CHARACTERISTICS OF THE PROTEROZOIC PORPHYRY-TYPE Cu OCCURRENCE AT TIENPÄÄ, HALSUA, WESTERN FINLAND

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The widespread, subeconomic porphyry-type Cu mineralization at Tienpää occurs in a Proterozoic tonalite complex. It is located in the marginal zone of the large granitoid complex of central Finland. The tonalites consist of five varieties with minor textural, mineralogical and chemical differences. Three of the varieties are porphyritic.

The Cu mineralization is of a stockwork type comprising a parallel set of narrow, mineralized and often quartz-filled fractures of subvertical dip. The *en échelon* fractures constitute a zone that crosscuts lithological boundaries. The maximum width of the zone is about 250 m and its length at least 1500 m. The only major ore mineral is chalcopyrite, which occurs on the surfaces of fractures and as dissemination around the fractures. The average Cu content along a profile across the middle of the mineralized zone is about 500 ppm and that of Mo about 45 ppm. Minor mineralization is also connected with a tourmaline-bearing quartz breccia and with a few narrow shear zones. Weak but widespread propylitic alteration and recrystallization of biotite are encountered. Muscovitization is also fairly common. Propylitic alteration and muscovitization are most intense in the immediate vicinity of the mineralized fractures.

The stockwork mineralization developed within a shear zone, and the mineralized fractures were extensional in character. Subsequent rotation of the stress field within the shear zone generated oblique foliation in the quartz-filled fractures.

Key words: Proterozoic, porphyry copper, stockwork, tonalite.

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Introduction

In recent years possible Precambrian analogies for the large porphyry Cu and Mo deposits associated with Phanerozoic granitoids have been described from Canada (Kirkham 1972, Findlay and Ayres 1977, Goldie *et al.* 1979, Sinclair 1979, Armbrust 1980, Ayres *et al.* 1982), Zambia (Wakefield 1978), Australia (Barley 1982), Sweden (Walser and Einarsson 1982) and Finland (Gaál and Isohanni 1979, Gaál *et al.* 1981). The studies in Canada have been summarized by Ayres and Černý (1982). The porphyry-type deposits in Australia and most of those in Canada have been interpreted as Archean in age and the others as Proterozoic.

These occurrences are geologically similar to the younger porphyry deposits although hydrothermal alteration is weaker and a clear zonal pattern of sulphide minerals is seldom present. From the economic point of view, however, they differ significantly, the Precambrian porphyry occurrences being much lower in grade and smaller in tonnage.

The present paper deals with a Cu deposit of stockwork type situated at Tienpää in Halsua, western Finland (Fig. 1), and describes the petrology of the occurrence and its host rocks as well as the structural features controlling the mineralization. Gaál and Isohanni (1979) have described three other porphyry-type occurrence located within 70 km of Halsua. In their opinion the deposits are situated in epizonal intrusions emplaced in previously metamorphosed and deformed supracrustal rocks; they occur in the same stratigraphic setting; and they are located near or at the intersection of northeast and northwest-striking faults.

Geological setting

The study area is situated in the marginal zone of the large granitoid complex of central Finland (Fig. 1). The tonalite host of the occurrence extends outside the study area of 3 × 4 km but its total extent is unknown. The plutonic rocks in and around the granitoid complex vary in age from 1800 to 1900 Ma (Simonen 1980).

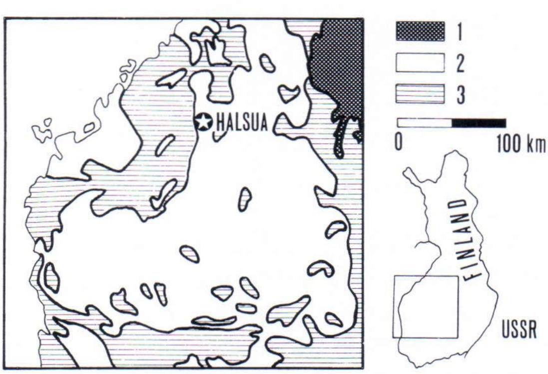

Fig. 1. Simplified geological map of central-western Finland and the location of the Cu occurrence at Tienpää, Halsua (modified after Simonen 1980). 1) Archean rocks; 2) Proterozoic plutonic rocks; 3) Proterozoic schists.

The supracrustal rocks west of the occurrence are metaturbidites and metavolcanics of intermediate composition (Pipping 1976). According to the scarce data available, the supracrustal rocks are multiply deformed and metamorphosed. The coexistence of staurolite and andalusite in the metaturbidites indicates low to medium pressure and medium-grade metamorphic conditions, though these minerals did not necessarily crystallize simultaneously nor under exactly the same pT conditions.

Petrography of tonalites

Five tonalite varieties have been distinguished by their textural and mineralogical differences (Fig. 2 a). These are 1) hornblende-bearing tonalite; 2) porphyritic tonalite; 3) equigranular tonalite; 4) tonalite porphyry; and 5) potassium feldspar-bearing tonalite. Sharp interphase contacts between equigranular tonalite and tonalite porphyry as well as between porphyritic and potassium feldspar-bearing tonalite have been observed in outcrops. In the latter case the potassium feldspar-bearing type is younger. Chemically the tonalites are of calc-alkaline affinity, and they have slight but characteristic variations of FeO, K_2O and Cu contents (Table 1). The Cu content is anomalously high in tonalite porphyry and equigranular tonalite. All varieties contain sparse quartz dioritic inclusions from 10 to 30 cm in diameter and a few crosscutting aplite veins from 5 to 20 cm thick. Numerous thin quartz veinlets crosscut both the tonalites and the aplite veins.

The tonalites, which are hypidiomorphic and either non-foliated or weakly foliated, show only slight petrographic differences. The hornblende-bearing variety is a porphyritic rock with

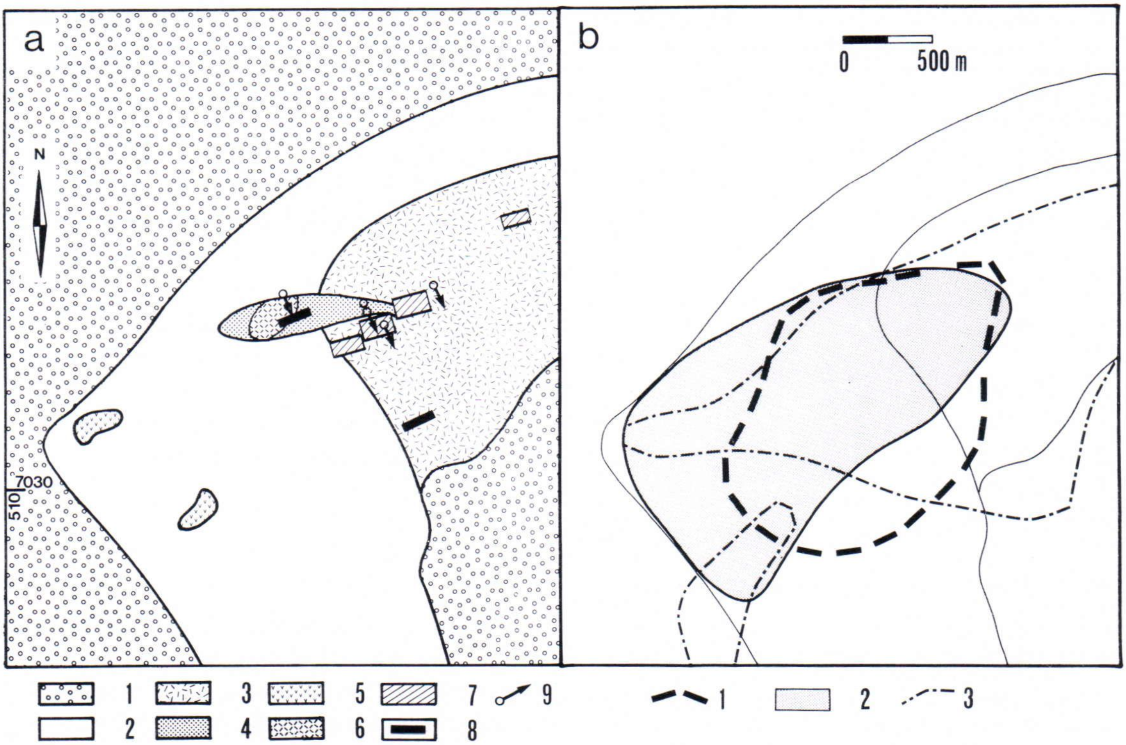

Fig. 2. The Cu occurrence of Tienpää, Halsua. a) Geological map and mineralizations. 1) hornblende-bearing tonalite; 2) porphyritic tonalite; 3) equigranular tonalite; 4) tonalite porphyry; 5) potassium feldspar-bearing tonalite; 6) quartz breccia with minor mineralization; 7) linear stockwork-type mineralization; 8) mineralized shear zone; 9) drill hole. b) Wall-rock mineralization and alteration. 1) disseminated mineralization; 2) secondary biotite; 3) propylitic alteration.

plagioclase, quartz, biotite and hornblende as the major rock-forming minerals. Euhedral plagioclase phenocrysts show oscillatory zoning with cores of andesine (An_{37-48}) and rims of oligoclase (An_{27-29}). Hornblende and occasionally biotite occur as phenocrysts. The grain size of the phenocrysts varies from 2 to 7 mm and that of the matrix from 0.3 to 2 mm. Accessory minerals are opaque, sphene, apatite, zircon, and rarely tourmaline and garnet.

Porphyritic tonalite has a matrix of plagioclase, quartz and biotite, the grain size being from 0.3 to 1 mm. The composition of euhedral, zoned plagioclase phenocrysts is similar to that of the phenocrysts in hornblende-bearing tonalite. Quartz occurs as anhedral phenocrysts, 1 to 3.5 mm in size, showing undulatory extinction. Accessory minerals are opaque, apatite, sphene and zircon.

Equigranular tonalite differs from the porphyritic variety not only in the lack of phenocrysts but also in the slightly lower An content of zoned plagioclase (An_{22-40}) and in the occurrence of hornblende as an accessory mineral. It is slightly darker than the porphyritic tonalite.

Subhedral, weakly zoned plagioclase phenocrysts with cores of andesine (An_{34-40}) and rims of oligoclase (An_{26-29}) are encountered in the potassium feldspar-bearing tonalite. The size of the phenocrysts varies from 1 to 5 mm, and that of the subhedral quartz phenocrysts from 1 to 3.5 mm. Both minerals also occur in the matrix

Table 1. Average chemical compositions[1] of the tonalites at Tienpää, Halsua (N = number of analyses; oxides in per cent; trace elements in ppm): 1) hornblende-bearing tonalite 2) porphyritic tonalite 3) equigranular tonalite 4) tonalite porphyry 5) potassium feldspar-bearing tonalite 6) tonalites of the Cu-mineralized zone.

	1	2	3	4	5	6
N	20	27	18	4	4	8
SiO_2	67.74	65.64	66.03	66.40	66.35	67.63
TiO_2	0.35	0.33	0.32	0.32	0.32	0.29
Al_2O_3	16.69	16.79	17.64	17.55	16.83	17.24
FeO	4.54	3.68	3.52	3.61	3.57	3.29
MnO	0.11	0.10	0.10	0.09	0.10	0.09
MgO	3.21	2.71	2.36	2.61	2.88	2.44
CaO	4.24	3.57	3.97	4.07	3.15	3.75
Na_2O	3.50	3.68	3.92	3.64	3.50	3.80
K_2O	1.62	1.97	1.56	1.57	2.55	1.61
P_2O_5	0.11	0.11	0.13	0.13	0.10	0.11
Total	99.10	98.77	99.76	100.14	99.52	100.42
Cu	37	36	156	242	17	474
As	6	5	3	4	5	3
Ba	597	626	532	536	719	564
Rb/Sr	0.09	0.09	0.07	0.07	0.11	0.08

[1] Major elements and Sr analysed by X-ray fluorescence on powder discs at the Geological Laboratory of Outokumpu Oy, Exploration. As, Ba and Rb analysed by instrumental neutron activation at the Reactor Laboratory of the Technical Research Centre of Finland. Cu analysed by atomic absorption spectrometry after aqua regia digestion at the Department of Geology, University of Helsinki.

together with biotite and potassium feldspar. Biotite forms aggregates that give the rock a porphyritic appearance. Potassium feldspar occurs both as antiperthite and as interstitial filling. Accessory minerals are sphene, apatite, opaque, zircon and rarely tourmaline.

Tonalite porphyry has the most conspicuous porphyritic texture of the tonalite varieties. The matrix, 0.2 to 1 mm in grain size, approaches half of the total volume of the rock. The major rock-forming minerals are plagioclase, quartz and biotite. Euhedral plagioclase phenocrysts ranging from 0.5 to 4.5 mm in size show oscillatory zoning with cores of andesine (An_{30-40}) and rims of oligoclase (An_{27}). Quartz is encountered both as an interstitial mineral and as subhedral grains 0.7 to 3.5 mm in size. Biotite forms small aggregates in places. Accessory minerals are opaque, apatite, zircon, hornblende and occasionally tourmaline.

Minor structures

Weak regional foliation controlling the orientation of biotite strikes north-northeast and dips moderately to steeply east. The foliation is slightly curving in the western part of the study area, and a mineral lineation plunging northeast has been observed on the plane of foliation.

The structure of the study area is characterized by ubiquitous fractures that occur as thin joints or fissures often filled with quartz. Three types of fractures have been distinguished: 1) mineralized fractures; 2) unmineralized quartz veins; and 3) unmineralized fractures devoid of quartz. All the fractures crosscut the foliation.

Mineralized fractures have a consistent 075° strike (Fig. 3 a), and they dip steeply (80°—85°) north. They are arranged *en échelon*. The

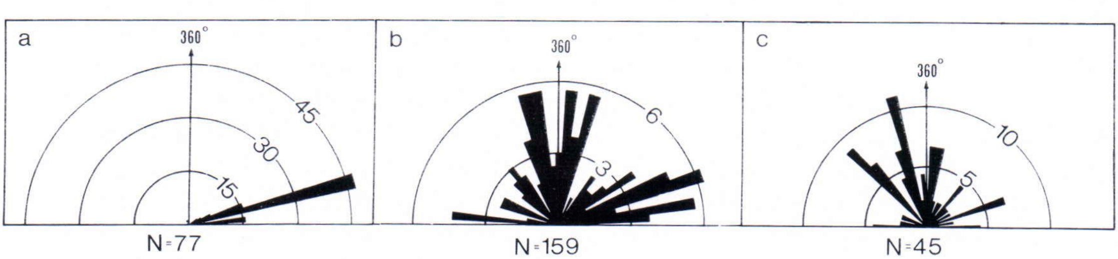

Fig. 3. Strike rosettes for a) mineralized fractures and fissures; b) unmineralized quartz veins, and c) unmineralized fractures and fissures devoid of quartz at Tienpää. Length of strike bar is proportional to percentage of total elements measured. N = number of observations.

quartz veinlets often show right-lateral shearing, which can be deduced from the oblique internal foliation of the veinlets. Fracturing of different generations can be observed locally. Unmineralized quartz veins dipping subvertically form several sets (Fig. 3 b). Unmineralized fractures are subvertical and some contain epidote. The sets trending 005° and 165° (Fig. 3 c) have been observed slightly to offset mineralized quartz veinlets. Minor mineralization is associated with the fractures trending 005°.

There are a few strongly sheared zones striking 070° and dipping subvertically. They vary in thickness from 10 cm to 1.5 m and are usually mineralized.

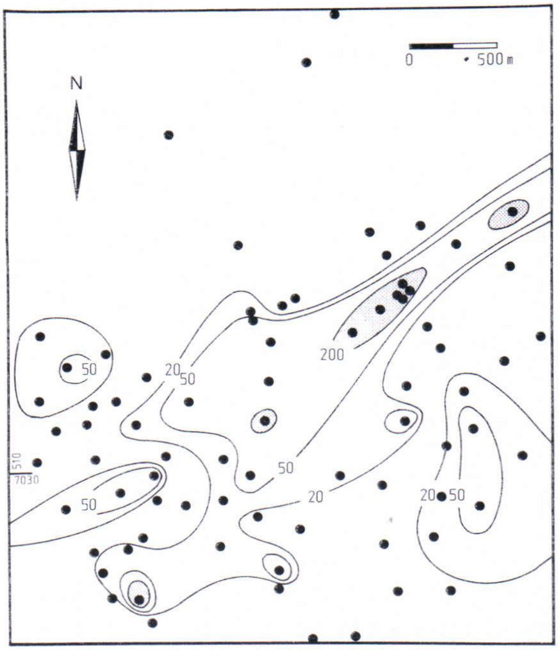

Fig. 4. Distribution of copper (in ppm) in tonalite at Tienpää. Sample sites are shown as black dots.

Mineralization and metal content

Samples consisting of several composites and having a total weight of 1.5 to 2.5 kg were collected for chemical analyses from the whole study area (Fig. 4). Distinctly mineralized portions were avoided during sampling, and so the geochemical map expresses variation in the background content of Cu in the area. A marked longitudinal zone of anomalous Cu content trends northeast across the area. The maximum of the anomaly covers the same area as the mineralization observed in the field. It can be concluded that the maximum width of the mineralized zone is about 250 m and that its length is at least 1500 m.

The Cu occurrence at Tienpää, which is of a stockwork type, consists of mineralized, quartz-filled fractures and dissemination. The *en échelon* fractures striking 075° constitute a 055° -trending zone, which crosscuts lithological boundaries (Fig. 2 a). The thickness of the quartz veinlets varies between 1 and 5 mm and rarely exceeds 1 cm. The length of individual veinlets ranges from 20 cm to several metres. Disseminated mineralization occurs in the vicinity of mineralized fractures. Sulphide-bearing quartz veinlets and weak dissemination are encountered sporadically in the surroundings of the stockwork over an area of at least 1200 × 1800 m (Fig. 2 b).

The major ore mineral is chalcopyrite, and the minor constituents are molybdenite, pyrite, bornite and pyrrhotite. Chalcopyrite occurs mainly on the surfaces of fractures filled subsequently with quartz; it is rare inside the quartz veinlets. Molybdenite occurring predominantly in the quartz veinlets seems to be slightly younger than chalcopyrite.

In the disseminated type, chalcopyrite is in the interstices of silicates, where it usually substitutes for mafic minerals. The diameter of anhedral chalcopyrite grains is usually under 0.2 mm. Pyrite is intergrown with chalcopyrite as subhedral-anhedral grains, or it occurs as separate, small grains. Molybdenite can be found as flakes that may be as large as 3 mm.

During diamond drilling carried out by the Geological Survey of Finland three cores out of

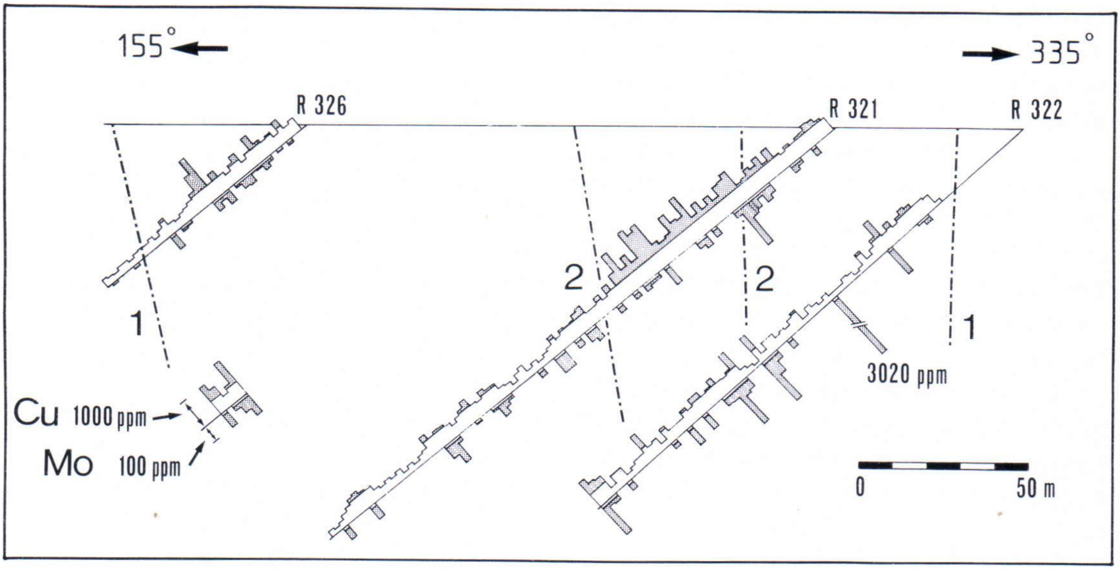

Fig. 5. Cu and Mo content along the Tienpää drill hole profile. The site of the profile is shown in Fig. 4. Cu analysed by atomic absorption spectrometry and Mo by energy dispersive X-ray fluorescence spectrometry at the Geochemical Department of the Geological Survey of Finland. Contents exceeding median values shaded (475 ppm for Cu, 15 ppm for Mo); 1) boundary of the mineralized zone; 2) body of higher metal concentration.

five intersected the mineralized stockwork. The sites of all five holes are shown in Figure 2 a. The average density of the mineralized veinlets and fractures is about 0.7 per m (projected to ground level) across the whole width of the zone; the density is 1 per m at a width of 100 m in the middle of the zone. The average Cu content is about 500 ppm. Mo is far less abundant (average 45 ppm) and is restricted to quartz veinlets. The Au content is very low (average 10 ppb), at its highest being 97 ppb over a width of 2 m.

Figure 5 shows the Cu and Mo distribution pattern along the drill hole profile mentioned above. On the basis of Cu content a body of higher metal concentration can be delineated along the axis of the mineralized stockwork. The body pinches out downwards. The Mo content is somewhat higher outside the body and increases slightly with depth. The mineralization proved to be weaker and less homogeneous in the other two drill cores than in the centre of the zone.

Two fluid inclusion measurements done on a typical quartz veinlet of the stockwork mineralization yielded homogenization temperatures of 150°—170°C for the two-phase inclusions.

There are two other mineralizations of minor importance in the study area. Tourmaline-bearing quartz breccia has been encountered in a restricted area west of the mineralized stockwork (Fig. 2 a). It contains small amounts of molybdenite as flakes in crosscutting quartz veinlets. A third mineralization type is associated with narrow shear zones, the widest of which is near the quartz breccia. The wall rock, which is an inclusion of intermediate composition, is strongly crushed and altered into a quartz—biotite—garnet—muscovite rock. The major ore mineral is chalcopyrite, which occurs as moderate dissemination in a zone 1.5 m wide. Minor ore minerals are pyrrhotite and pyrite.

Wall-rock alteration

Weak propylitic alteration is common in all the tonalite varieties except hornblende-bearing tonalite (Fig. 2 b). Plagioclase is altered into epidote, sericite, carbonate and chlorite. Biotite and hornblende are chloritized to a lesser extent. Alteration of plagioclase into muscovite is also fairly common in all the tonalite varieties except equigranular tonalite. Propylitic alteration and muscovitization of plagioclase are most intense in the immediate vicinity of mineralized fractures.

Pervasive recrystallization of biotite to a greenish type is nearly as widely distributed as propylitic alteration (Fig. 2 b). Part of the recrystallization of biotite and replacement by chlorite may be due to foliation. Minor secondary potassium feldspar replaces plagioclase. Some late fractures within quartz veinlets contain prehnite and apophyllite together with some molybdenite.

The silica content is fairly constant in all the tonalite varieties (Table 1). The content of SiO_2, however, rises slightly in the mineralized zone, indicating silification (Nurmi 1984).

Discussion

Sulphide mineral assemblages and alteration types in each of the three mineralization types at Tienpää indicate that the shear zone assemblage formed at higher temperature than the fracture fillings and dissemination. The tourmaline-bearing quartz breccia and associated molybdenite mineralization was the last to develop. It thus corresponds to the trend of decreasing complexity of sulphide mineral and alteration assemblages towards younger vein systems found in Butte, Montana (Brimhall 1977). According to Berzina and Sotnikov (1977), in Cu—Mo deposits of central Asia muscovitization took place at a temperature range of 410° to 320° and the principal ore deposition at 400° to 200°C. At Tienpää, sulphides controlled by fractures trending 075° were deposited above 170°C.

Most of the replacement phenomena observed at Tienpää are of hydrothermal origin, as can be deduced from the appearance of propylitic alteration and muscovitization around mineralized fractures and sulphide aggregates of the dissemination. Some chlorite and recrystallized biotite, however, may be pre-mineralization alteration products of biotite due to regional deformation and associated low-grade metamorphism. In the Gibraltar porphyry Cu deposit in Canada, hydrothermal alteration of previously saussuritized and foliated quartz diorite can be observed as sericitic and chloritic alteration envelopes around mineralized veins and as a pervasive increase in sericite in the mineralized zone (Drummond *et al.* 1976). This is a rare example of a regionally metamorphosed porphyry deposit.

The consistent trend of the mineralized fractures, their rectilinear appearance and their varying *en échelon* pattern (Fig. 6 a) indicate that they are extensional fractures. The mineralized stockwork is interpreted as a right-hand shear zone (Fig. 6 b). The angle between the direction of the shear zone and the extensional fractures is common in brittle fracturing (Hancock 1972). Subsequent shearing of the quartz veinlets (Fig. 6 c) is due to rotation of the maximum principal stress within the shear zone as stated by Lajtai (1969). The stress field postulated here applies only to the mineralized fractures, and not to other fracture sets. Since at least some of the latter are younger than the mineralized ones, the stress field must have changed afterwards.

The occurrence at Tienpää is similar to the three porphyry-type deposits described by Gaál and Isohanni (1979), except that there are no signs of regional faults.

Comparison of the occurrence at Tienpää with younger porphyry deposits reveals many similarities. The latter are characterized by 1) large size and low grade; 2) spatial association

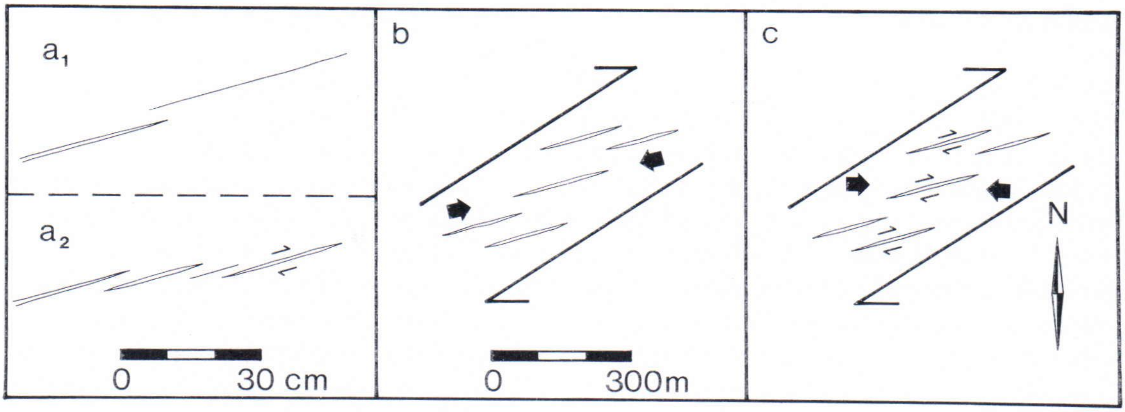

Fig. 6. a_1) and a_2) Two outcrop sketches of the distribution pattern of mineralized fractures at Tienpää. b) and c) Interpretation of the *en échelon* fracture array within the mineralized zone. b) Formation of extensional quartz-filled fractures within a right-hand shear zone; c) shearing of the fractures due to rotation of maximum principal stress within the zone.

with high-level, felsic to intermediate porphyritic plutons; 3) structural control of hypogene sulphide mineralization by fractures and breccia zones; and 4) extensive and zoned hydrothermal alteration associated with mineralization (Lowell and Guilbert 1970, Sutherland Brown 1976). The genetic association of the occurrence at Tienpää is obscure because premineralization foliation can be observed in the host rock, indicating a relative age difference between the host rock and the epigenetic mineralization. The occurrence is, however, genetically related to the tonalites. The phase that generated the mineralizing fluids apparently solidified somewhat later than the visible tonalites. The style of mineralization is similar to that of younger porphyry deposits (Haynes and Titley 1980, Heidrick and Titley 1982). The fracture densities and the amount of disseminated Cu are, however, much lower, i.e. the grade is considerably lower. The uneconomical grade of ore minerals is a feature common to all the Precambrian porphyry-type deposits identified so far.

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References

Armbrust, G. A., 1980. Geology of the Jogran disseminated Cu—Mo deposit, Ryan Township, Ontario. In: Pye, E. G., ed., Geoscience research grant program, summary of research, 1979—1980. Ont. Geol. Surv. Misc. Pap. 93, 11—15.

Ayres, L. D., Averill, S. A. & Wolfe, W. J., 1982. An Archean molybdenite occurrence of possible porphyry type at Setting Net Lake, northwestern Ontario, Canada. Econ. Geol 77, 1105—1119.

Ayres, L. D. & Černý, P., 1982. Metallogeny of granitoid rocks in the Canadian Shield. Can. Mineral. 20, 439—536.

Barley, M. E., 1982. Porphyry-style mineralization associated with early Archean calc-alkaline igneous activity, eastern Pilbara, Western Australia. Econ. Geol. 77, 1230—1236.

Berzina, A. P. & Sotnikov, V. I., 1977. Physicochemical conditions of endogene processes in copper-molybdenum deposits in central Asia. Econ. Geol. 72, 25—36.

Brimhall, Jr., G. H., 1977. Early fracture-controlled disseminated mineralization at Butte, Montana. Econ. Geol. 72, 37—59.

Drummond, A. D., Tennant, S. J. & Young, R. J., 1973. The interrelationship of regional metamorphism, hydrothermal alteration and mineralization at the Gibraltar Mines copper deposit in B.C. Can. Inst. Min. Metall., Bull. 66, 48—55.

Findlay, D. J. & Ayres, L. D., 1977. Lang Lake — an early Precambrian porphyry copper-molybdenum deposit in northwestern Ontario. Geol. Surv. Can. Pap. 77—1B, 25—28.

Gaál, G. & Isohanni, M., 1979. Characteristics of igneous intrusions and various wall rocks in some Precambrian porphyry copper-molybdenum deposits in Pohjanmaa, Finland. Econ. Geol. 74, 1198—1210.

Gaál, G., Front, K. & Aro, K., 1981. Geochemical exploration of a Precambrian batholith, source of a Cu—W mineralization of the tourmaline breccia type in southern Finland. J. Geochem. Explor. 15, 683—698.

Goldie, R., Kotila, B. & Seward, D., 1979. The Don Rouyn mine: an Archean porphyry copper deposit near Noranda, Quebec. Econ. Geol. 74, 1680—1687.

Hancock, P. L., 1972. The analysis of *en échelon* veins. Geol. Mag. 109, 269—276.

Haynes, F. M. & Titley, S. R., 1980. The evolution of fracture-related permeability within the Ruby Star granodiorite, Sierrita porphyry copper deposit, Pima County, Arizona. Econ. Geol. 75, 673—683.

Heidrick, T. L. & Titley, S. R., 1982. Fracture and dike patterns in Laramide plutons and their structural and tectonic implications. In: Titley, S. R., ed., Advances in geology of the porphyry copper deposits, southwestern North America. Tucson, Univ. Ariz. Press, 73—91.

Kirkham, R. V., 1972. Geology of copper and molybdenum deposits. Can. Geol. Surv. Pap. 72—1A, 82—87.

Lajtai, E. Z., 1969. Mechanics of second order faults and tension gashes. Geol. Soc. Am., Bull. 80, 2253—2272.

Lowell, J. D. & Guilbert, J. M., 1970. Lateral and vertical alteration-mineralization zoning in porphyry ore deposits. Econ. Geol. 65, 373—408.

Nurmi, P. A., 1984. Lithogeochemistry in exploration for Proterozoic porphyry-type molybdenum, copper and gold deposits, southern Finland (in preparation).

Pipping, F., 1976. Geological map of Finland, pre-Quaternary rocks, sheet — 2332 — Perho. Geol. Surv. Finl.

Simonen, A., 1980. The Precambrian of Finland. Geol. Surv. Finl., Bull. 304, 58 p.

Sinclair, W. D., 1979. Copper-molybdenum occurrences of the Matachewan area, Ontario. Geol. Surv. Can. Pap. 79—1A, 253—258.

Sutherland Brown, A., 1976. Morphology and classification. In: Sutherland Brown, A., ed., Porphyry deposits of the Canadian Cordillera. Can. Inst. Min. Metall., Spec. Vol. 15, 44—51.

Wakefield, J., 1978. Samba: a deformed porphyry-type copper deposit in the basement of the Zambian Copper Belt. Inst. Min. Metall. Trans., 87, B43—B52.

Walser, G. & Einarsson, Ö., 1982. The geological context of molybdenum occurrences in the southern Norrbotten region, northern Sweden. Geol. Rundsch. 71, 213—229.

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