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The geochemistry, fluid inclusions, sulfur isotopes and origin of the Hammaslahti copper ore deposit, Finland

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THE GEOCHEMISTRY, FLUID INCLUSIONS, SULFUR ISOTOPES AND ORIGIN OF THE HAMMASLAHTI COPPER ORE DEPOSIT, FINLAND

BY

LAURI HYVÄRINEN, KARI KINNUNEN and MARKKU MÄKELÄ

WITH 14 FIGURES

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The origin of the Hammaslahti copper ore deposit was investigated through a geochemical study of the Cu, Ni, Co, silicate iron, Zn and Pb distributions in the ore proper and in the adjoining clastic, non-volcanic sedimentary rocks. A total of 27 fluid inclusion examinations were carried out on gangue minerals from the ore proper and from its host rocks. The isotope composition of sulfide sulfur was determined in 34 samples.

The ore is surrounded by distinct negative aureoles of Cu and Co, and by a positive Ni aureole.

Fluid inclusion studies indicated a minimum formation temperature of 310°C and H_2O, H_2S, CO_2 and Se as the main chemical components of the ore-forming fluids.

The overall range of the $\delta^{34}S$ values is from $+1.4$ to $+14.2\ ^0/_{00}$; the arithmetic mean being $+5.5\ ^0/_{00}$. The sulfides of the ore proper exhibit a mean $\delta^{34}S$ of $+3.8\ ^0/_{00}$ with a standard deviation of 0.8, whereas those from host rocks outside the ore show a mean $\delta^{34}S$ of $+6.3\ ^0/_{00}$ with a standard deviation of 2.6.

The results favor the conclusion that once-disseminated synsedimentary sulfides were remobilized to form the ore.

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INTRODUCTION

In 1966 disseminated chalcopyrite was found in an arkosite outcrop in Hammaslahti (Fig. 1). As a consequence the Ore Department of the Geological Survey of Finland started prospecting activities in the region, which in 1968 led to the discovery of the Hammaslahti ore deposit. The exploration phase ended in 1970 (Hyvärinen 1970) but prospecting activities were carried out in the surrounding area until 1971 (Hyvärinen 1972). Recently, investigations in the region have begun again in co-operation with the Outokumpu Company, which is quarrying the Hammaslahti ore.

The aim of the present study was to investigate the origin of the Hammaslahti copper ore deposit through a study of geochemical (Hyvärinen), fluid inclusion (Kinnunen), and sulfur isotope data (Mäkelä). The samples and the field data were gathered by the Geological Survey.
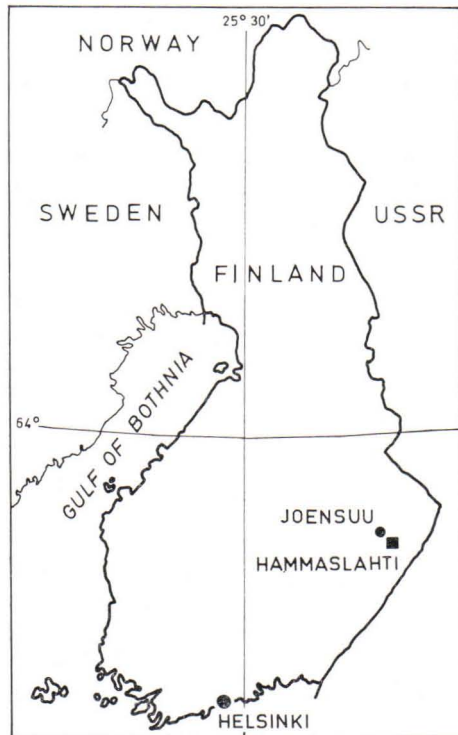

Fig. 1. Index map of Finland showing the
Hammaslahti mine.

GEOLOGICAL OUTLINE

The bedrock in the Hammaslahti area consists of NNW-trending Karelian schists that can be divided into three zones: two synclinal basins dominated by Kalevian schists (the Höytiäinen basin in the east and the Pyhäselkä basin in the west) and an anticlinorium between them. The typical rocks in the anticlinorium are meta-arkoses, para-conglomerates, black schists, phyllites and dolomites. In Hammaslahti these rocks belong to a phyllite-mica schist formation in the lower parts of a Kaleva sequence. However, the so-called Mulo schists (black schists) can be correlated to the Marine Jatulian and can be concluded to lie stratigraphically under the meta-arkositic schists of Hammaslahti (Nykänen 1971).

The Hammaslahti copper ore is situated in a shear zone, which cuts the western border of the syncline situated in the anticlinorium (Figs. 2 and 3). This syncline has a length of at least 15 km and a width of 2.5—3.0 km. Its axial plane trends 340° and the axis plunges 25°—30° to the southern direction. In places the syncline is characterized by isoclinal folding.

GEOLOGY OF THE ORE DEPOSIT

There are eight ore bodies in the N-S striking shear zone spatially controlling the Hammaslahti ore deposit. The ore bodies run parallel to one another and to the lineation of the zone traced by the drillings for some 1.5 km. Geophysical measurements, however, suggest a length of at least 8 km for the shear zone.

The immediate host rock of the ore is mainly impure arkose, but phyllite fragments are also met with. As a consequence of dynamic metamorphism, micas and feldspars + quartz have frequently segregated into different bands. Moreover, quartz has replaced plagioclase in arkosites and tremolite in amphibolites. The crystallization order of the gangue minerals is as follows: albite, biotite, chlorite, quartz, calcite and/or siderite with fluorite. In addition to these, some scheelite has been found. Albite and fluorite are accessories. The quartz usually contains fluid inclusions and occasionally rutile needles.

The ore is mainly of the breccia type, but there are places where disseminated sulfides predominate. The ore contacts are gradual, sulfide content being anomalous throughout the shear zone, which is 50 m wide at least. The northern part of the deposit is composed of two and the southern part of six ore bodies, the dimensions and metal content of which vary a great deal. The largest ore body in the southern part is as much as 20 m thick, 200 m wide and 700 m long. In 1970 the Geological Survey estimated the ore reserves to be, at minimum, 4 million tons of 1 % copper ore.

Chalcopyrite and pyrrhotite are the principal ore minerals. Sphalerite is ubiquitous but in the northern end of the deposit it occurs together with pyrite in appreciable
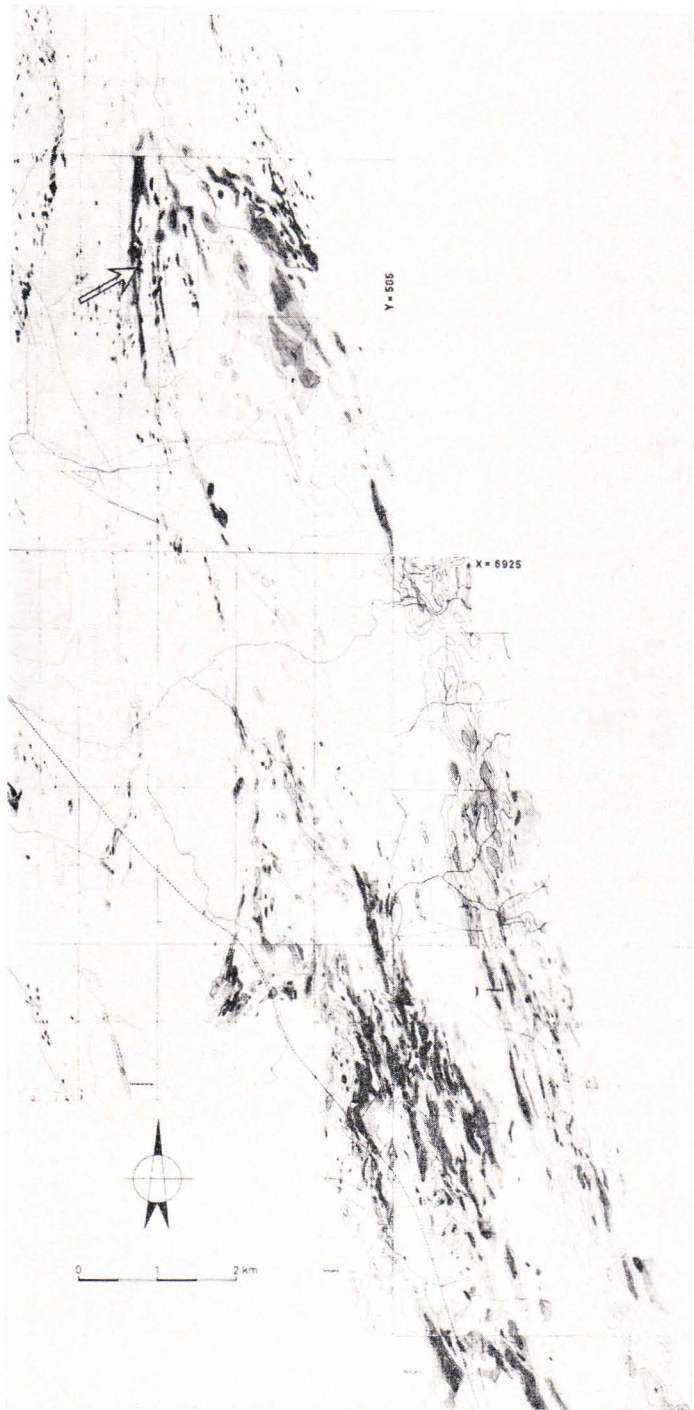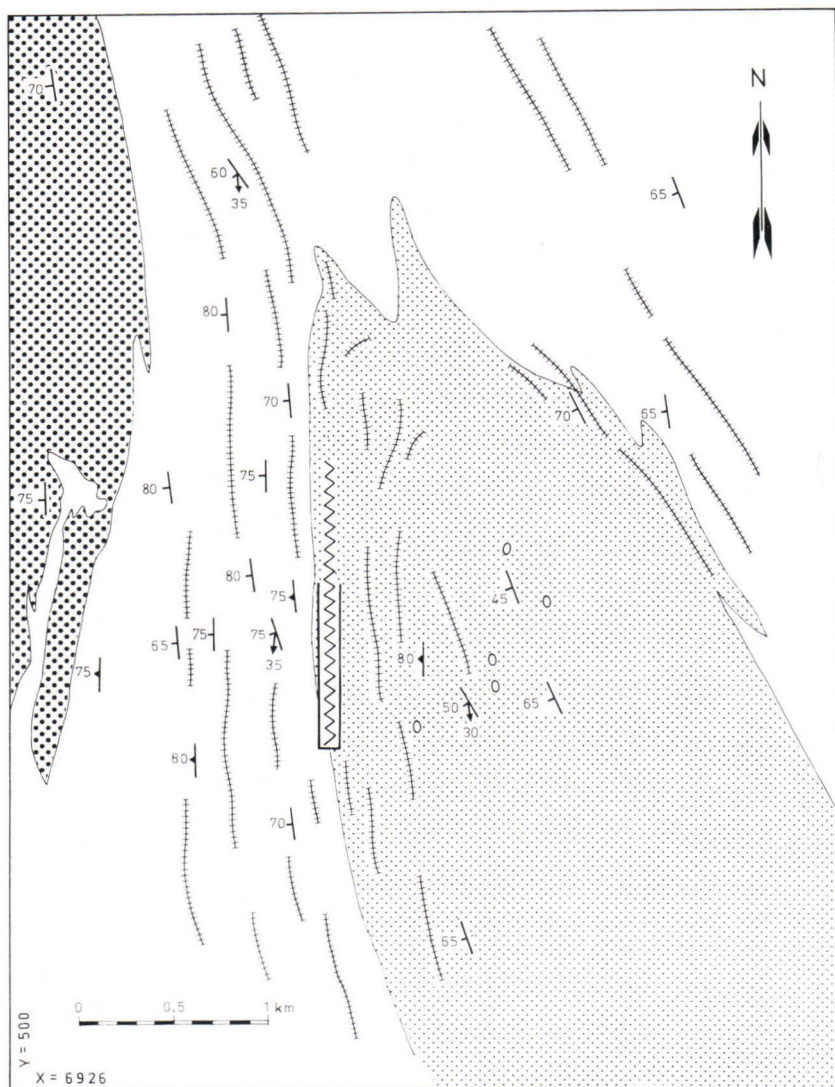
Fig. 2. Magnetic map showing the arkosite sequence of Hammas-
lahti. The arrow points to the Hammaslahti copper ore deposit.
Magnetic anomalies > 250 NT.

Fig. 3. Geological map of the area surrounding the Hammaslahti ore deposit. Northern end of the arkosite sequence. According to the map by Nykänen (1971) and to the geophysical maps (Siikarla 1970) compiled by Hyvärinen. Symbols: 1. Black schist (Mulo schist), 2. Black schist intercalations, 3. Phyllite, partly mica schist, 4. Meta-arkose, 5. Conglomerate intercalations, 6. Bedding, 7. Foliation, 8. Lineation, 9. Shear zone, and 10. Hammaslahti ore deposit.
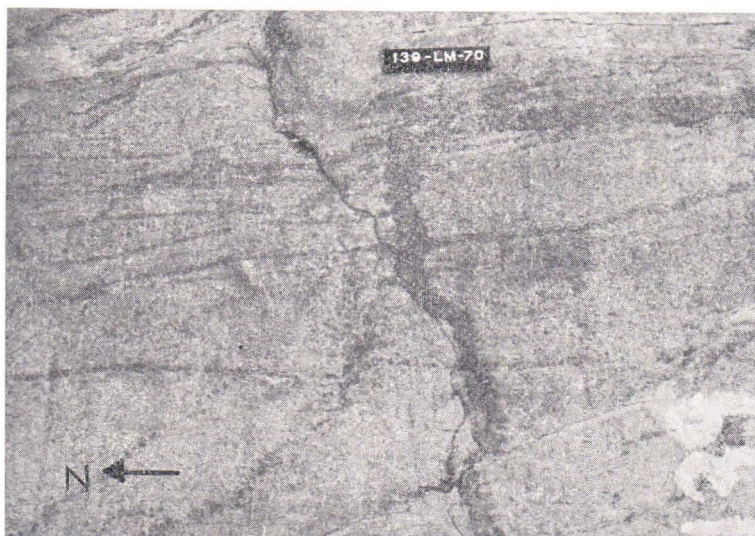
Fig. 4. Quartz veins with sulfide minerals in sheared arkosite.

amounts. Galena is everywhere scarce. Mackinawite, cubanite, and fahlerz occur as exsolutions. Arsenopyrite is met with as a curiosity. The crystallization order of the ore minerals is: pyrrhotite, sphalerite, pyrite, chalcopyrite, and galena.

Economic concentrations of sulfide minerals together with secondary quartz occur mainly as fracture fillings. In these fractures the sulfide minerals crystallized after the gangue minerals. The W-E fractures probably opened before the N-S and N 5°—10° E fractures (Fig. 4).

GEOCHEMISTRY

Ore deposit

The most significant economic metal in the Hammaslahti ore is copper. Its average content in the northern part of the deposit is 0.6 % and in the southern part 1 %. The copper content varies markedly in different parts of the same ore body.

Zinc is unevenly distributed in small amounts in the southern part of the deposit. In the drill core R 21 (Fig. 8) the zinc content varies from 100 ppm to 3600 ppm with an average of 510 ppm. In the northern part of the deposit zinc is more abundant and also fairly homogeneously distributed. In the surface section (600 m²) the average zinc content is almost 3.5 %. Galena occurs only as a weak dissemination: in the drill core R 21 the average lead content is 140 ppm and in the drill core R 52 from the same profile, 20 ppm lead, which is only slightly more than in the surrounding arkosites.

Cobalt and nickel are scarce in the ore: the cobalt contents are all under 450 ppm and the nickel contents under 80 ppm (Fig. 5). The Ni/Co ratio remains below 1 in the ore, whereas it increases to above 1 in the host rocks (see also Fig. 8). The Cu/Co relation (Fig. 6) shows that a rise in the copper content is accompanied by a rise in the cobalt content.

The arithmetic mean of silver in the mineralized zone is only 6.6 g/t, so that it is not an economic metal. The silver and copper contents follow each other (Fig. 7), indicating that Ag as well as Co are present in the lattice of chalcopyrite. Gold distribution in the mineralized zone is uneven and without economic significance.
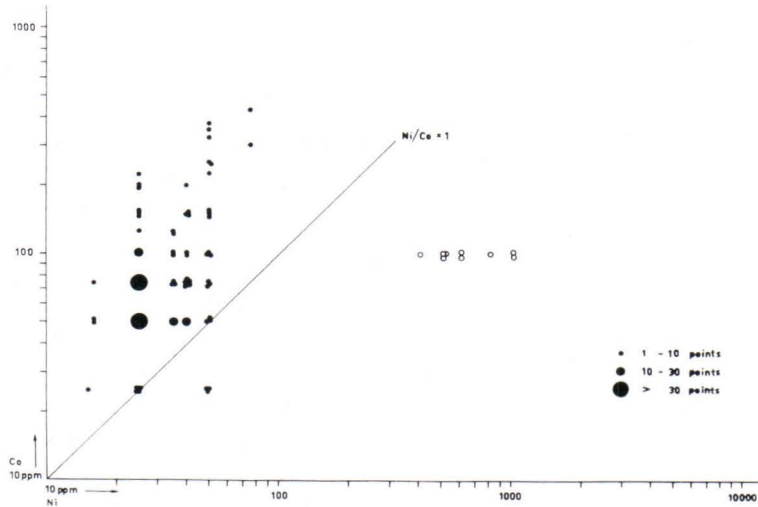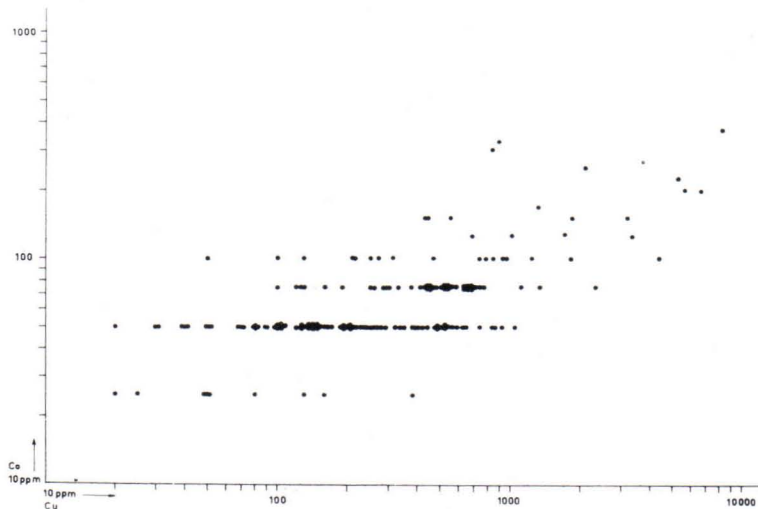

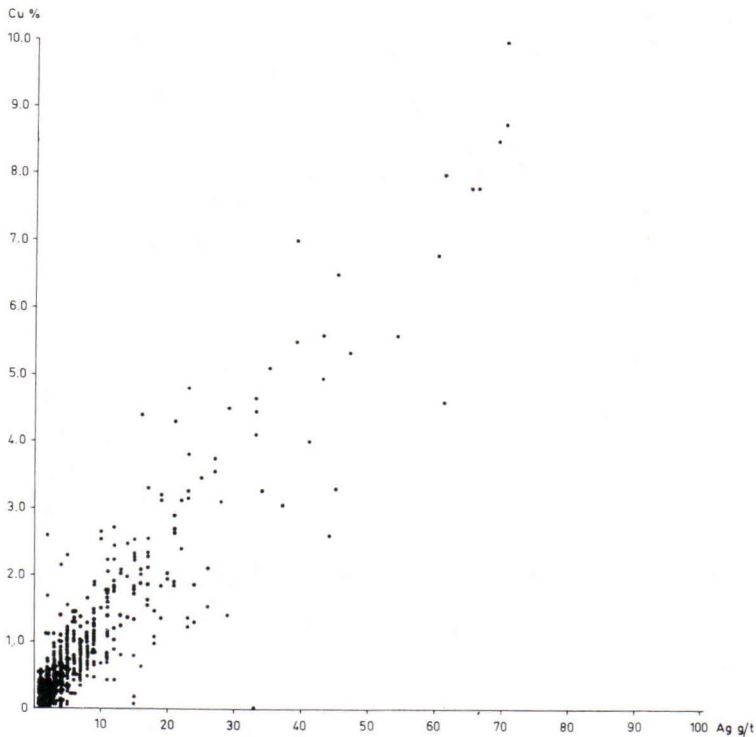Fig. 5. Ni-Co diagram.● Hammaslahti ore,○ black schist.

Fig. 6. Cu-Co diagram.

Fig. 7. Ag-Cu diagram.

Host rocks

Variations in the metal contents and ratios in host rocks were investigated from a profile (X = 6 928 300). It crosses almost the center of the known ore deposit, and the drillings extend from the ore body 230 m into the host rocks at the hanging-wall side and 130 m at the foot-wall side. The drill cores R 21 and R 52 were analyzed with a distance between samples of 5 m (5.00—7.00 m, 12.00—14.00, 19.00—21.00, etc.). Total Fe and Zn contents were analyzed by the AAS-method: Cu, Ni, Co and Pb spectrographically, and sulfidic sulfur with the Leco M 621 sulfur analyzer. The results for Cu, Fe, Zn, Co are presented in Fig. 8.

Copper. The ore is surrounded by a 70—100 m wide negative copper aureole, where the copper concentration is clearly lower than in the surrounding area. At the hanging-wall side the average copper contents in the arkosite are 78 ppm (R 21, 20—40 m), 32 ppm (R 21, 40—140 m), and close to the ore 113 ppm (R 21, 140—180 m). In the arkosite at the foot-wall side they are 132 ppm (R 52, 140—160 m) and 102 ppm (R 52, 70—140 m).
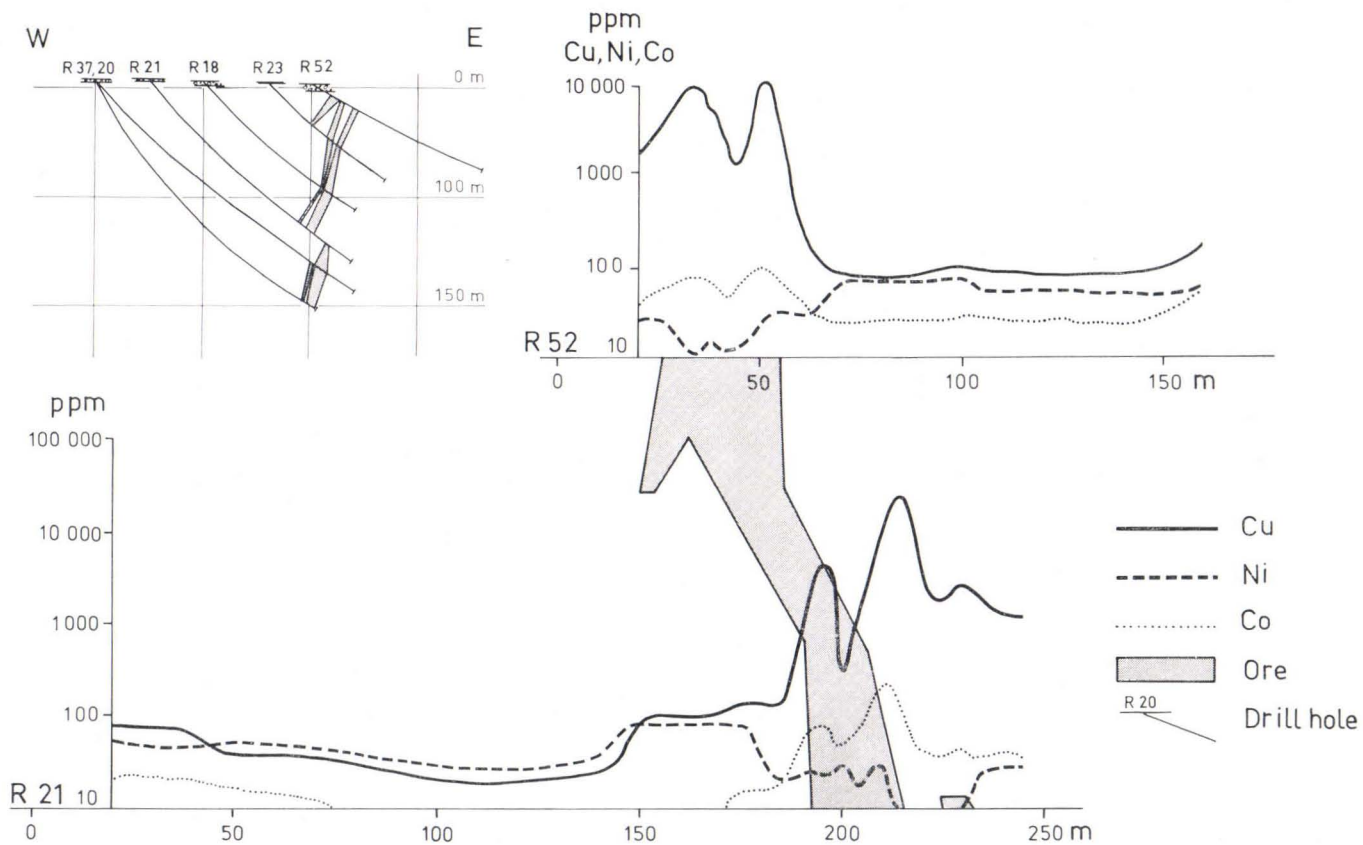
Fig. 8. The variations in the Cu, Ni and Co contents in the host rocks of the Hammaslahti ore deposit (curves smoothened by using moving averages).

Cobalt. As in the ore (Fig. 5), cobalt follows copper also in the host rocks (Fig. 8). At the hanging-wall side the cobalt contents are 21 ppm (R 21, 20—40 m) and < 10 ppm (R 21, 70—170 m). At the foot-wall side the cobalt contents are 29 ppm close to the ore (R 52, 70—140 m) and 41 ppm away from it (R 52, 140—160 m).

Nickel. The behaviour of nickel in the ore and its host rocks differs from that of copper and cobalt. In the ore body itself the average nickel content is 20 ppm (R 21). At the hanging-wall side the average content is 86 ppm (R 21, 140—175 m) and in the arkosite 44 ppm (R 21, 20—140 m). Correspondingly, in the upper part of the ore the nickel content is only 20 ppm (R 52), whereas close to the ore in a 30—40 m wide zone it is 94 ppm (R 52, 65—100 m), and east from this zone in the arkosite 59 ppm (R 52). Thus the ore body is surrounded by a 30—40 m wide zone, where nickel is 0.6—1.0 times enriched.

Iron. Only the silicate iron from the drill core R 21 is considered here. The average iron contents are 32 500 ppm (20—60 m), 28 000 ppm (60—180 m), and 49 000 ppm (180—240 m). Thus it seems to form a negative aureole, at least at the hanging-wall side.

Zinc and lead. In arkosite at the hanging-wall side the average zinc content is 135 ppm (R 21), and at the foot-wall side 270 ppm (R 52). The average Zn content in black schist is 600 ppm (see also Fig. 4). The average lead content in arkosite is 12 ppm (R 21 and R 52) and in black schist 140 ppm (R 21). Zinc and lead are not enriched or impoverished in the host rocks, but the drill core R 21 contains 10 ppm more zinc and 2 ppm more lead at 20 to 70 m than at 70 to 150 m. After this the zinc and lead concentrations rise, reaching maximum values in the ore.

The ore is thus surrounded by distinct negative aureoles of copper and cobalt, and by a positive aureole of nickel. One possible explanation of the positive aureole of nickel is its tendency to replace magnesium diadochically in mineral structures (cf. Fig. 14, FeO/(FeO + MgO) -ratio. The positive nickel aureole also indicates the primary origin of the negative aureoles of copper and cobalt, since the geochemical behaviour of nickel and cobalt should be similar (Rankama and Sahama 1950) and both should enrich in secondary aureoles. Accordingly, we conclude that the aureoles are the results of remobilization of Ni, Co, and Cu, and to a lesser extent Fe, from the host rocks to the shear zone.

FLUID INCLUSIONS

Fluid inclusions were examined in 27 samples from the drill core R 18 taken at an average sample distance of 5 m.

The fluid inclusions were homogenized by the decrepitation method. This method was chosen because the fluid inclusions were too small for ordinary homogenization heatings: the diameters were almost always under 10 μm and very often about 2 μm. The decrepitation was followed visually from the rapid movement of quartz grains

when their fluid inclusions exploded. All quartz samples were as free as possible of sulfide mineral inclusions, weighed about 2 g and had a mean grain size of about 1 mm. The accuracy of the temperature measurements was $\pm 5°C$ according to organic melting point standards. In the decrepitation heatings coloured vapors from the open inclusion cavities erupted and sublimated on the quartz glass window of the heating stage. For further analysis with an electron-microprobe, the sublimates were gathered on a glass slide, which was put in place of the quartz glass window.

Fluid inclusions characterized the quartz in the quartz-chalcopyrite-pyrrhotite veins of the ore proper and the adjoining host rocks. A network of healed micro-fractures often radiated from ore mineral microveins to the quartz (Fig. 9) These fractures were filled with quartz, secondary fluid inclusions and chalcopyrite (Fig. 10). The bipyramidal secondary fluid inclusions were composed, at room temperature, mainly of gas under high pressure, according to crushing-stage studies; a non-magnetic opaque phase (chalcopyrite?); and liquid, which was seen only on the edges of the inclusion cavities (Fig. 11). The relative volume of the opaque phase varied in different fluid inclusions. Thus the particles may have been mechanically trapped inside the inclusion cavities, for the necking down process has been slight in these inclusion planes. In some of the fluid inclusions a small bubble of liquid CO_2 nucleated when cooled below room temperature.

Some microfractures were filled only with secondary fluid inclusions and quartz. Their phases at room temperature were usually liquid and vapor bubble, according
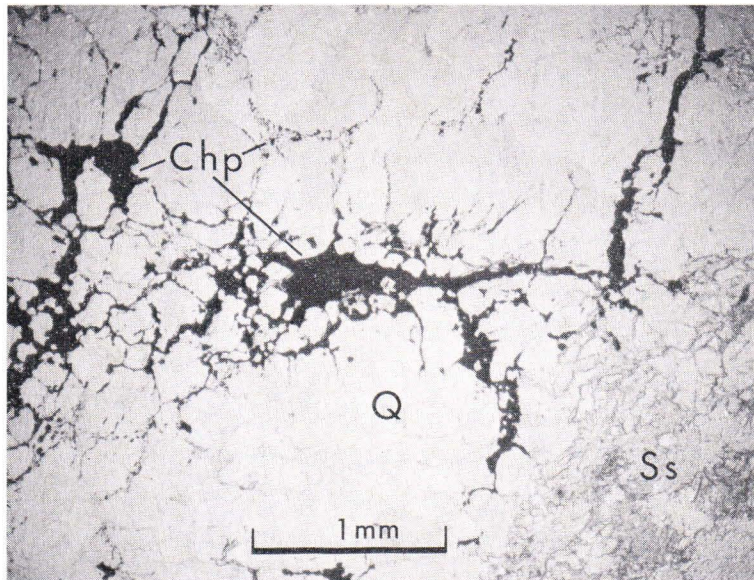

Fig. 9. Photomicrograph of a quartz (Q)-chalcopyrite (Chp) vein in sericite schist (Ss). Polished thin section under plane polarized light.
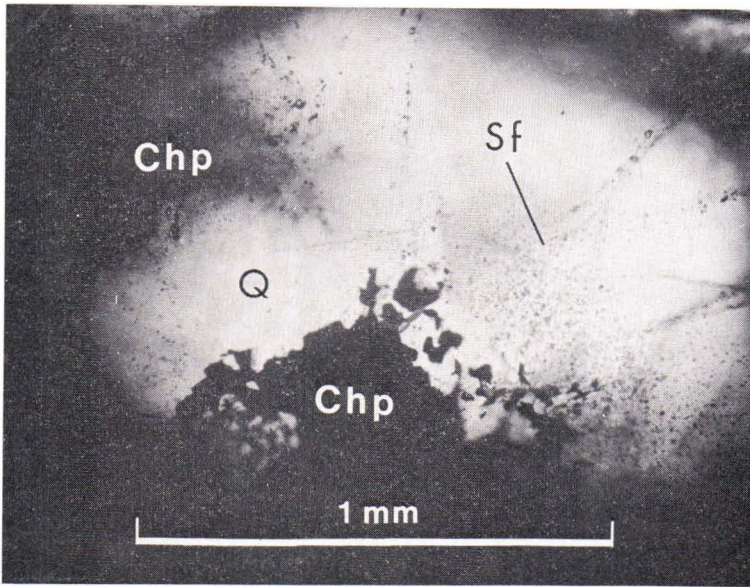
Fig. 10. Photomicrograph of a network of microfractures in vein quartz. Chp = chalcopyrite, Q = quartz, Sf = secondary fluid inclusions. Polished thin section under plane polarized light.
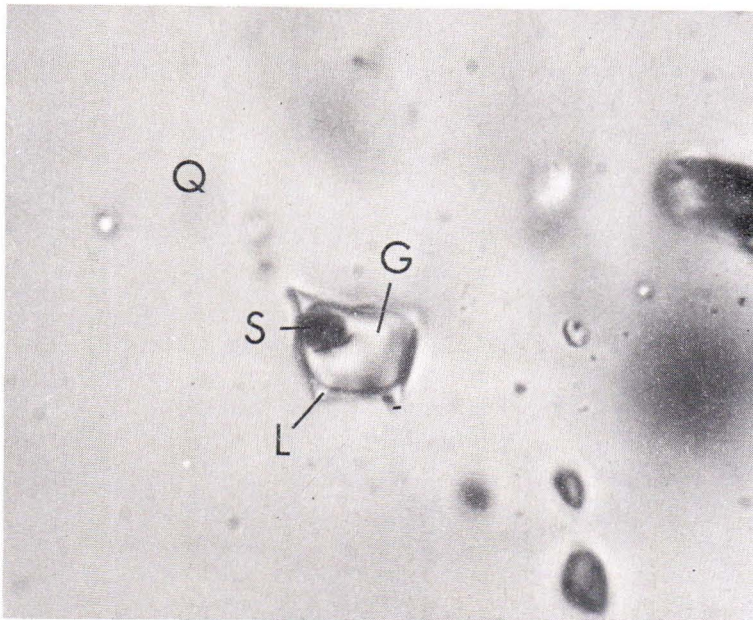

Fig. 11. Photomicrograph of a secondary fluid inclusion in quartz. G = gas, L = liquid, S = opaque solid phase (chalcopyrite?). Inclusion diameter 10 μm.

to crushing-stage studies. In rare cases also two solid phases occurred in fluid inclusions: an isotropic cube (halite?) and one strongly anisotropic mineral. Most probably these solids were real daughter minerals, crystallized from the over-saturated liquid inside the sealed inclusion cavities.

Most of the secondary fluid inclusions in the ore-bearing micro-fractures de-crepitated at 310°C. This value is interpreted as their minimum filling temperature. The fluid in the open inclusion cavities in these fractures vaporized to water vapor at about 100°C and to a brown-yellow gas with a distinct odour of H_2S from 120°C to 190°C. Electron microprobe analysis of the sublimates of these gases showed them to contain S and traces of Se.

Thus the data collected from the fluid inclusions suggest that the ore-forming fluid contained H_2O, H_2S, CO_2, and Se as gaseous solutions of low density. The minimum trapping temperature for these solutions was about 310°C. In addition the solutions were saturated with silica and contained high concentrations of heavy metals. It seems possible, therefore, that hydrosulfide complexes have transported heavy metal compounds, as Barnes (1960) has shown experimentally for zinc. If the solid opaque phase represents real daughter minerals, the ore-forming fluid has been unusually highly oversaturated with heavy metal compounds (cf. Roedder 1972). The experiments on diffusion of ions through intergranular spaces in water-saturated rocks indicate that the diffusion should be greater in rocks with small but numerous closely spaced fractures (Garrels et al. 1949). The numerous micro-fractures both in the ore and in its host rocks could thus have been the channelway along which the ore components moved (see Figs. 9 and 10).

The Se content in the fluid inclusions may indicate fluid migration from the surrounding rocks into the fractures (Koljonen 1974, Table 1, Group 29). Further-more, according to Koljonen (1975) the Se content is probably highest in Cu-rich ores mobilized from carbon-rich metasediments.

On the basis of the above considerations, we believe that at least part of the ore-forming components originate in the adjacent black schists.

SULFUR ISOTOPES

The isotope composition of sulfide sulfur in the Hammaslahti ore proper and in the adjoining clastic, nonvolcanic sedimentary rocks was determined in altogether 34 samples.

Sulfides indended for isotope analysis were selected manually with the help of a binocular stereo microscope. They were converted into SO_2 by oxidation with V_2O_5, and the SO_2 was isotopically analyzed in the Laboratory of Economic Geology, Helsinki University of Technology, as described by Mäkelä and Tammenmaa (1977). Laboratory values were standardized against troilite sulfur of the Canyon Diablo

meteorite (CDT) via the Isotope Laboratory of the University of Göttingen. The analytical precision of $^{34}S^1$) values is $\pm$ 0.1 $^o/_{oo}$.

The $\delta^{34}S$ values (Fig. 12) range from + 1.4 $^o/_{oo}$ to + 14.2 $^o/_{oo}$, with an arithmetic mean of + 5.5 $^o/_{oo}$. The sulfides of the ore proper exhibit a mean $\delta^{34}S$ value of + 3.8 $^o/_{oo}$ with a standard deviation of 0.8, whereas those from the host rocks outside the ore show a mean $\delta^{34}S$ value of + 6.3 $^o/_{oo}$ with a standard deviation of 2.6.

According to Schwarcz and Burnie (1973) sulfur isotope ratio distributions in clastic nonvolcanic sediments can be accounted for by one of two models: open system reduction of seawater sulfate under stationary state conditions with the fractionation between initial seawater sulfate and sulfide $\Delta = 50$ $^o/_{oo}$; or, closed system reduction of a limited sulfate pool with -3 $^o/_{oo} < \Delta < 25$ $^o/_{oo}$. The latter conditions arise (Schwarcz and Burnie op.cit.) in labile, nearshore sedimentary environments where the organic nutrient supply, either washed in or grown in situ periodically rises above the rate of bacterical consumption, and where tidal action or movement of sediment causes the formation of isolated pools of sea water.

There is insufficient evidence concerning the isotopic composition of the Precambrian marine sulfate. Thode and Monster (1967) give + 14.5 $^o/_{oo}$ for sea water contemporaneous with the Grenville Series (around 1 000 Ma) and + 14.6 $^o/_{oo}$ for marine sulfate contemporaneous with formations < 1 000 Ma and > 635 Ma. Recently Mäkelä and Tammenmaa (1977) gave an estimate of + 14.6 $^o/_{oo}$ for marine sulfur $\delta^{34}S$ coeval with the ore formations in the Central Lapland schist zone (around 2 100 Ma).

Our adoption of the estimate + 14.6 $^o/_{oo}$ for sea water sulfate contemporaneous with the original sedimentary precipitation of the Hammaslahti sulfides is supported by the $\delta^{34}S$ value of + 14.2 $^o/_{oo}$ determined from pyrrhotite in the coarse-grained meta-arkose at the foot-wall side of the ore body.

Taking then the seawater $\delta^{34}S$ value of + 14.6 $^o/_{oo}$ as our reference, the Hammaslahti $\delta^{34}S$ distribution with + 0.4 $^o/_{oo} < \Delta < + 13.2$ $^o/_{oo}$, although probably constricted subsequent metamorphism, indicates an original closed system reduction in labile nearshore environment. This is consistent with what could be expected on the basis of the bedrock association.

In relation to the sulfur isotope patterns the Hammaslahti ore falls where the values change towards lighter $\delta^{34}S$ (Fig. 13). The 10 ore sulfides analyzed are, on the average, 2.5 $^o/_{oo}$ isotopically lighter than the sulfides in the adjoining metasedimentary host rocks. Moreover, the $\delta^{34}S$ population of the ore sulfides is more constricted than that of the host rocks, the standard deviation of the former being 0.8 and that of the latter 2.6. These results are incompatiple with a simple synsedimentary situation but quite compatible with the theory that once-disseminated

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[1]) $\delta^{34}S$ is defined as the per-mille deviation of the $^{34}S/^{32}S$ ratio of the sample from the given CDT standard

$$\delta^{34}S \; ^o/_{oo} = \left[\frac{(^{34}S/^{32}S)\text{sample}}{(^{34}S/^{32}S)\text{standard}} \right] - 1 \times 10^3$$
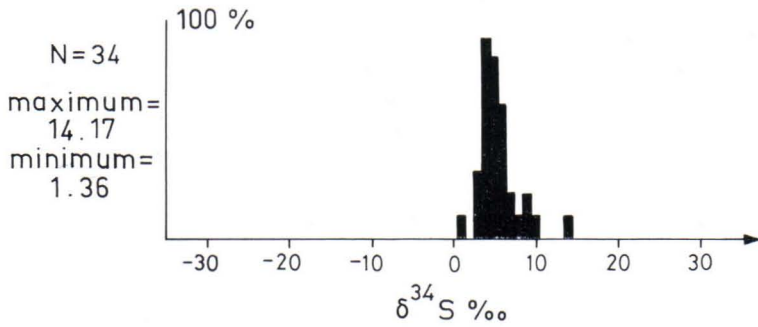
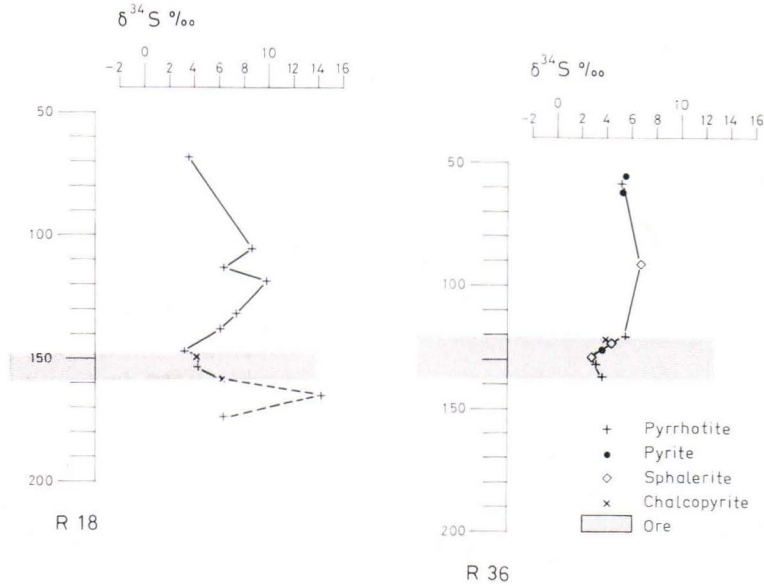Fig. 12. Histogram of the [34]S values of Hammaslahti sulfides.

Fig. 13. δ^{34}S values of the sample populations in drill cores R 18 and R 36.

synsedimentary sulfides were remobilized to form the ore. The seeming contradiction rises from the fact that extended fractionation between sulfate and sulfide occurs. Since large Δ values imply low sedimentation rates, the ore deposition should have taken place over a long period. But formation of the ore with low sedimentation rates is improbable and low sedimentation rates normally produce a large δ^{34}S scatter.

However, if the remobilization of once-disseminated synsedimentary sulfides is assumed, both the relative depletion of [34]S in the ore sulfides and the constriction of their δ^{34}S values are explained.

Three different mechanisms were obviously important in the remobilization: 1) the plastic flow of sulfides, 2) solid-state diffusion, and 3) the formation of meta-hydrothermal solutions (Mikkola and Väisänen 1972). Diffusion is the common factor in mechanisms 1 and 2 and leads to kinetic separation as molecules containing the light isotope move more rapidly than those with the heavy one. In the case of the plastic flow of sulfides, solid state diffusion is associated with recrystallization. Moreover, there is a free energy increase of the material under the plastic deformation preceding the actual flow of sulfides, which may lead to the depletion of ^{34}S in the remobilized phase. The isotopic composition of metahydrothermal solutions is essentially determined by the δ^{34}S values of sulfur-bearing minerals that have penetrated into this fluid phase. Thus, the end results is due to the tendency of meta-hydrothermal solutions to adopt the average δ^{34}S values within their sphere of influence.

Interrelations between sulfur isotope composition and base metal distribution in the sample populations were tested by applying modified factor analysis. No correlation between δ^{34}S values and metal contents was found. Moreover, an apparent negative correlation (correlation factor —0.593) prevails between δ^{34}S and the sulfur content. Both results support the theory that once-disseminated synsedimentary sulfides were remobilized to form the ore.
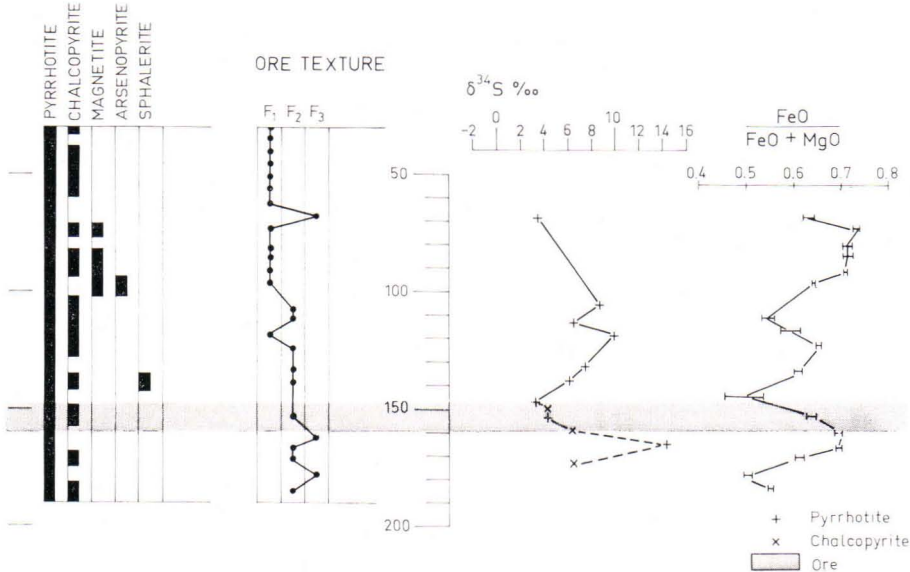

Fig. 14. Ore mineral composition, ore textures, sulfur isotope pattern, and FeO/(FeO+MgO) variation from the drill core R 18. Symbols: F_1 disseminated in foliation planes, F_2 disseminated in shear planes, F_3 fracture filling.

Since the plastic flow of sulfides and solid-state diffusion both are affected by PT gradients, the remobilization grade and grade of metamorphism should be to some extent analogous.

On the basis of this and on the finding that in biotites a decrease in Fe^{2+} and an increase in Mg can be correlated with an increasing grade of metamorphism (Engel and Engel 1960), microprobe analyses were carried out on 14 biotites and 4 chlorites of the sample population R 18. The result is given as the ratio FeO/(FeO + MgO) and compared with the $\delta^{34}S$ pattern in Fig. 14.

With decreasing FeO and increasing MgO the ratio decreases and thus indicates increasing grade of metamorphism and an increase in grade of remobilization. The similarity between the sulfur isotope patterns and the FeO/(FeO + MgO) pattern (Fig. 14) accordingly implies that remobilization was of importance in concentrating the sulfides to form the ore.

In the Outokumpu stratiform copper ore deposit, an overall effect, a depletion of ^{34}S in remobilized sulfides by an average of 2.6 $^{0}/_{00}$, is observed, and solid-state diffusion is considered to be the main factor causing the depletion (Mäkelä 1972).

The effect of remobilization on sulfur isotope composition has been studied more recently in the Vuonos ore (Mäkelä, unpublished data). Here an $\delta^{34}S$ evolution from —6.0 $^{0}/_{00}$ in the ore proper to —10.2 $^{0}/_{00}$ in the remobilized joint filling in the host rock is evident. The depletion of ^{34}S is a function of the distance along the joint from the ore proper.

CONCLUSIONS

The Hammaslahti copper ore deposit lies in a transversal shear zone extending several kilometers. Thus the ore mineralization has a distinct time-place relationship with the shear tectonics.

The positive nickel aureole surrounding the ore indicates primary origin also for the negative aureoles of copper and cobalt, because the geochemical behaviour of nickel and cobalt should be similar and thus they should both enrich into secondary geochemical aureoles.

The lead model age of the Hammaslahti ore deposit is 2 300 Ma (Kahma 1973). This value cannot represent the age of the shear zone or of the ore formation, however, because the Marine Jatulian rocks are only 2 050 Ma old (Kouvo 1976). Possibly the age of the ore lead represents the sedimentation age in the original Karelian sediments. Thus the lead isotope determinations also suggest that the material of the Hammaslahti ore originated in the surrounding schists.

According to the fluid inclusion data the ore-forming fluids were silica-rich gaseous solutions of low density. Their principal chemical components were H_2O, H_2S, CO_2, and Se. Because these fluids were present also in the fractures surrounding the actual shear zone, they could leach copper and cobalt and transport them into

shear zone traps of least pressure. The metal components deposited as sulfide minerals of an average temperature of at least 310°C. This process is now manifested in the negative geochemical aureoles of these metals that surround the ore deposit.

In relation to the sulfur isotope patterns the Hammaslahti ore is located on the curve where the values change towards lighter $\delta^{34}S$. The average difference between the $\delta^{34}S$ values of ore sulfides and those of the metasedimentary host rocks is 2.5⁰/₀₀. The $\delta^{34}S$ population of the ore sulfides is more constricted than that of the host rocks, the standard deviation of the former being 0.8 and that of the latter 2.6. The present results are not compatible with an original synsedimentary situation but favor the possibility that the once-disseminated synsedimentary sulfides were remobilized to form the ore.

There is no correlation between $\delta^{34}S$ and metal contents. Moreover, and apparent negative correlation prevails between $\delta^{34}S$ and the sulfur content. The results both support the idea of remobilization of the once-disseminated synsedimentary sulfides.

The similarity between the sulfur isotope patterns and the FeO/(FeO + MgO) pattern taken to be indicative of the remobilization grade implies that remobilization was of importance in concentrating the sulfides to form the ore.

The geochemical, fluid inclusion, and sulfur isotope data imply that the Hammas-lahti copper ore deposit is epigenetic in origin and that the ore-forming substances were remobilized from the host rocks. A similar explanation has been proposed by Gosh (1972) for the copper ore deposits of the Singhbhum shear zone in eastern India. According to Gosh, Precambrian metasedimentary and metavolcanic rocks served as the source and diffusion of the ore constituents and their precipitation took place in physicochemically favourable structural traps formed in shearing.

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