Discrimination between Magmatic and Hydrothermal Ni-Cu-PGE and PGE Mineralization

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Introduction
Mafic-ultramafic-hosted Ni-Cu-(PGE) and PGE deposits are believed to have formed by segregation of immiscible sulfide melts and/or alloys from mafic-ultramafic magmas in dynamic magmatic systems such as lava channels, feeder dikes, and magma chambers. However, some of the mineralization in some deposits (e.g., hydrothermal veins at Kambalda: Lesher & Keays, 1984; Stillwater J-M reef: Boudreau et al., 1986; Sudbury footwall ores: Farrow & Watkinson, 1996) is associated with hydrous and/or halogen-bearing phases and is interpreted to have formed from or been modified by hydrothermal fluids.

Different base, precious, and semi-metals have different solubilities and partition differently between silicate magmas, sulfide melts, and supercritical fluids/volatiles (e.g., Keays & Crocket, 1970; Keays et al., 1982; Barnes & Maier, 1999; Mathez, 1999; Wood, in press). For example, the solubilities of Fe, Co, Ni, Cu, PGEs, and Au are different in sulfide melts and hydrothermal fluids; Au, Cu, and platinum-group PGEs (PPGE: Pt, Pd, Rh) behave differently than Ni, Co, and iridium-group PGEs (IPGE: Ru, Ir, Os); and Ru and Ir behave differently than other IPGEs. Therefore, it should be possible to distinguish between those ores deposited by magmatic processes and only modified by hydrothermal fluids. Unfortunately, very few deposits have been systematically analyzed for complete suites of base, precious, and semi-metals, but it is possible to make some preliminary interpretations.

Discrimination
Although the behavior of the different metals varies with magma/fluid composition, temperature, pressure, $fO_2$, and $fS_2$, the general order of partitioning into sulfide melts appears to be PGE ~ Au > Cu > Ni > Co > Fe, whereas the general order of solubility in hydrothermal fluids appears to be Fe > Cu ~ Au > Pt ~ Pd > Ni > Co >> Ru ~ Ir. Differential crystallization/precipitation processes can further fractionate different elements, but it is possible, at least in most cases, to distinguish between magmatic and hydrothermal mineralization on the basis of Au/Cu/Pt/Pd, Ir/Ni, and Cr/Fe ratios. These differences are best illustrated on primitive mantle-normalized variation diagrams (Figs. 1-5; data sources shown as initials of authors and year; ore types: DS = disseminated, NS = net-textured, RN$ = reverse net-textured, M$ = massive, IPS = Interpillow, Ni-SED = Ni-enriched metasedimentary, V$ = hydrothermal vein.)

For example, the majority of the ores at Kambalda (Fig. 1), Langmuir (not shown), Donaldson West (Fig. 2), and Sudbury (Fig. 3) exhibit relatively systematic variations in metal ratios with fractionations consistent with magmatic segregation from komatiitic, basaltic komatiitic, and noritic magmas (see Barnes & Naldrett, 1985), respectively, and local mobilization of Au, Pd, Pt, and/or Cu. However, hydrothermal veins and Ni-enriched metasediments in these localities are strongly depleted in Ir, sometimes depleted in other IPGE (e.g., Rh at Sudbury, Rh-Ru-Os at Donaldson), and also depleted (where data are available) in Cr. In contrast, ores at Lac des Iles, New Rambler, and Rathbun Lake (Fig. 4) are strongly enriched in PPGE relative to IPGE and strongly depleted in Ir relative to Ni and/or other PGE. Their compositions are consistent with hydrothermal modification of magmatic sulfides (Lac des Iles and some Rathbun Lake samples) or with hydrothermal transport and deposition (New Rambler and some Rathbun Lake samples).

The ores in the Bushveld and Stillwater complexes (Fig. 5) are depleted in Ni and Cu relative to other metals, but are not significantly depleted in Ir or other IPGE. Their Ir contents are more consistent with magmatic segregation (e.g., Campbell et al., 1983) and hydrothermal modification than with hydrothermal generation (e.g., Boudreau et al., 1986). However, Stillwater ores appear to have lower Cu and much higher Pd and Pt contents, consistent with stronger hydrothermal modification.
Clearly, more experimental data are required to establish the relative mobilities of PGEs in hydrothermal fluids, but if the observed fractionations in known hydrothermal ores are characteristic, then they suggest that the PGE mineralization in the Bushveld and Stillwater Complexes segregated via magmatic processes and was subsequently modified by hydrothermal processes.

References


Jones, R.T., 1999, Platinum Smelting in South Africa (http://www.mintek.ac.za/Pyromet/Platinum/Platinum.htm)


