION: Post-Archean. Known deposits are Early Cambrian and Devonian, however, there is potential for deposits of other ages.

HOST/ASSOCIATED ROCK TYPES: Black shale is the host; associated limestones, dolomitic limestones, calcareous shale, cherts, siliceous shale, siliceous dolomite, muddy siltstone and tuffs. Commonly associated with phosphate horizons. In the Yukon at base of a 10 to 20 m thick phosphatic shale bed and in China the Ni-Mo beds are in black shales associated with phosphorite.

DEPOSIT FORM: Thin beds (0 to 15 cm thick, locally up to 30 cm) covering areas up to at least 100 hectares and found as clusters and zones extending for tens of kilometres.

TEXTURE/STRUCTURE: Semimassive to massive sulphides, phosphorite, quartz and organic matter as nodules, spheroids, framboids and streaks or segregations in a fine-grained matrix of sulphides, organic matter and nodular phosphorite or phosphatic carbonaceous chert. Mineralized bed may be rhythmically laminated; often has thin discontinuous laminae. Brecciated clasts and spheroids of pyrite, organic matter and phosphorite. In China nodular textures (~ 1 mm diameter) grade to coatings of sulphides on tiny 1-10  $\mu\text{m}$  spherules of organic matter. Fragments and local folding reflect soft-sediment deformation. Abundant plant fossils at Nick occurrence and numerous fossils of microorganisms (cyanobacteria, algal mats) in the Chinese ores.

ORE MINERALOGY [Principal and subordinate]: Pyrite, vaesite ( $\text{NiS}_2$ ), amorphous molybdenum minerals (jordisite  $\text{MoS}_2$ ), bravoite ( $[\text{Fe},\text{Ni}]_2\text{S}_2$ ), sphalerite, wurtzite, polydimite ( $\text{Ni}_2\text{S}_4$ ), gersdorffite ( $\text{NiAsS}$ ), violarite ( $\text{Ni}_2\text{FeS}_4$ ), millerite, sulvanite, pentlandite, tennantite and, as traces, native gold, uraninite, tiemannite ( $\text{HgSe}$ ), arsenopyrite, chalcopyrite and covellite. Discrete platinum group minerals may be unusual. Some ore samples are surprisingly light because of abundant organic matter and large amount of pores.

GANGUE MINERALOGY: Chert, amorphous silica, phosphatic sediments, barite and bitumen. May be interbedded with pellets of solid organic matter (called stone coal in China). Barite laths are reported in two of the Chinese deposits.

ALTERATION MINERALOGY: Siliceous stockworks and bitumen veins with silicified wallrock occur in the footwall units. Carbonate concretions up to 1.5 m in diameter occur immediately below the Nick mineralized horizon in the Yukon.

WEATHERING: Mineralized horizons readily oxidize to a black colour and are recessive. Phosphatic horizons may be resistant to weathering.

## SHALE-HOSTED Ni-Zn-Mo-PGE

E16

**ORE CONTROLS** : The deposits developed in restricted basins with anoxic conditions. Known deposits are found near the basal contact of major formations. Underlying regional unconformities and major basin faults are possible controls on mineralization. Chinese deposits occur discontinuously in an arcuate belt 1600 km long, possibly controlled by basement fractures.

**GENETIC MODEL**: Several genetic models have been suggested, reflecting the limited data available and the unusual presence of PGEs without ultramafic rocks. Syngenetic deposition from submarine springs with deposition of metals on or just beneath the seafloor is the most favoured model. Siliceous venting tubes and chert beds in the underlying beds in the Yukon suggest a hydrothermal source for metals.

**ASSOCIATED DEPOSIT TYPES**: Phosphorite layers (F07?), stone coal, Sedex Pb-Zn (E14), Sediment-hosted barite (E17), sediment-hosted Ag-V, uranium deposits.

**COMMENTS**: Ag-V and V deposits hosted by black shales have been described from the same region in China, hosted by underlying late Precambrian rocks.

### EXPLORATION GUIDES

**GEOCHEMICAL SIGNATURE**: Elevated values of Ni, Mo, Au, PGE, C, P, Ba, Zn, Re, Se, As, U, V and S in rocks throughout large parts of basin and derived stream sediments. In China average regional values for host shales of 350 ppm Mo, 150 ppm Ni, several wt % P<sub>2</sub>O<sub>5</sub> and 5 to 22% organic matter. Organic content correlates with metal contents for Ni, Mo and Zn.

**GEOPHYSICAL SIGNATURE**: EM for pyrite horizon. Scintillometer to detect anomalous U.

**OTHER EXPLORATION GUIDES**: Anoxic black shales deposited in sub-basins within marginal basins. Chert or phosphate-rich sediments associated with a pyritiferous horizon. Barren pyrite layers from 5 mm to 1.5 cm thick, located up to tens of metres above mineralized horizon.

### ECONOMIC FACTORS

**TYPICAL GRADE AND TONNAGE** : These thin sedimentary horizons (not economic) may represent hundreds of thousands of tonnes grading in percent values for Ni, Mo or Zn with significant PGEs. In China the Zunyi Mo mines yield ~2000 tonnes per year averaging ~4% Mo and containing up to 4% Ni, 2% Zn, 0.7 g/t Au, 50 g/t Ag, 0.3 g/t Pt, 0.4 g/t Pd and 30 g/t Ir. The ore is recovered from a number of small adits using labour-intensive mining methods.

**ECONOMIC LIMITATIONS**: In China the Mo-bearing phase is recovered by roasting followed by caustic leaching to produce ammonium molybdate. Molybdenum-bearing phases are fine grained and all ore (cutoff grade 4.1% Mo) is shipped directly to the smelter after crushing.

**IMPORTANCE**: Current world production from shale-hosted Ni-Zn-Mo-PGE deposits is approximately 1000 tonnes of ore with grades of approximately 4% Mo. Deposits of this type are too thin to be economic at current metal prices, except in special conditions. However, these deposits contain enormous tonnages of relatively high grade Ni, Mo, Zn and PGE which may be exploited if thicker deposits can be found.

### REFERENCES

Coveney Jr. and Nansheng (1991); Coveney *et al.* (1992); Coveney *et al.* (1993); Fan Delian (1983); Horan *et al.* (1994); Hulbert *et al.* (1992); Murowchick *et al.* (1994).

There is potential to find these deposits in a number of sedimentary sequences in British Columbia. The most obvious is the southeasterly extension of the Devonian black shales of the Selwyn Basin that host the Nick deposit, into the Kechika Trough of northeastern British Columbia (Figure 2). Although no shale-hosted nickel sulphide occurrences have been reported from this area, there is geochemical evidence that they could exist. In 1978 Texasgulf Inc. found a tufa deposit with up to 8.4% Zn immediately northeast of the confluence of the Kechika and Gataga rivers (Carne, 1991). Subsequently Noranda Exploration Company, Limited and Archer, Cathro and Associates Limited outlined widespread areas with high Zn-Cu-Mo-Ag values. Archer, Cathro and Associates Limited have since found values in excess of 10000 ppm Zn and 4000 ppm Ni near Red Bluff Creek, in the area, now covered by the Netson claims (Figure 2). As there are no igneous rocks in the area, shale-hosted nickel sulphide occurrences are currently the presumed source of the nickel and molybdenum. The anomaly lies near the transition between dominantly calcareous or dolomitic shale and mudstone of the Ordovician to Lower Devonian Road River Group and siliciclastic turbidite and debris-flow deposits interlayered with carbonaceous cherty argillites of the Middle Devonian to Mississippian Earn Group (Ferri *et al.*, 1995, this volume).

Other potentially prospective black shale sequences are the Bowser Lake Group of central British Columbia and the Exshaw and Fernie Formations in the southeastern corner of the province.

## SUMMARY

There is potential to find a wide variety of orebodies in British Columbia. The mineral deposit profiles being developed by the British Columbia Geological Survey Branch may provide explorationists with information on deposit types with no known orebodies in the province.

## ACKNOWLEDGEMENTS

These two deposit profiles represent the results of a literature review by the author. The only "ground truthing" is thanks to reviews and instructive conversations with Sunil Gandhi and Larry Hulbert of the Geological Survey of Canada and Ray Coveney of the University of Missouri -Kansas City. Comments by Tom Setterfield of Westminer Canada Ltd. and Rob Carne of Archer, Cathro and Associates Limited were also appreciated.

The manuscript benefited from reviews by Dani Alldrick, John Newell and Patrick Stinson.

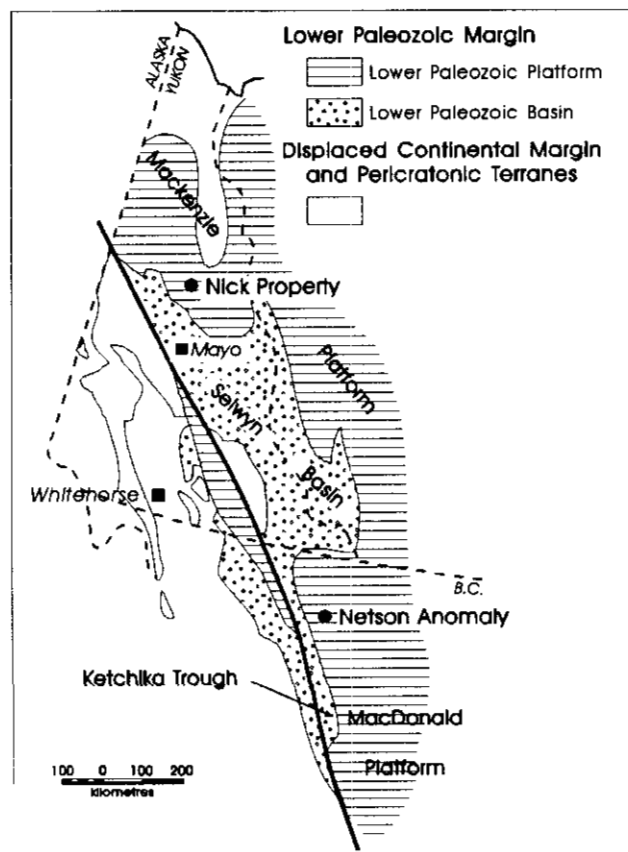


Figure 2. The extension of the Mackenzie Platform into northeastern British Columbia is a prospective area for finding shale-hosted Ni-Zn-Mo-PGE deposits. Both the Nick occurrence and Netson property are hosted by shale outliers similar to Road River Group and Earn Group rocks found within the Selwyn Basin and Kechika Trough. Figure modified from Hulbert *et al.* (1992).

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## NOTES