Processes affecting the massive sulphide lenses at the Delta deposit, Cape Smith Belt, Canada: Implication for the distribution of PGE

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Abstract. Two Ni-Cu-PGE massive sulphide lenses associated with komatiitic basalt sills of the Delta deposit (Cape Smith Belt, Canada) have been studied in order to determine the contribution of metamorphism and deformation to the exsolution of platinum-group minerals (PGM) from massive sulphide. Indeed, the post-magmatic processes that affect the deposits are expected to change the primary mineral assemblage and the compositions of the minerals which would result in the redistribution of trace metals such as the PGE. preliminary results show that (i) the two lenses have been deformed and metamorphosed, but still maintain their magmatic mineral assemblage; (ii) one of the lenses has been injected along a fault far from its parental intrusion; (iii) the incompatible chalcophile elements expected to be associated with chalcopyrite can be found in both chalcopyrite-rich samples and chalcopyrite-poor samples, which are rich in IPGE. This suggests that metamorphism can have an important role for the redistribution of the siderophile and chalcophile elements present in komatiitic massive sulphides.

Keywords. Massive sulphides, platinum-group elements, deformation, metamorphism, Cape Smith Belt

1 Introduction

Many komatiite hosted Ni-Cu-PGE deposits are affected by metamorphism, deformation and possibly the migration of fluids. These post-magmatic processes modify the primary magmatic assemblage of the massive sulphide and consequently the composition of the minerals. This can result in the redistribution of the metals within the massive sulphide lenses. Thus, it is important to understand how the massive sulphides are affected by these post-magmatic processes.

The southern part of the Cape Smith Belt (CSB), northern Quebec, is composed of komatiitic basalts which host Ni-Cu-PGE deposits. The CSB has been metamorphosed at a greenschist to lower amphibolite facies and regionally deformed during the Trans-Hudson orogen (between 1.8-1.7 Ga). We have chosen to study one of these, the Delta deposit, which consists of two massive sulphide lenses associated with a fault zone. These two lenses represent an opportunity to investigate the effects of post-magmatic processes on the massive sulphide lenses.

2 Geological context

The 1.9 Ga Cape Smith Belt, northern Quebec, Canada, corresponds to an oceanic opening in the Archean Superior Province. The belt is divided in two domains, north and south, composed of rocks showing the transition from an initial continental rift to an ocean basin. The southern domain hosts numerous Ni-Cu-PGE deposits associated with the emplacement of komatiitic basalts into sediments formed during the rift phase. The lavas are thought to have eroded thermo-mechanically into the underlying sediments and assimilated enough sulphur to reach sulphur saturation. This resulted in the formation of multiple massive sulphide lenses at each deposit (Lesher 2007). Sills that represent a part of the feeder conduit of the komatiite lavas intruded the sediment and led to the formation of massive sulphide lenses such as the lenses (D8 and D9) of the Delta deposit. Giovenazzo (1991) reported that the D8 and D9 lenses of the Delta deposit are deformed and metamorphosed.

The D8 lens is overlain by an ultramafic intrusion and underlain by a gabbroic intrusion and could be in situ. In contrast, the D9 lens is overlain by sediments and underlain by a gabbroic intrusion. This location of the D9 lens suggests that it has been displaced along the fault.

3 Sampling and methodology

Twenty samples were selected from drill cores cross cutting the two lenses D8 and D9 of the Delta deposit. The samples were chosen to represent the full stratigraphy of the lenses. Petrographical observations were carried on polished thick sections. Whole rock geochemical analyses were performed at LabMaTer (UQAC) for S, PGE, Ni and Cu. Sulphur was determined by infrared HORIBA EMIA 220V analyser. Copper and Nickel were analysed by Atomic Absorption Spectrometry. Platinum-group elements were analysed by Ni-sulphide fire assay and Te-coprecipitation coupled with ICP-MS. Iron and the other chalcophile elements (Ag, Se, Sb, Cd, Co, As, Zn) were analysed by instrumental neutron activation analysis at the laboratory of the École Polytechnique de Montréal.

4 Preliminary results

4.1 Petrographic observations

Both massive sulphide lenses have a magmatic mineral assemblage composed of 57-83% pyrrhotite, 7-29% pentlandite and 0.2-33% chalcopyrite with accessory magnetite, some rare pyrite and platinum-group minerals (PGM). In both lenses pyrrhotite shows triple junctions (Fig. 1a) and pentlandite can be present as large eyes (1 cm). Chalcopyrite is typically associated with silicates (Fig. 1b). In some samples, chalcopyrite and silicates are aligned and elongated. Some pentlandite exsolutions are also aligned along the same planes (Fig. 1c). The samples from the lens margins contain more chalcopyrite and silicate inclusions (Fig. 1b).

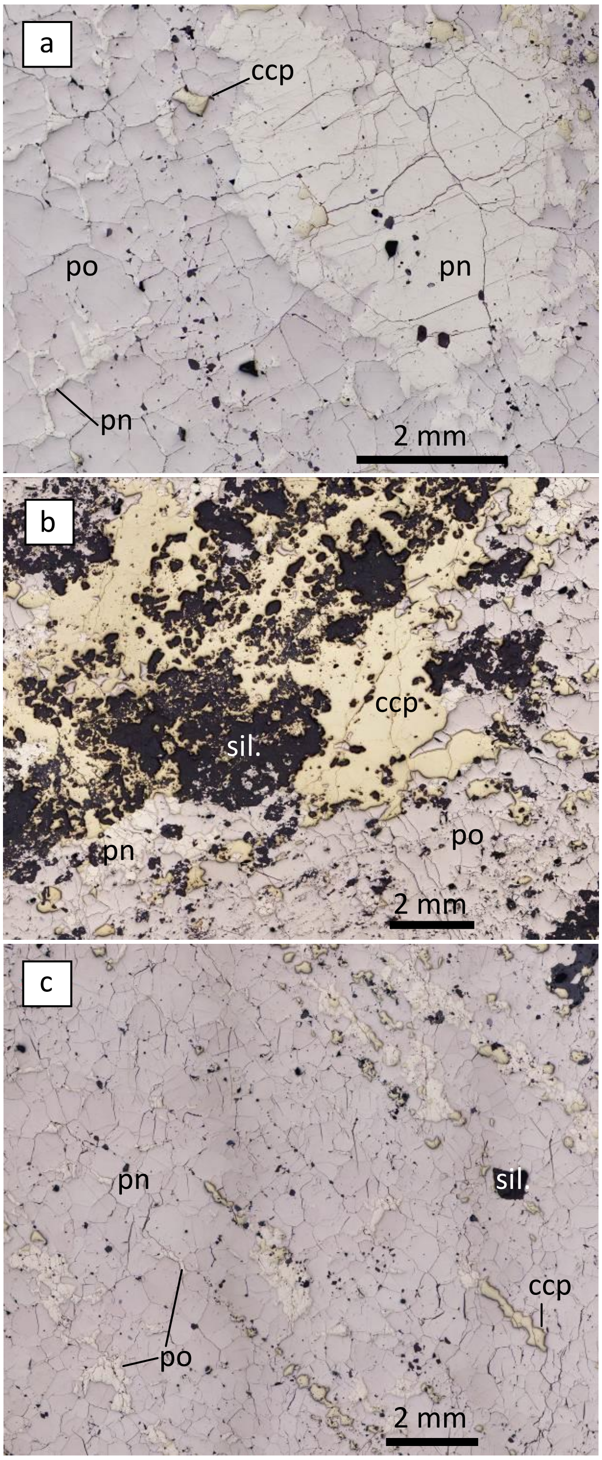

Figure 1. Photomicrographs of the massive sulphides showing: a) the mineral assemblage pyrrhotite (po), pentlandite (pn) and chalcopyrite (ccp). Po has triple junctions, pn is present as large eyes and some pn exsolutions can be observed at po grain boundaries; b) a ccp-rich mineral assemblage at the boundary of the D9 lens. Ccp is associated with an important fraction of silicates (black), po grains still have triple junctions; c) alignment of ccp and silicate within a primary recrystallized assemblage. Ccp grains are elongated along planes and some pn exsolutions follow the same plane.

Giovenazzo (1991) reported the presence of the following PGM: sperrylite ($PtAs_2$), merenskyite ($[Pd,Pt][Te,Bi]_2$), sudburyite ([Pd,Ni]Sb), testibiopalladinite (Pd[Sb,Bi]Te) and kotulskite (Pd[Te,Bi]).

4.2 Geochemistry

The S/Se ratios of the samples are above the range of the mantle domain, varying from 3550 to 7890. Selenium is an immobile element but S (as Fe) can be very mobile during post-magmatic processes. Considering that the mineral assemblage is magmatic, the only solution to obtain S/Se ratios above the mantle domain is an addition of external S. Thus, the S/Se ratios are in agreement with the hypothesis of S assimilation by the komatiitic basalts proposed by Lesher (2007). Ni usually exceeds Cu (ratio > 1) except for two samples of the D9 lens which are extremely enriched in Cu and have Ni/Cu ratios ~ 0.3. These samples are chalcopyrite-rich with a chalcopyrite fraction varying between 25 and 33%.

The D8 lens shows enrichment in IPGE (Ru, Os, Ir) + Rh and has a relatively flat PGE pattern (Fig. 2a) which is characteristic of monosulfide solid solution (mss). Its IPGE content decreases from the lower gabbroic contact to the upper ultramafic contact suggesting that this lens is a mss cumulate formed from the ultramafic intrusion. The PPGE (Pd, Pt) are enriched at the upper contact. The semi-metals (Sb, As) are enriched in the margins.

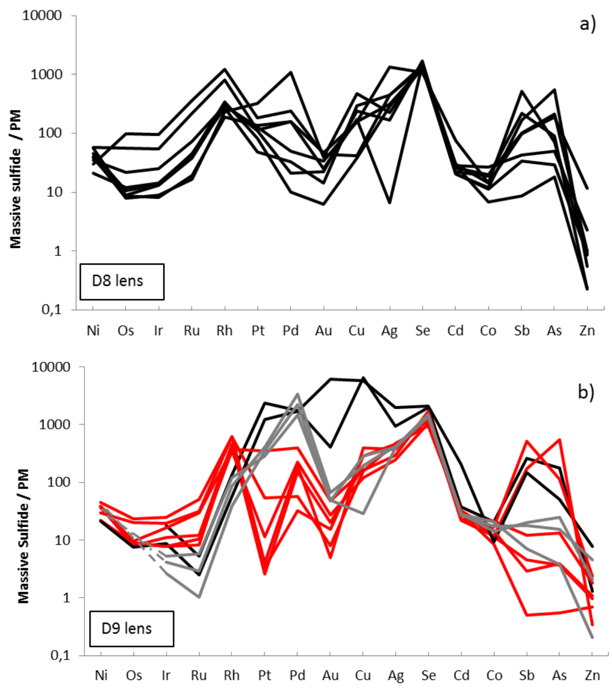

Figure 2. Primitive mantle-normalized chalcophile multi-element diagrams (values for primitive mantle are from Lyubetskaya 2007); elements are ordered according to their degree of compatibility between silicate liquid and sulphide liquid (Barnes personal communication), the elements most compatible with sulphide liquid are on left; a) the D8 lens has a flat PGE pattern characteristic of a mss cumulate; b) the D9 lens contains both mss (red) and more fractionated patterns (black and grey) typical of a more evolved sulphide liquid.

The D9 lens shows more fractionated patterns (Fig. 2) typical of a more evolved sulphide liquid. This lens shows three types of signatures (i) Pt, Au depleted and IPGE-rich samples (Fig. 2b red) which have a mss pattern. These samples are also semi-metal poor except for two samples located at the base of the lens that are the most As- and Sb-rich samples; (ii) the PPGE-rich but semi-metal-poor samples (Fig. 2b grey) which have the lowest IPGE content; (iii) the Cu-rich samples which are also enriched in PPGE (Rh, Pd, Pt) + Au and semi-metal and depleted in IPGE (Fig. 2 black).

The Se, Cd and Co contents show a narrow range of values within both lenses and in agreement with a MSS-sulphide liquid partition coefficient ~1.

5 Discussion

Petrographic study of the lenses reveals that both lenses have been metamorphosed and deformed, but they still have a primary mineral assemblage. Coupled with their location, it appears that the D9 lens is not in contact with its parental intrusion. This suggests that the sulphide liquid was first injected at a liquid state along the fault before being deformed and recrystallized. The D8 lens has a lithological contact with its overlying ultramafic parental intrusion.

Mungall (2007) demonstrates for the Expo Ungava Intrusive Suite of the CSB that intrusive system can assimilate up to 50% of the original mass of magma that leads to the sulphur saturation of the magma. Lesher (2007) shows that the sulphur isotopes of some Cape Smith Belt deposits indicate that sulphur saturation of the parental magma was reached by assimilation of the sediments. The S/Se ratios of the Delta deposit leads to the same conclusion, suggesting that the sills associated with the feeder conduit of the komatiite assimilated material from the sediment formation they intruded. The S/Se ratios also imply that the potential remobilization of mobile elements (such as S) by fluids has not occurred at the Delta deposit.

The distribution of PGE within sulphide minerals is related to the cooling rate of the sulphides. If the cooling rate is fast, the PGE will be mainly in solid solution within the sulphides. Barnes et al. (2006) and Patten et al. (2012) observed that quenched sulphide droplets do not contain PGM and that all the PGE were in solid solution within the sulphides. In contrast, if the cooling rate is slow, more PGE will be exsolved as PGM from the sulphides (Dare 2010). In non-metamorphosed intrusions 40-60% of the PGE are considered to be present in the sulphide minerals (Barnes et al. 2008). It is possible that the metamorphism and the deformation will drive the exsolution of the remaining PGE of the sulphides, resulting in the formation of new mineral phases such as PGM. The same hypothesis can be made for the exsolution of the remaining Ni of the pyrrhotite that will lead to the formation of secondary pentlandite.

6 Conclusions

The massive sulphide lenses of the Delta deposit show evidence of deformation and metamorphism. Our preliminary results suggest that (i) the D8 lens is in contact with its overlying parental ultramafic intrusion; (ii) the D9 lens was injected at a liquid state along the fault. In addition, the PGE and other chalcophile elements distribution within the lenses shows that (iii) the chalcopyrite-rich samples are enriched in chalcophile elements; (iv) the IPGE-rich samples that contain less than 2% chalcopyrite can have high concentrations of semi-metals. This suggests that the metamorphism possibly led to the formation of PGM in these IPGE-rich samples.

PGM require further study and a precise characterization for each sample in order to determine the contribution of the metamorphism and the deformation to the exsolution of PGM.

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