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GEOCHEMISTRY, STRUCTURE AND GENESIS OF THE HAMMASLAHTI COPPER MINE — EXPLORATIONAL TOOLS FOR A SEDIMENT-HOSTED MASSIVE SULPHIDE DEPOSIT

by
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Introduction

Although the Hammaslahti Cu deposit is situated in a geologically well-known area close to the Archaean — Proterozoic boundary and at the proximity of the Outokumpu Cu-Zn-Co district, its geology is dealt with only in a few papers. Sulphur isotopes and fluid inclusions were examined by Hyvärinen et al. (1977) who concluded that the deposit is of synsedimentary origin later tectonically remobilized. Evaluation of the structure of the deposit by Gaál (1977) suggested a deformation in three phases with sinistral shear during a late stage. A structural and sedimentological analysis of the area surrounding the deposit supplied the regional background (Ward 1987).

The present study was initiated with the purpose of summarizing existing data and filling in the gaps in knowledge in the areas of geochemistry, lithology and structure. Systematic sampling was carried out for geochemical and lithological studies. Altogether 259 outcrop and 336 drillcore samples were analysed at the Outokumpu Geoanalytical Laboratory by XRF and AAS and at the Technical Research Centre of Finland by INAA (neutron activation) methods. Element concentration maps were compiled by computer from surface and drillcore profiles, and these, together with the structural geology maps, were used to generate block diagrams. Data obtained in earlier structural mapping were supplemented with observations on drillcores and underground openings. Sedimentary structures, younging directions and the various generations of foliation and their relation to bedding deserved particular attention. Geological cross sections were supplemented with S_0/S_1 and S_2 form lines whose relation to the geometry of the orebodies was studied.

The extended version containing original data and comparison with sediment-hosted stratiform copper deposits and Besshi-type massive sulphide deposits will be presented in the proceedings of the 8th IAGOD Symposium (Loukola-Ruskeeniemi et al. 1990 and in press).

Geological setting

The Hammaslahti deposit is located at the eastern margin of the Early Proterozoic Svecofennian Orogen (2.0—1.75 Ga), 12 km west of the exposed Archaean — Proterozoic boundary (Fig. 1). Between 1973 and 1986, Outokumpu Oy mined seven million tonnes of ore grading on average 1.16 % copper and containing minor amounts of zinc and gold. The country rocks of the deposit belong to a NNW-trending linear belt, the Höytiäinen Basin (Ward 1987), which is separated from the Outokumpu District to the west by reverse faults and belongs to the Kalevian Group (2.0—1.9 Ga). The majority of the epiclastic sediments of the Höytiäinen Basin are interpreted as middle-fan

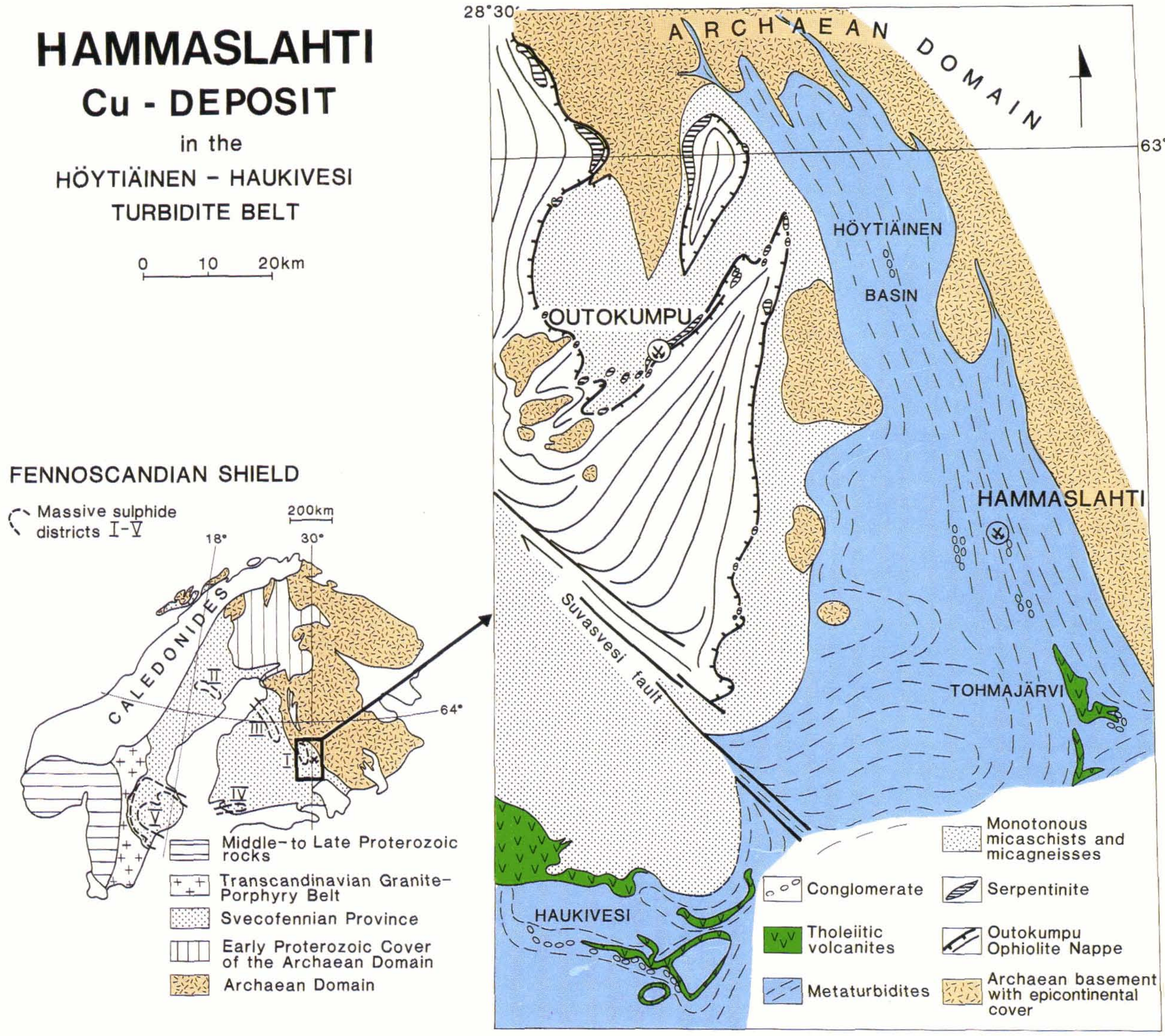

Fig. 1. Geological setting of the Hammaslahti Cu deposit. Massive sulphide districts: I Outokumpu, II Skellefte, III Vihanti — Pyhäsalmi, IV Aijala — Orijärvi, V Bergslagen; K = Kainuu Schist Belt. The deposit is located in the Höytiäinen — Haukivesi metaturbidite belt at the eastern margin of the Proterozoic Svecofennian Province.

turbidites. Tholeiitic metabasalts (Nykänen 1971), which are interpreted to have erupted in a rifted basin (Ward 1987), outcrop 15 km to the south along the strike. The metaturbidites swing around the Outokumpu District and can be correlated with the well-preserved metaturbidites of the Haukivesi area in the SW (Gaál & Rauhamäki 1971). The Höytiäinen Basin has been considerably shortened by eastward thrusting of the Svecofennian Orogen onto the Archaean basement complex in the east. The thrust brought the 2.5—2.0 Ga old epicontinental cover rocks of the basement complex of the Karelian Province into juxtaposition with the geosynclinal rocks of the Svecofennian Province (Gaál & Gorbatschev 1987).

The well-preserved metaturbidites allow detailed studies on primary and secondary structures and the good coverage of diamond drilling provides a reliable three-dimensional view of the deposit (Fig. 2). The structure is characterized by upright to inclined and gently south-plunging F_2 folds of S_0/S_1 surfaces with penetrative S_2 axial-plane cleavage. S_0 is expressed in sedimentary layering. The deposit comprises three orebodies which are located in hydrothermally altered rocks on the western limb of an upright anticline, close to its hinge zone. The irregular elongate 'en echelon' orebodies occur in a N — S trending zone below a steeply W-dipping black schist layer (black schist = metamorphosed black shale). The black schist is sheared and coincides with a reverse fault resulting in the upthrow of the western side. The elongated orebodies plunge 25° to 30° to the south parallel to the intersection of S_0/S_1 with S_2.

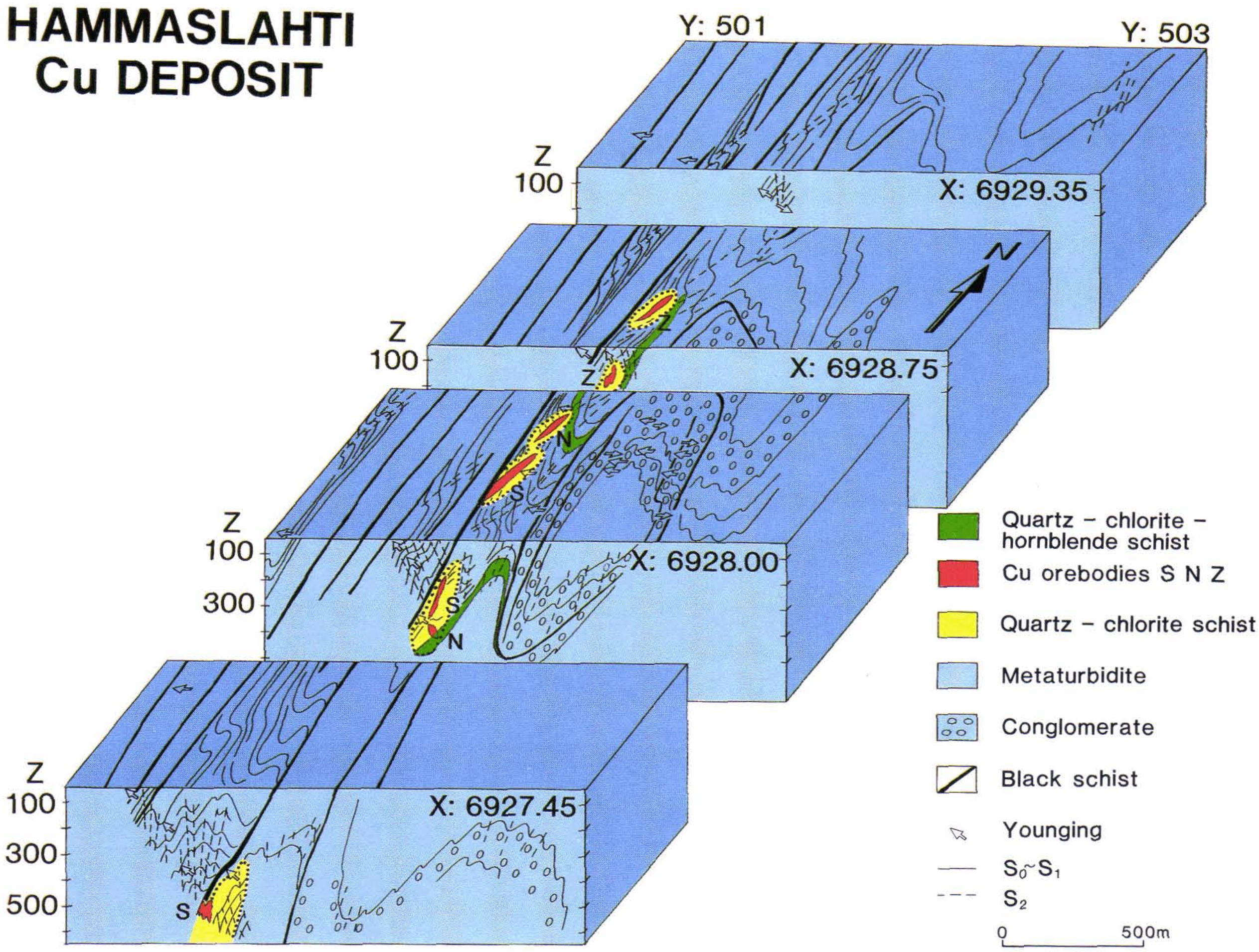

Fig. 2. Block diagram of the Hammaslahti Cu-deposit. Size of the area is 2 km * 2.5 km. Orebodies and fold structures plunge 25° to south. Younging and structural facing indicate upright to slightly inclined synclines and anticlines.

The three orebodies are named: S orebody, which is the southernmost, N orebody in the middle and the northernmost Z orebody (Fig. 2). The S orebody accounts for 70 % of the total ore reserves. Most of the rocks in the hydrothermally altered zone with Na_2O < 1.1 % are metaturbidites, although what may be metavolcanics or volcanoclastics have also been encountered. These metavolcanics contain quartz, biotite and hornblende with plagioclase phenocrysts (Fig. 3a) and have andesitic composition, although silicification has probably altered the original composition. There is a layer of quartz-chlorite-hornblende schists which provides a marker horizon; it can be traced along the footwall of the N and Z orebodies (Fig. 2). The N orebody is lower in stratigraphy than the other two.

Generally in the alteration zone, a greenschist facies chlorite + quartz mineral assemblage prevails. However, accessory hornblende has grown on the chlorite + quartz mass indicating conditions of lower amphibolite facies at the time of regional metamorphism (Fig. 3b).

Geochemistry reflecting hydrothermal alteration

Three-dimensional gold, copper, sodium and potassium anomaly patterns are illustrated in Fig. 4. Even the most unaltered metaturbidites point to the proximity of a hydrothermal alteration zone. This is seen in the elevated Fe, slightly elevated Mg and lower Mn concentrations in greywacke relative to the average graywacke composition. Likewise, the rather high sulphur and base metal concentrations of the phyllites are indicative of hydrothermal alteration (median values for 75 samples are 0.24 % S, 4.2 % Fe, 60 ppm Cu, 100 ppm Zn, 60 ppm Ni, 30 ppm Co and 20 ppm Pb). Anomalously high concentrations of certain metals like Cu, Zn, Ni, Co and Pb in the sheared black schists of the hanging-wall are attributed to hydrothermal influx (median values are 340 ppm Cu, 1250 ppm Zn, 400 ppm Ni, 40 ppm Co and 90 ppm Pb). The Hammaslahti black schists also contain elevated metal abundances as compared with the average concentrations of Early Pro-

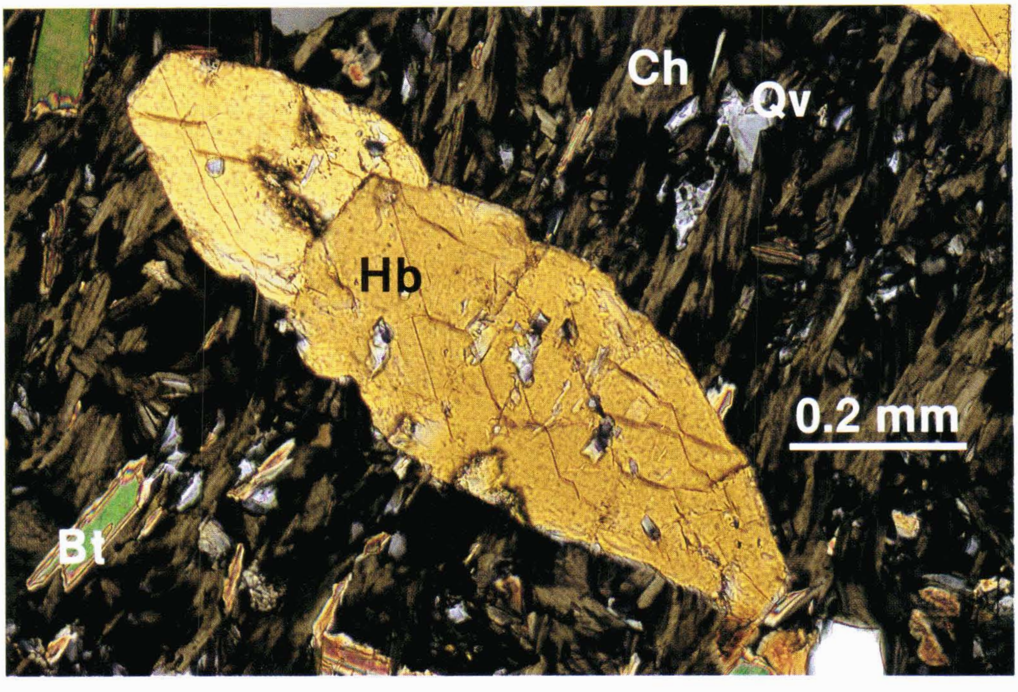

Fig. 3. a) Possible metavolcanite from the S orebody, drill hole 449: 474m. Plagioclase phenocryst (Pl), partly seritized and saussuritized, with quartz, biotite, hornblende, chlorite, apatite and ilmenite. b) Evidence for prograde metamorphism after hydrothermal alteration. Quartz-chlorite-hornblende schist from the N orebody, drill hole 5182: 54.80m (Fig. 2). Hornblende (Hb) and biotite (Bt) have grown on the chlorite (Ch) + quartz (Qv) mass.

terozoic (1.96—2.10 Ga) black schists in eastern Finland, though still higher concentrations are found in the Kainuu Schist Belt ('K' in Fig. 1, Loukola-Ruskeeniemi 1990, 1991, Loukola-Ruskeeniemi et al. 1991).

The concentrations of zinc and lead at Hammaslahti are higher in the black schists than in other lithologies. Massive sulphide deposits of both volcanic and sedimentary association are commonly vertically zoned from a Cu-rich stringer zone in the footwall towards a Zn-Pb rich hanging-wall (Franklin et al. 1981; Large 1981). It is therefore

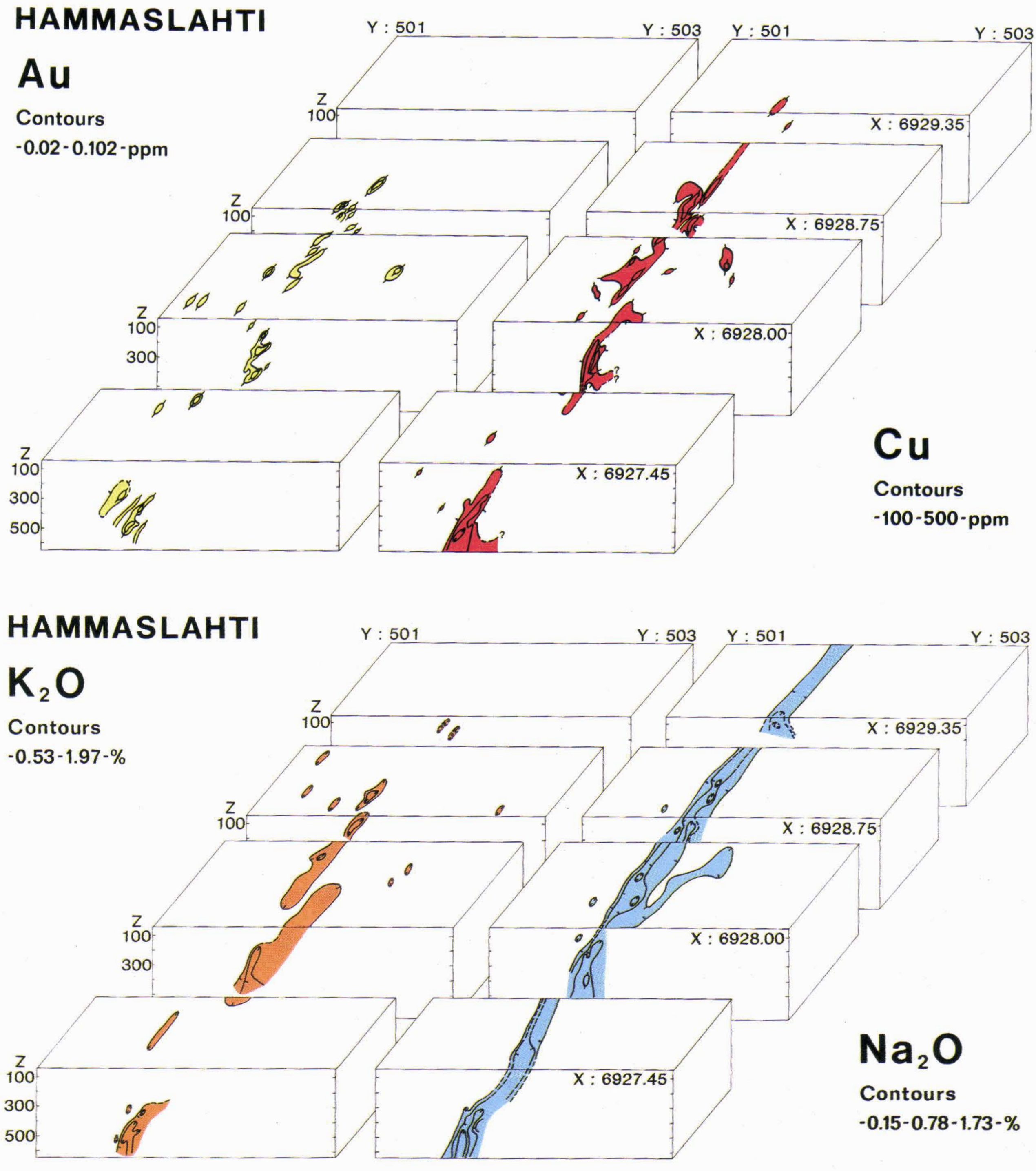

Fig. 4. Three-dimensional gold, copper, sodium and potassium anomaly patterns. Gold is enriched in 'en echelon' pattern parallel to the S_2 axial-plane cleavage. Lowest (Na_2O < 0.15 %) sodium value corresponds with copper mineralization.

concluded that elevated Zn and Pb concentrations in the Hammaslahti hanging-wall black schist derived from mineralizing fluids.

Conclusions

The zone of Na depletion, 1.5 km in length and 200 m wide, marks the axis of hydrothermal alteration. The lowest (less than 0.15 % Na_2O) tenor correlates with mineralization. Compared with the less altered metaturbidites, the hydrothermally altered rocks are depleted in Ca, Sr, Na, K and Rb and enriched in S, Fe, Cu, Zn and Au. Geochemical anomaly patterns suggest that the mineralized zone continues to the south in the direction of the N — S trending shear zone, but not to the north (Fig. 4). Gold appears as anomalies in 'en echelon' pattern parallel to the S_2 axial-plane cleavage.

Both hydrothermal alteration patterns characteristic of massive sulphides and the tectonic environment with tholeiitic metabasalts are features the Hammaslahti deposit bears in common with deposits such as Besshi (Japan), Green Mountain (California), Matchless (Namibia), Ducktown (Tennessee) and those encountered at modern sediment-covered spreading axis (NE Pacific). Also Cu-Zn-Pb concentrations of the Hammaslahti deposit are comparable to the Besshi deposit of Japan.

Equally important features are hydrothermally altered metasedimentary host rocks and the sheared hanging-wall black schist layer, with a thickness greater than that of the Kupferschiefer. Thus the Hammaslahti deposit can also be compared with sediment-hosted Cu deposits, particularly the Boleo Cu deposit in Mexico (Gustafson & Williams 1981). Typical sediment-hosted stratiform Cu deposits, however, are not closely associated with volcanism, although most of them are situated in basins with contemporary volcanic activity, or thick piles of volcanic rocks are encountered below the sediment-hosted ores.

There seems to be a transition between volcanogenic massive sulphide deposits and sediment-hosted stratiform deposits (Gustafson & Williams 1981). The Hammaslahti deposit is interpreted here to be an intermediate between Besshi-type and sediment-hosted Cu deposits.

The use of the chemical composition of black schists, especially elevated Pb and Sb concentrations, is recommended as an exploration tool at Hammaslahti. Another useful geochemical signature of this kind of ore deposit is sodium depletion in connection with other pathfinder elements (e.g. -Sr, -K, -Rb and +Mg), a feature common with other massive sulphide deposits (Hashiguchi et al. 1983).

Hammaslahti is genetically classified in this paper as a deposit hosted by metaturbidites in the close vicinity of mafic volcanics. This particular rock association is encountered in wide areas of the Svecofennian Province in Finland, and it is recommended that exploration be carried out in the turbidite belt of the Höytiäinen basin and its continuation to the south and southwest (Fig. 1).

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