Sulphide trace element, sulphur isotope and hydrothermal alteration studies in the Juomasuo and Hangaslampi Au-Co deposits, Kuusamo belt, northeastern Finland

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Abstract. The Juomasuo and Hangaslampi Au-Co deposits are hosted by the Paleoproterozoic Kuusamo belt in northeastern Finland. Sulphur isotope and trace element data from sulphides indicate that the geochemically distinct, Au-Co and Co-only enrichments were formed from fluids of different origin. Accordingly, sericite alteration is typical in the zones of the Au-Co enrichment, whereas the chlorite-biotite-amphibole alteration occurs in relation to the Co-only mineralization. Variation in the composition of host rocks does not seem to have a strong control on the type of mineralization.

1 Introduction

Finland currently produces 66% of the EU cobalt supply, extracted from sulphide ores from the Sotkamo, Kevitsa, Hitura and Kylylahti mines (European Commission 2018). With the cobalt demand related to rechargeable batteries expected to rise in the following years, the importance of Finland’s cobalt resources becomes even more pronounced. A better understanding of the formation processes of the already known Co-rich deposits is needed to enhance successes of exploration for new deposits.

This study concentrates on the Juomasuo and Hangaslampi Au-Co deposits, which are located in northeastern Finland, approximately 45 km north of the town of Kuusamo (Fig. 1). These deposits are situated in the Paleoproterozoic Kuusamo belt (KB) and are part of the Kuusamo-Kuolajärvi orogenic gold metallogenic area (Eilu et al. 2012), comprising several epigenetic Au-Co-Cu occurrences (Pankka 1992; Vanhanen 2001). Previous studies proposed different genetic classifications for the Au-Co-Cu mineralization including iron-oxide-copper-gold (IOCG), orogenic gold with atypical metal association, epithermal type (Pankka 1992; Vanhanen 2001; Eilu & Pankka 2009; Slack et al. 2012). The Juomasuo deposit is the most important known epigenetic-hydrothermal Au-Co deposit in the Kuusamo belt. Hangaslampi is situated approximately 1 km south from Juomasuo and is also mainly enriched in Au and Co. Cu, Mo and REE are the most typical associated trace metals in these deposits. For the purpose of better understanding the hydrothermal processes that led to the mineralization in Juomasuo and Hangaslampi we applied in situ multi- and single collector LA-ICP-MS analytical techniques to study sulphur isotope and trace element characteristics of sulphide minerals from these deposits. Additionally, we utilized whole-rock geochemical data in order to classify the heavily altered host rocks and to study the control of the alteration mineralogy on the mineralization types with different metal associations at Juomasuo.

2 Regional geological setting

The KB is a part of the larger Karasjok-Kuusamo-Lake Onega belt that extends from northern Norway to the Lake Onega in Russia (Pankka 1992). The rocks comprising this belt are part of the Karelian supracrustal formations. Their age ranges from 2.5 to 1.9 Ga (Silvennoinen 1972, 1992). The KB was at least partially formed in an intracratonic failed rift setting related to the Paleoproterozoic breakup of the Archean Karelian craton (Hanski & Huhma 2005). The KB consists of several formations of volcanic and sedimentary origin,

![Figure 1. Simplified geological map of the Kuusamo belt. Modified after Laajoki (2015) and Vanhanen (2001).](image-url)
including three or four stages of mafic volcanism with associated mafic sills and dykes (Pankka 1992). The stratigraphy of the Kuusamo belt was defined by Silvennoinen (1972) (Fig. 2).

The stratigraphic sequence of the KB underwent deformation and regional metamorphism during the Svecofennian orogeny (1.9-1.8 Ga; Silvennoinen 1972, 1992). The metamorphic grades vary from lower greenschist facies in the central parts of the belt to upper amphibolite facies in the western parts, near the contact with the Central Lapland Granitoid Complex. Higher metamorphic grades are also present in the eastern part of the KB. Mineralization has been mostly encountered near the upper and lower boundaries of the Greenstone Formation II (GF II), but some mineralization is also hosted by the upper part of the Ruokatunturi Quartzite Formation (RQF) (Vanhanen 1990, 2001) (Fig. 2).

3 Geology and mineralogy of the Juomasuo and Hangaslampi Au-Co deposits

The host rocks of the Juomasuo deposit are characterised by strong albitionisation but the mineralised zones also contain quartz, chlorite, biotite, sericite, carbonate, amphibole and talc in addition to albite. The most abundant sulphide is pyrrhotite followed by pyrite and lesser chalcopyrite. Cobaltite can be found in the Co-rich parts of the ore as inclusions in pyrrhotite and sometimes in pyrite. Cobaltpentlandite is also present mainly as exsolutions in pyrrhotite. Molybdenite, rutile, magnetite, native Au and tellurides (altaite, tellurobismuthite and melonite) are noteworthy accessories in the deposit. The Juomasuo deposit consists of one major mineralized zone and several smaller adjacent sulphidized zones (Vanhanen 2001). The total mineral resource estimate for the Juomasuo deposit is 2.37 million tonnes grading at 4.6 g/t Au and 0.13 wt% Co and an additional 5.04 million tonnes of Co resources without Au grading at 0.12 wt% Co (Dragon Mining 2014).

The orebodies at Hangaslampi occur in a local antiformal structure just below the GF II (Vanhanen 2001). The resource estimates amount to 403 thousand tonnes grading at 5.1 g/t Au and 0.06 wt% Co and an additional 180 thousand tonnes of ore grading at 0.1 wt% Co without Au (Dragon Mining 2014). The gangue minerals at Hangaslampi comprise albite, quartz, chlorite, biotite, sericite, lesser carbonate, amphibole and accessory tourmaline, apatite and zircon. The most common sulphide is pyrite. Pyrrhotite has a weak presence and is mostly found as inclusions in pyrite and magnetite and sometimes as disseminated grains in the silicates where it is occasionally associated with chalcopyrite. Cobaltite is rare in Hangaslampi and cobaltpentlandite occurs sporadically as exsolutions in the disseminated pyrrhotite. Magnetite is more widespread compared to Juomasuo. Other common accessory ore minerals at Hangaslampi include molybdenite and some minor tellurides.

4 Lithogeochemistry at the Juomasuo deposit

Previous studies have described the heavily altered and metamorphosed rocks at Juomasuo and Hangaslampi mainly on the basis of the dominating alteration minerals (Pankka 1992; Vanhanen 2001). For the Juomasuo deposit, the Dragon Mining Ltd. provided a detailed lithogeochemical dataset for the purpose of our studies and we utilized this database for the geochemical classification of the protoliths of the altered rocks. We combined drill core observations with immobile element ratios and recognized the following six rock types: ultramafic rock, mafic rock, intermediate rock, felsic rock, metasediment and albite (Fig. 3). By plotting the samples belonging to the Au-Co and Co-only type of ores on the Nb/Y-Zr/TiO2 discrimination diagram, it is evident that both types of mineralization are present in all of the rock types, apart from the albitites and the ultramafic rocks (Fig. 3).

A second application of the lithogeochemical database was to calculate Molar Element Ratios (MER) to determine the control of the alteration mineralogy on the different types of mineralization. The MER diagrams (Fig. 4) show that different types of alteration affected different rock types. By plotting the gold and cobalt grades together with the MER data for the metavolcanic rocks it seems that gold enrichment is mainly associated with sericite alteration and much less with chlorite-biotite alteration (Fig. 4). Co enrichment is strongly associated with chlorite-biotite and amphibole alteration and additionally with sericite alteration (Fig. 4). Similar trends can be demonstrated for the metasediments.
5 Sulphur isotope and trace element data

Systematic sulphur isotope analyses were performed on pyrite, pyrrhotite and chalcopyrite from Juomasuo and Hangaslampi with the use of multi-collector LA-ICP-MS. Trace element contents of the same sulphide grains were determined by single-collector LA-ICP-MS analyses. Analytical spots for sulphur isotope and trace element determination were placed next to each other. Matrix-matched sulphide standards were used during these analyses.

Sulphides from the ore zones at Juomasuo have δ\(^{34}\)S values between -2.6 and +6.9 (median +3.45) and at Hangaslampi between -0.9 and +9 (median +5.3). Sulphides from barren samples range from -0.5 to +13.5. Whereas most of the values are positive, there is a shift to negative or near-zero values in some sulphides in both deposits (Fig. 5). By examining the Co/Ni ratio of pyrite grains from different mineralization types, distinct mineralization stages become evident: one represented by distinctly high Co/Ni ratios and one with low Co/Ni ratios. Pyrite grains with high Co/Ni ratios show a relatively narrow range of positive δ\(^{34}\)S values, whereas the grains with low Co/Ni ratios have a wider range of δ\(^{34}\)S values including all the negative ones (Fig. 5). A similar trend is present for the Se/S ratios of the two stages with the high Co/Ni pyrite having a narrow range of low Se/S ratio values and the low Co/Ni pyrite having a wider range. Other trace elements also vary systematically within the two Co/Ni ratio categories (Fig. 6). The Co/Ni ratio is mostly controlled by the Ni content of sulphides with differences up to two orders of magnitude (Fig. 6).

The wider range of δ\(^{34}\)S, Se/S ratios and the relatively
high Ni, Se and Te contents in the low Co/Ni category could indicate a mixing of different fluid and sulphur sources. The low Co/Ni stage comprises mainly Au-Co mineralization in both deposits. The high Co/Ni category on the other hand has a narrow range of δ34S and Se/S ratios and low Ni, Se and Te contents. The high Co/Ni stage could thus be attributed to a single hydrothermal event and a homogeneous sulphur source. The high Co/Ni stage mainly includes Co-only mineralization with some Au-Co mineralization included in Juomasuo.

6 Summary and conclusions

The Juomasuo and Hangaslampi Au-Co deposits are characterized by multi-stage hydrothermal processes that are recorded in the sulphur isotope and trace element characteristics of sulphides. A hydrothermal stage responsible for the accumulation of the Co-only ores in both deposits, and some Au-Co mineralization in Juomasuo, deposited pyrite characterized by high Co/Ni ratios, low Se/S ratios and positive δ34S values showing a relatively narrow range of values. Pyrite from a different stage of hydrothermal activity that created mostly Au-Co mineralization in both deposits is characterised by low Co/Ni ratios, a wide range of Se/S ratios, 834S values and high Ni, Se and Te contents. The distinct sources of parent fluids are also supported by contrasting alteration parageneses of the same lithologies depending on enrichment type. The Au-Co mineralization in Juomasuo mainly occurs within sericite alteration zones whereas the Co-only mineralization is hosted by chlorite-biotite-amphibole alteration. These results are in agreement with the U-Pb dating of hydrothermal monazite from Hangaslampi suggesting two major stages of mineralization, one at 1.85 and the other at 1.81 Ga (Pohjolainen et al., 2017).

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References


