Geochemistry of the Sakatti magmatic Cu-Ni-PGE deposit, northern Finland

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Abstract. The Sakatti deposit comprises disseminated and massive sulphide hosted by an ultramafic cumulate. The cumulate consists of olivine with high Mg (Mg# 0.85-0.91) and high Ni contents (0.3-0.5 wt%). Pt minerals hosted within the sulphide are exclusively tellurides with an unusual array of Pt-Pd-Ni compositions. S isotope compositions are similar to mantle rocks with $\delta^{34}S$ values clustering around 3‰, whereas the nearby Matarakoski sulphide-bearing sediments show fractionated values. Initial εNd values are negative implying the deposit has been contaminated by continental crust. Similarities with the Kevitsa deposit 15 km away suggest that these deposits have a shared genetic history.

Keywords. magmatic-nickel-Finland-Sakatti

1 The Sakatti deposit

The Sakatti deposit is a greenfield discovery in northern Finland that subcrops beneath glacial till and was essentially blind. The deposit consists of both disseminated and massive Cu-Ni sulphide mineralisation, with significant platinum group element (PGE) content, hosted by an olivine cumulate. The cumulate has a conduit-like profile, at least 0.5 km in cross section, surrounded by a volcanic footwall and capped by a breccia.

Sakatti is located in the Central Lapland Greenstone Belt (CLGB), 15 km from the Kevitsa Ni-Cu-PGE deposit that has recently entered production. The stratigraphy of the CLGB, into which both Sakatti and Kevitsa are intruded, contains the substantial Matarakoski sulphide-bearing black schist unit, as well as sedimentary quartzites and mafic-ultramafic volcanics (Lehtonen et al. 2005).

2 Mineral Chemistry

2.1 Silicate mineral chemistry

The olivine cumulate that hosts the Sakatti deposit is heavily serpentinised. In spite of this, magmatic olivine, pyroxene and amphibole are preserved sporadically throughout the unit. Sampling was designed to target these areas, with moderate success. The chemistry of the primary silicates provides a window through the alteration into the character of the host silicate magma.

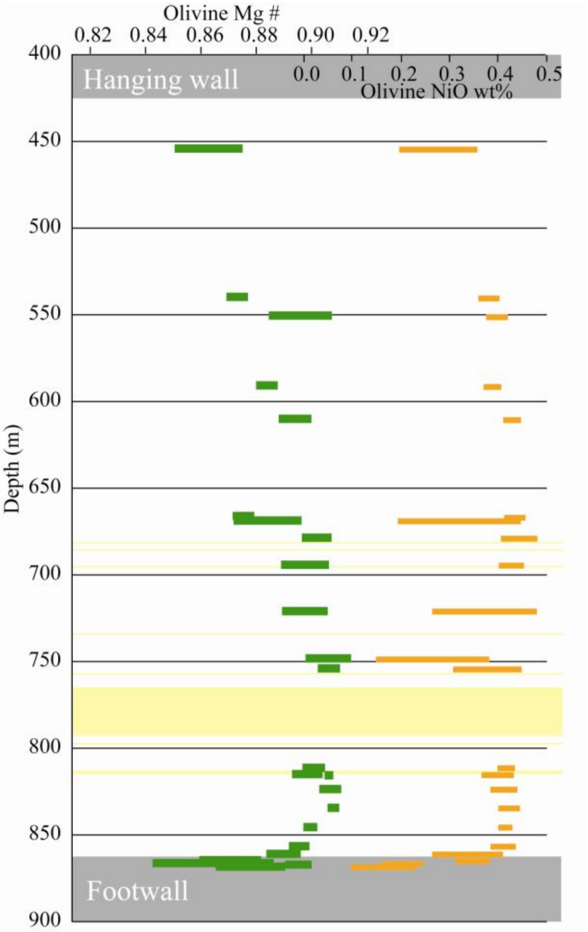

Figure 1. Range of olivine mineral chemistry from the Sakatti deposit plotted against depth down-hole. Mg# is Mg/(Mg+Fe). Data from electron microprobe analysis.

Olivine has a Mg# typically 0.84-0.92 and a Ni content of ~0.4 wt%. Clinopyroxene also consistently contains ~0.1 wt% Ni. Ni content in olivine correlates with Mg# throughout the unit (Fig. 1), although in samples with sulphide mineralisation olivines occasionally show variable Ni within individual crystals.

2.2 Sulphide mineral chemistry

Sulphide at Sakatti comprises a chalcopyrite-pyrrhotite-pentlandite assemblage typical of a magmatic Ni-Cu deposit. Pyrrhotite typically contains ~1 wt% Ni and has sub-mm scale pentlandite flames at crystal boundaries. Pentlandite is also present as discrete grains containing up to 1 wt% Co and is varyiably altered to millerite and violarite. Chalcopyrite is usually segregated from the pentlandite-pyrrohotite domains.

An unusual alteration style is present where large sub-spherical cobalt-bearing pyrite grains appear to replace the pentlandite-pyrrhotite. Complete pyritisation results in bravoite and pentlandite forming interstitially to the pyrite grains.

2.3 PGE mineral chemistry

PGE are usually important by-products of magmatic Ni deposits, often occurring in discrete phases associated with sulphide. Common phases are sulphides (e.g. braggite), arsenides (e.g. sperrylite), tellurides (e.g. moncheite), bismuthides (e.g. froodite), antimonides (e.g. isomertiete) and alloys.

The Sakatti deposit is exceptional as all PGE-bearing mineral phases found to date are tellurides (Fig. 2), with no other PGE semi-metal minerals observed. Over 200 separate PGE telluride grains have been found in 30 samples spread across the Sakatti deposit.

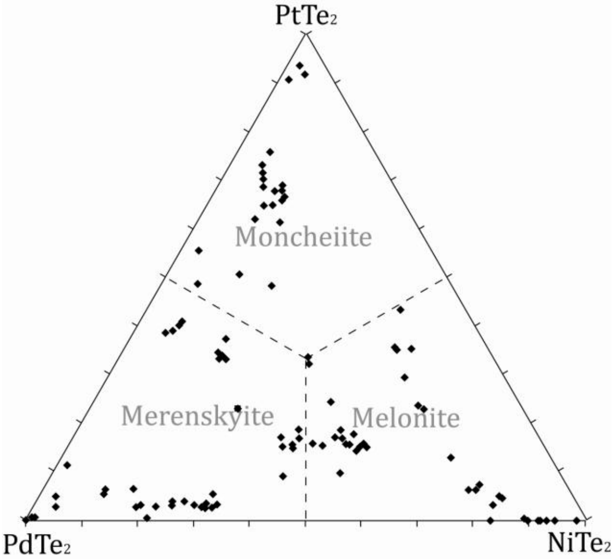

Figure 2. Compositions of (Pt,Pd,Ni) tellurides from the Sakatti deposit. Data from electron microprobe analysis.

There is also a range of composition in these tellurides across the moncheite ($PtTe_2$) - merenskyite ($PdTe_2$) - melonite ($NiTe_2$) system (Fig. 2). This diverse telluride mineralogy is shared with the Kevitsa deposit (Gervilla and Kojonen 2002). This assemblage is unusual as almost all other known deposits have tellurides falling either on a $PtTe_2$-$PdTe_2$ trend or on a $PdTe_2$-$NiTe_2$ trend, with Pt and Ni generally being mutually exclusive.

3 Whole rock geochemistry

The application of whole rock geochemistry in cumulate systems must be considered with care. This is because the cumulus and intercumulus phases are unlikely to be in equilibrium and will represent different stages in the evolution of the system. The amount of cumulus relative to intercumulus can therefore dramatically affect whole rock composition without any difference in composition of the coexisting magmatic phases.

At the Sakatti deposit there is also extensive serpentinisation and talc-carbonate alteration, which variably affect whole rock geochemistry. However, REE plots from samples across the deposit are relatively consistent showing a slight LREE enrichment trend and depleted Eu anomaly (Fig. 3).

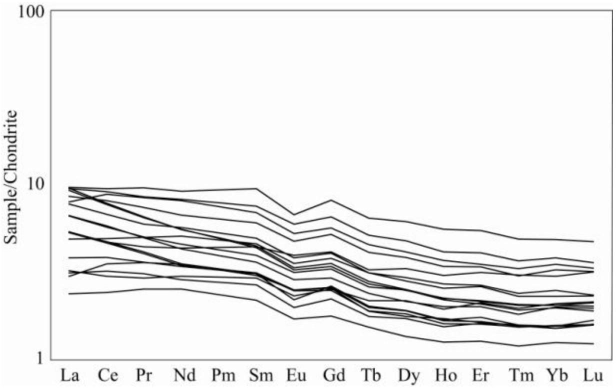

Figure 3. Whole rock REE concentrations normalised to chondrite values from McDonough and Sun (1995).

4 S isotopes

Samples were collected from across the Sakatti deposit and also from nearby sulphide-bearing black schists of the Matarakoski Formation. The schist samples were selected from drillholes within 5 km of the Sakatti deposit to the NW, NE and SE. The samples are graphitic black schist with visible pyrrhotite laminae intercalated with sedimentary laminations. Pyrrhotite from these laminae was separated and analysed. The data are plotted on Figure 4.

Sakatti sulphides from across the deposit display a remarkable S isotopic homogeneity, with a $\delta^{34}S$ mean of 2.9 ± 0.8‰. In contrast, sulphides in the black schists show a very large S isotopic range from -23.9 to +19.9‰.

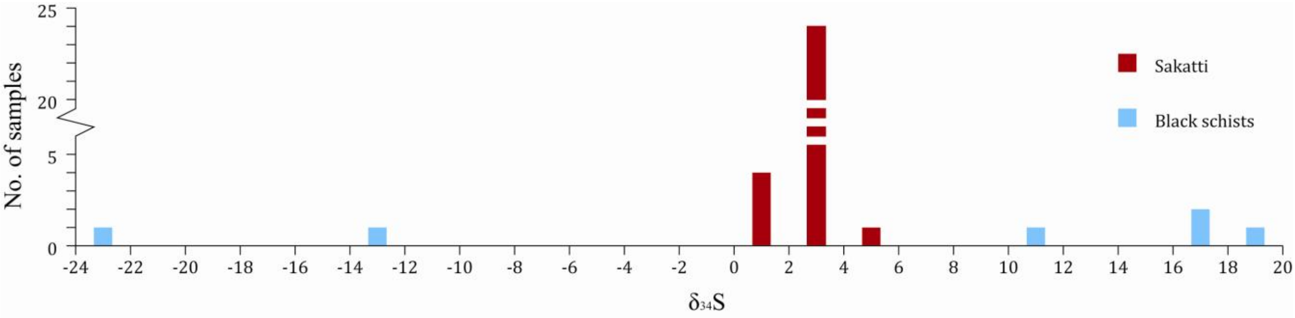

Figure 4. Sulphur isotope data from the Sakatti deposit showing deviation from the V-CDT standard in parts per mil (‰). Note the marked homogeneity of the deposit data (NB break in Y axis), versus the large isotopic range in the background sediments.

4 Nd isotopes

The least serpentinised samples were selected, as determined by thin section study, for Nd isotope analysis. Both whole rock and mineral separates were analysed.

The samples do not provide a valid isochron indicating this system cannot provide a precise age of the Sakatti deposit. However, initial εNd were calculated from the data and corrected using a geologically estimated range of ages for the deposit (Table 1). This yields a significantly negative εNd value.

Depleted mantle εNd values across this interval are estimated between +3 and +4 (DePaolo 1981) which differs considerably from these data. Continental crustal material has negative εNd values. The deposit has inherited a crustal signature implying that it must have assimilated continental crust.

		εNd_t	
Depth (m)	**2.2 Ga**	**2.0 Ga**	**1.8 Ga**
529.08	-2.76	-3.63	-4.50
539.50	-4.32	-5.12	-5.93
666.16	-5.60	-6.27	-6.94
668.20	-4.69	-5.77	-6.85
678.23	-4.62	-5.26	-5.89
744.75	-3.96	-4.61	-5.25
822.20	-2.25	-3.10	-3.94

Table 1. Possible initial εNd values for whole rock samples from the Sakatti deposit. The absolute age of the deposit is unknown so the likely range is shown.

6 Discussion

The silicate mineral chemistries provide an insight into the magmatic history of the deposit. The cumulate is remarkably homogeneous with little variation in Mg#. What variation there is shows a general decrease in Mg# from bottom to top, suggesting that the host magma was evolving as the cumulate was being deposited and that the unit is the right way up. Further trace element analysis of olivine is underway to establish if this trend is genuine and if separate pulses of intrusion can be identified.

The high Ni concentration in the olivine suggests that these olivines did not form from a melt at S saturation and must have crystallised before sulphides formed or been introduced to pre-existing sulphide after they had crystallised. There is variable Ni within a minority of olivine crystals in samples that host abundant sulphide. This is thought to be due to loss of Ni from crystalline olivine by diffusion or late stage olivine growth in an S depleted melt.

There is a decrease in Mg# in the lower 50 m of the unit. While there is abundant textural evidence for melting and assimilation of the mafic footwall into the intercumulus melt, it is unlikely this would affect the cumulus olivine. The decrease in Mg# could be a small marginal reversal at the base of the cumulate, as seen at other mafic-ultramafic intrusions (Latypov 2003).

The unusual telluride chemistry may suggest that the formation of this deposit departs from established models. The fact that this unusual chemistry is shared with Kevitsa deposit implies a shared mode of formation.

Negative εNd values indicate that the rock hosting the deposit has been contaminated by crustal material during its history. This is consistent with LREE enrichment. The mineralogy of the deposit is ultramafic, with high Mg olivines, and so crustal contamination must have been limited. The Kevitsa deposit also exhibits significantly negative εNd (Hanski and Huhma 2005).

Sulphides analysed throughout the deposit show a remarkable homogeneous $\delta^{34}S$ around a mean of 2.9 ± 0.8‰. In contrast, the sulphide-rich Matarakoski sediments, which present as an obvious potential source of S contamination, show a distinctly heterogeneous S isotopic range indicating that local incorporation of these sediments is not a realistic mechanism of S saturation.

The $\delta^{34}S$ value is similar to the main ore at the Kevitsa deposit (Grinenko et al. 2003). The value is consistent with a magmatic S source. This means that the deposit has either formed entirely from mantle-derived S or from assimilation S in Archaean crustal rocks, which have limited S isotope range (Farquhar et al. 2010).

7 Conclusions

The similarity between the Sakatti and Kevitsa deposits, in terms of mineralogy, telluride chemistry, $\delta^{34}S$ and εNd, points towards these two deposits having a shared genetic history. In both deposits, the assimilation of crustal material is implicated in achieving S saturation and thus ore formation. Our S isotope study shows that assimilation of sedimentary sulphide younger than 2.4 Ga, such as that which occurs in abundance in the Matarakoski schists, is not implicated in the contamination.

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