HYDROTHERMAL NI-CU-PGE SULPHIDE MINERALIZATION FROM THE VERMILION OFFSET , SUDBURY, CANADA: MINERALOGY AND FLUID INCLUSION STUDIES

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Introduction

The Vermilion deposit was intermittently mined between 1887 and 1918. 4000 tons of ore grading 6.64% Ni and 6.69% Cu with significant platinum group element (PGE) values were exploited during that period of time (Farrow and Lightfoot 2002). The mine is famous for being the locality where H.L. Wells discovered sperrylite ($PtAs_2$) (Wells, 1889). Our detailed geological mapping, surface and exploration drill core sampling, and mineralogical studies revealed that there are sulphide-poor, but extremely PGE-rich domains within the mineralization. Those zones have features that are atypical of magmatic sulphide ore deposits of the Sudbury Igneous Complex (SIC).

Geology

The 1.85 Ga. SIC is an impact-related, oval-shaped layered igneous body composed, from base to top of norite, gabbro and granophyre. It is located close to the boundary of the Archean Superior and Proterozoic Southern Provinces of the Canadian Shield. At the base of the SIC, there is a discontinuous unit termed Contact Sublayer that is host to most of the magmatic Ni-Cu(-PGE) sulphide mineralisation; this consists of pyrrhotite-pentlandite-chalcopyrite magmatic segregation assemblages. Quartz diorite (QD) dikes radiating away from the periphery of the SIC as far as 25 kilometres contain Cu-Ni-PGE sulphide deposits. The Vermilion Offset dike (Grant and Bite, 1984) is one of the QD dikes and consists of a northwest-striking, 20 to 200 m long pods of amphibole-biotite QD in a zone of impact related Sudbury Breccia (pseudotachylite breccia) at the southwest margin of the Sudbury Structure. This part of the Sudbury Structure is characterised by north-eastward oriented thrusting that affected the SIC along local brittle-ductile shear zones. The age of thrusting is uncertain and it may have taken place between the late stages of the Penokean Orogeny (1.9-1.7 Ga) and the Grenville Orogeny (1.1 Ga).

Results

Mineralogical data. The QD pods consist of amphibole-biotite feldspar and quartz with relics primary magmatic blebby sulphide assemblages dominated by pyrrhotite, pentlandite and chalcopyrite. Locally amphibole-biotite QD alters to biotite-QD which contains finely disseminated 1-5 mm grains of sulphide minerals in complicated intergrowths with hydrous silicates. In this type of mineralization chalcopyrite is abundant, characteristically with maucherite and nickeline inclusions. Individual sector-zoned maucherite contains numerous sudburyite, chalcopyrite and gold grains. Large grains of chalcopyrite are replaced by millerite and bornite. Bornite contains radial blebs of hessite-wittichenite with fine-grained native Au. Hessite-electrum-froodite-michenerite-sudburyite-annivite-parkerite assemblages form complicated intergrowths with chalcopyrite, bornite, digenite, chlorite, epidote, albite, quartz and calcite. Sperrylite appears as solitary grains in chalcopyrite and in hydrous silicate minerals. Gersdorffite encrusts earlier sulphide phases and occurs as fine euhedral grains in silicates throughout the whole QD pod. In foliated Sudbury Breccia, PGM aggregates occur along foliation planes, and they are entirely included in chlorite, biotite and quartz grains. Quartz-carbonate veins that cut QD and its inclusions, also contain chalcopyrite-bornite-tetrahedite-millerite-violarite-pyrite-marcasite assemblages and one vein in QD contained numerous coarse michenerite grains associated with abundant galena.

Fluid inclusion data. In carbonate-rich, quartz-carbonate (0.5-3 cm thick) veins cutting the QD pods, quartz is brecciated and cemented by fine to coarse-grained carbonate matrix. Only in some quartz-sulphide veins, quartz shows no evidence of re-crystallization. Sulphide minerals in these veins are chalcopyrite, millerite, violarite, pyrite, marcasite, sphalerite, bornite, cobaltite-gersdorffite, galena and michenerite. Aqueous fluid inclusions were studied in quartz from quartz-sulphide veins and three major types were distinguished according to their phase composition at room temperature. In accordance with the microthermometric behaviour of all inclusions, their compositions were modelled in the $H_2O-NaCl-CaCl_2$ ternary system. Type I fluid inclusions are of two-phase (L-V), fracture related secondary inclusions with consistent 10 vol. % degree of filling. Homogenization temperatures (to liquid) are 160-180 °C (Fig. 1). Eutectic melting occurred at around −50 °C and final ice melting took place between −8 and −35 °C. In a few cases, deposition of hydrohalite was also observed and its melting occurred after ice melting in some of these inclusions. Calculated salinities are between 12 and 26 $NaCl+CaCl_2$ equiv. wt. %. Type II inclusions are of two-phase (L-V) secondary inclusions with highly variably degrees of filling between 25 to apparently 100 vol. %. In a few cases, homogenization to vapour was observed at 340-360 °C in these inclusions. Homogenization to liquid occurred between 200 and 400 °C (Fig. 1) in inclusions of low degree of filling but was never observed in inclusion of high degree of filling. Eutectic melting occurred at around −50 °C. Ice melting was observed at around

−31 °C and at around −12 °C referring to 16-25 $CaCl_2$ equiv.wt.%. Preliminary Raman probe data indicate the presence of low density CH_4-N_2 in the vapour phase. Type III fluid inclusions have three-phase (L-V-Halite) composition. Most of them are fracture related secondary inclusions with a consistent 10-15 vol. % degree of filling. Their total homogenization took place either by halite dissolution or by vapour homogenization to liquid between 170 and 230 °C (Fig 1.). Final ice melting was observed between −29 C and −40 °C and considering the halite dissolution temperatures, the compositions of inclusions are between 35 and 38 NaCl+$CaCl_2$ equiv. wt.%. Preliminary Raman analyses indicate the presence of a very small amount of low density CO_2 in the vapour phase. Type III inclusions with very different microthermometry behaviour occur in isolation, in small groups and as pseudosecondary inclusions along fractures terminating within the host grain. In the latter case, these inclusions also contain a subhedral-round, stubby or short columnar prismatic and strongly anisotropic daughter mineral in addition to halite. Halite dissolution into liquid phase occurred between 230-310 °C. Total homogenization occurred by vapour homogenization to liquid between 290 and 450 °C (Fig. 1) in inclusions with no unknown daughter mineral. Melting of the last phase during freezing was below −50 °C indicative of very high $CaCl_2$ content in the inclusion liquid. Calculated salinities are between 40 and 45 NaCl+$CaCl_2$ equiv. wt. %. In Type III inclusions with an unknown daughter mineral, total homogenization takes place by dissolution of that mineral; however, due to their small size, total homogenization was observed only in one of them and it occurred at 448 °C.

Conclusions

Results of mineralogical and fluid inclusion studies reveal that the PGM-rich mineralization of the Vermilion deposit was formed during circulation of high-temperature, very saline fluids. Remnants of PGE-poor primary magmatic sulphide assemblages are considered to be the source of metals which were remobilized and redeposited by those fluids. Fluid inclusion studies suggest that the minimum temperature range of the hydrothermal activity is 170-450°C, with several, possibly independent fluid circulation stages. The multi-stage hydrothermal evolution is also recorded by the ore mineral assemblages. Chalcopyrite rich assemblages with nickeline-maucherite-sudburyite-gold and pentlandite-michenerite were formed at the early stages. Intergrowths of chalcopyrite with quartz in veins and fluid inclusion petrography indicate that this stage of evolution of the SIC may be related to circulation of fluids that were trapped in Type III, high temperature fluid inclusions that occur in isolation or in within-grain fractures. A second stage of hydrothermal activity caused complete alteration of pentlandite to millerite and violarite, marginal to complete replacement of nickeline by gersdorffite, replacement of chalcopyrite by bornite and introduction of the complex PGM rich assemblage. Fluids trapped in Type II and Type I inclusions may have had a role in this second process. Multi-stage circulation of highly saline fluids may be related to the emplacement and cooling of SIC and to tectonism resulting in thrusting of the southern part of the SIC. Results of fluid inclusion studies carried out at the Vermilion deposit are similar to the results of earlier studies that have been described from Cu- and PGE- rich hydrothermal veins at many other places around the northern and southern periphery of the SIC (Farrow and Watkinson, 1992; Molnár et al., 2001).
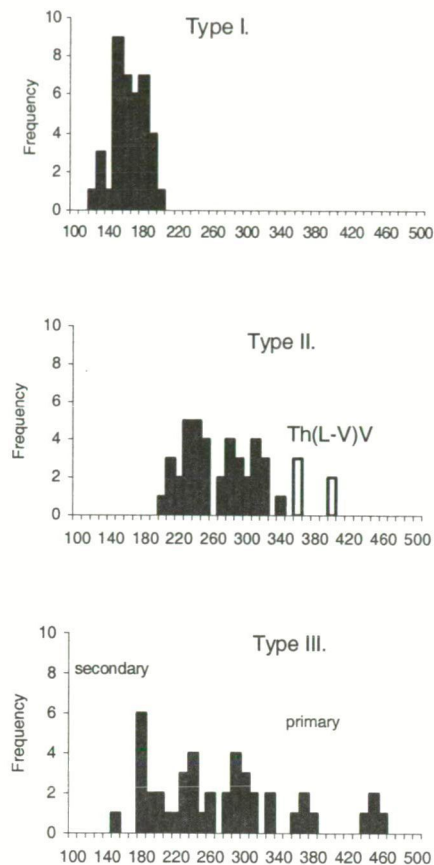

Figure 1: Frequency distribution of total homogenization temperatures Th(L-V)L/Th(L-V)V/Th(L-H)L of different fluid inclusion types.

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