

Recent Advances in Base Metal Indicator Mineralogy: An Update from Overburden Drilling Management Limited

Introduction

Most heavy mineral geochemistry laboratories process samples primarily for kimberlite indicator minerals (KIMs). Some KIM species have distinctive features and are readily identified by mineral technicians but others are more obscure. The laboratory of Overburden Drilling Management Limited (ODM) in Nepean (Ottawa), Ontario, Canada differs from other heavy mineral laboratories in that all indicator mineral logging is performed by experienced exploration geologists rather than mineral technicians. Geological logging not only ensures improved identification of difficult KIM species but also permits recognition of all other heavy minerals in the sample including indicator minerals other than KIMs and background mineral assemblages that fingerprint the potential source regions of the indicator minerals.

Indicator minerals in general are heavy (concentratable), coarse grained (readily identifiable) and chemically stable in weathered surficial sediments. The stability requirement excludes most sulphide minerals except chalcopyrite and sphalerite which are somewhat resistant to degradation. For example, a major sphalerite anomaly in till detected recently for the Alberta Geological Survey suggests the presence of previously

unrecognized Mississippi Valley-type Pb-Zn mineralization in the northwestern part of the province (Plouffe *et al.*, 2006). However, ODM has identified several other suites of magmatic/metamorphosed massive sulphide indicator minerals (MMSIMs®) that are much more resistant than sulphides and are diagnostic of specific types of sulphide deposits (Averill, 2001). At present, the company's principal focus is on porphyry Cu indicator minerals (PCIMs®) and Ni-Cu-PGE indicators. For example, it is assisting the Canadian Mining Industry Research Organization (CAMIRO) with a major study of indicator minerals in both bedrock and overlying glacial and nonglacial sediments at five Ni-Cu-PGE deposits in

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Canada, Australia, Russia and China. To facilitate such studies, an electric pulse disaggregator is being installed. This device crushes rocks primarily around their constituent mineral grains rather than through the grains as in conventional milling.

Ni-Cu-PGE Indicator Minerals

The types of indicator minerals potentially present in the vicinity of a Ni-Cu-PGE deposit are inexorably linked to the conditions of formation of the deposit because these conditions involve chemical factors that influence mineral compositions. The two principal conditions of deposit formation have been elucidated most recently by

Mungall (2005). The first condition is that the parental melt must be enriched in Ni-Cu-PGE; *i.e.* partial melting of the source rocks, normally garnet peridotite in the upper mantle, must progress to a sufficient degree to produce a fertile melt. Such high-degree melts are also enriched in Mg and Cr and therefore tend to crystallize Mg- and Cr-bearing indicator minerals including olivine (especially forsterite), orthopyroxene (especially enstatite), Cr-diopside and chromite. Very high concentrations of these indicator minerals can further signify proximity to a restricted conduit where the separation of cumulus and sulphide minerals was concentrated during fractional crystallization of the melt after its ascent to the crust. Chromite is of particular interest because it is a significant collector of PGMs in the

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Figure 1. Binocular microscope photographs of representative populations of transported chromite grains derived from specific bedrock lithologies. All grains are of 0.5 to 1.0 mm size. (a) sharp to ragged crystals derived from peridotite; (b) resorbed crystals derived from kimberlite; (c) crystals corroded by lateritic weathering, masking their primary form and paragenesis.

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form of minute inclusions.

The above-mentioned Ni-Cu-PGE indicator minerals include species that are also used as KIMs because garnet peridotite horizons similar to those that produce Ni-Cu-PGE-fertile melts are sampled by kimberlitic melts during their ascent through the upper mantle. However the two suites differ in detail both chemically and in their physical characteristics. For example, Cr-diopside derived from a Ni-fertile intrusion typically contains less Cr_2O_3 and therefore is of a less vivid green colour than kimberlitic Cr-diopside. Chromite crystals from such intrusions are sharp, ragged or pitted (Fig. 1a) rather than rounded by resorption (Fig. 1b) as in kimberlite although in a lateritic environment these physical differences may be masked by corrosive weathering (Fig. 1c).

The second condition for successful formation of a Ni-Cu-PGE deposit is that the fertile silicate melt becomes sulphide saturated while passing through the conduit and crystallizing, causing the separation of a sulphide liquid. Sulphide liquid is a major collector of Ni-Cu-PGE. As well, being heavy, it will settle to the bottom of the conduit (or concentrate in particular layer in the case of a stratiform complex) to form a significant deposit provided a sufficient volume of fertile magma passes through the conduit. Sulphide solubility is inherently high in Fe and Mg-rich melts under mantle conditions and

increases with decreasing pressure (ascending magma). It decreases with decreasing temperature but sulphide saturation can be reached most efficiently through removal of Fe and Mg from the melt by concentrated crystallization of olivine and pyroxene or through addition of SiO_2 and Al_2O_3 to the melt by assimilation of felsic crustal rocks. Sulphide saturation would, of course, be greatly accelerated if the assimilated rocks also contained sulphides but this increases the risk of sulphide oversaturation, resulting in a very low-grade deposit.

Assimilation of felsic rocks by mafic magmas produces hybrid Fe-Al, Mg-Al and Cr-Al alteration minerals such as black hercynitic spinel, green Cr-garnet (Cr-grossular, Cr-andradite or uvarovite) and ruby (Cr-bearing) corundum. The sulphide mineralization itself, other than the chalcopyrite component if present, is not a potential source of indicator minerals, nor are most PGE-bearing minerals (PGMs). In many deposits, Pt and Pd are held mainly in unstable sulphides such as braggite ((Pt,Pd,Ni)S) or tellurides such as merenskyite ((Pd,Pt)(Te,Bi)₂) rather than in stable native minerals or arsenides such as sperrylite. The susceptibility to weathering of Pt and Pd sulphides and tellurides in sediments is further increased by their tendency to occur as minute, silt-sized (<0.063 mm) grains rather than in the medium to coarse sand sizes (0.25 to 2.0 mm) like the other indicator minerals.

Porphyry Cu Indicator Minerals

In 2001 ODM developed the PCIM method, initially targeting porphyry Cu deposits in arid regions such as the Atacama desert where the climate has stabilized primary Cu-sulphide mineralization by converting it into chemically resistant (to ongoing arid weathering) supergene minerals such as atacamite. The original test samples were primarily of chusca developed on alluvium and were typically collected at a depth of 0.2 to 0.3 m, taking care to avoid surface sediment potentially containing wind-blown mineral contamination from mining or drilling activity. More humid regions have also been tested with appropriate changes to the sampling medium and indicator mineral suite. In addition, PCIM

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technology has been used to explore for epithermal Au deposits peripheral to porphyry Cu deposits.

PCIMs are as large as KIMs and Ni-Cu-PGE indicator minerals (0.25 to 2.0 mm) and produce even stronger anomalies in surficial sediments due to the extreme size of mineralized porphyry systems. Consequently only 1 kg samples, rather than 10 to 20 kg, are required facilitating sample collection and shipping, and just one sample/km² is sufficient to identify and outline significant porphyry Cu and epithermal Au systems. However, processing costs are similar to KIM projects because PCIMs have a wider specific gravity range, requiring the extraction and examination of both a mid-density and heavy mineral concentrate.

PCIMs that have been used successfully to date include six hypogene alteration species – diaspore, tourmaline (dravite), FeCaMn-garnet (andradite, grossular and spessartine; common metamorphic almandine is conveniently absent from Atacama samples), primary alunite, red rutile and barite – plus two supergene alteration minerals – jarosite and secondary alunite – and two “oxide” Cu minerals, turquoise and atacamite. Together these minerals fingerprint the overall porphyry Cu system; some also define individual alteration and mineralization zones within the system. For example, the presence of diaspore, tourmaline or primary alunite indicates advanced argillic alteration, FeCaMn-garnet indicates propylitic alteration and barite indicates a transition from porphyry Cu to epithermal Au mineralization. Other minerals being investigated include apatite, anatase, rose zircon and blond titanite. As in exploring for kimberlite with KIMs, it is not the presence of a single PCIM but rather a systematic suite of PCIMs in surficial sediments in a restricted area that indicates proximity to a porphyry Cu alteration system. Blind surveys in sloped areas with relatively thin (<20 m) cover have clearly distinguished between and accurately outlined the individual alteration zones whereas samples collected on thicker alluvial plains tend to give a blended PCIM response reflecting the overall porphyry system. Processing of alluvium from deep reverse circulation holes drilled to test bedrock has proved effective in extending the exploration coverage of the holes at minimal added cost.

In summary, PCIMs can be as useful as KIMs because: 1) there are more useable PCIM species than KIM species; 2) porphyry Cu alteration systems are much larger than kimberlite pipes and therefore supply far more indicators; and 3) the different alteration zones associated with porphyry deposits supply different and distinct suites of indicators. Together these features make PCIM exploration just as effective as KIM exploration, and even more discriminatory. Having recognized the broader indicator mineral associations, several questions concerning mineral chemistry are now apparent. Which, if any, of the three garnet species associated with propylitic alteration zones is the best indicator of Cu fertility? Is red colouration in rutile due to Cu or Cr? What imparts the distinctive rose colour to some zircons in otherwise colourless populations? Does blondness in titanite have any chemical significance? Can we discriminate chemically between primary and secondary alunite grains? To what extent are weak Cu anomalies in selective extraction soil geochemical surveys due to traces of Cu-bearing mineral grains in the sediment versus some mechanism of aqueous, gaseous or electrochemical migration of Cu from bedrock to surface? Recent record Cu prices suggest that the answers to such questions are of more than academic interest.

References

Averill, S.A. 2001. The application of heavy indicator mineralogy in mineral exploration with emphasis on

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base metal indicators in glaciated metamorphic and plutonic terrains. *In: McClenaghan, M. B. et al. (eds) Drift Exploration in Glaciated Terrain. Geological Society of London, Special Publication 185, p. 69-81.*

Mungall, J.E. 2005. Magmatic geochemistry of the platinum-group elements *In: Mungall, J.E. (ed), Exploration for Platinum-Group Element Deposits. Mineralogical Association of Canada, Short Course Series, Volume 35, p. 1-34.*

Plouffe, A., Paulen, R.C. and Smith, I.R. 2006. *Indicator mineral content and geochemistry of glacial sediments from northwest Alberta (NTS 84L, M): new opportunities for mineral exploration. Alberta Geological Survey Special Report 77, Geological Survey of Canada, Open File 5121.*

Stuart Averill

Overburden Drilling Management Limited

107 - 15 Capella Court

Ottawa, ON, CANADA

K2E 7X1

Email: odm@storm.ca

Telephone: 613-226-1771

