SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 790 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 76 NR 3

SVEN-ÅKE SVENSON

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A VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT IN THE SKELLEFTE DISTRICT NORTHERN SWEDEN

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ISBN 91-7158-256-8
ISSN 0082-0024

Kartan på s. 10 är godkänd ur sekretessynpunkt för spridning.
Statens lantmäteriverk 1982-12-30.

Adress:
Sven-Åke Svenson
Boliden Mineral
S-936 00 Boliden

FOTOSATS: ORD & FORM AB
TRYCK: UPPSALA OFFSET CENTER AB, 1982

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ABSTRACT

Näsliden is a massive sulphide deposit of Precambrian age situated in the Skellefte metallogenic district, northern Sweden. The country rock consists mainly of acid metavolcanics, largely of pyroclastic origin, which have calc-alkaline affinity. Phyllites and greywackes overlie the volcanic rocks. The supracrustals were metamorphosed to greenschist facies and folded during two phases of deformation. In the mine area, they are almost isoclinally folded around steeply dipping axes.

The ore deposit is situated in the border zone between the volcanic and sedimentary rocks. In the strongly altered footwall volcanics, sulphides occur as disseminations and stringers. Primary features in the massive ore include macro-banding, stratigraphic compositional zoning and a variety of relic colloform textures, which characterize much of the pyrite content. Folding, boudinage and faulting are features caused by dynamometamorphism. Other secondary ore features include the formation of pyrite micromosaics, recrystallization of relic colloform pyrite, development of subgrains in pyrrhotite, and twinning of sphalerite.

The Näsliden ore deposit is regarded as a member of the "submarine exhalative" class of ores.

INTRODUCTION

The Näsliden ore deposit, which is owned and mined by Boliden Mineral AB, is a complex, massive sulphide ore. It is located in the Skellefte district in northern Sweden (Fig. 3) at latitude 65°06′N and longitude 19°06′E, about 96 km WNW of the town Skellefteå. Much simplified, the Skellefte district may be described as a metallogenic province of Precambrian age, characterized by a series of folded supracrustal rocks intruded by two generations of granites. The first stage in the evolution of the district mainly produced acid volcanic rocks such as quartz keratophyres, rhyolites, keratophyres, and dacites. A later stage is characterized by basic rocks, predominantly andesites and basalts. When volcanism was ceasing, sedimentation of epiclastic rocks of variable character became predominant.

During the orogenic phase, the oldest granitoid, the Jörn granite, was intruded. The younger plutonic rock, the Revsund granite, is a post- or late-kinematic granite with an isotope age of 1745 ± 40 Ma (Welin 1979, p. 311).

The ores of the district characteristically form massive sulphide bodies occurring roughly conformable to the supracrustal rocks. They are most often found in the border zone between the volcanic and sedimentary rocks, but are occasionally situated lower down in the volcanic rock sequence. The ores are surrounded by alteration zones, which have transformed the country rocks into sericite and/or chlorite quartzites or schists.

Ores of similar type on the Finnish side of the Bothnian Gulf have been equated to the Swedish occurrences as an easterly prolongation of the Skellefte district (Gavelin 1955, p. 84). Other writers maintain, however, that the connection is indistinct and that the Finnish ores belong to a separate metallogenic province (Rouhunkoski 1968, p. 9).

First indications of ore in the Näsliden area were noted in 1922 with the discovery of mineralised erratic boulders; the Näsliden B-orebodies could then be localized by EM-surveys. The first holes were drilled in 1922 some 400 m north of the present mine. However, the grade and size of the mineralizations were not of economic interest.

A more thorough geophysical revision of the region was conducted during the years 1946–1947. Loop frame measurements resulted in a much better picture of the known orebodies north of Näsliden, in addition to a number of new EM-indications. However, as the ores are in contact with carbonaceous phyllites, which are also good conductors, it was not possible to determine whether the new anomalies had been caused by ore or phyllite.

To solve these problems the area was covered by a gravity survey. Apart from the anomalies associated with the known sulphide bodies of Näsliden B, a gravity high was observed approximately 400 m further to the south. This new anomaly was investigated by diamond drilling in 1952 resulting in an immediate intersection of the Näsliden orebody which was to be later developed.

The Näsliden ore is a steeply dipping body known to a depth of 760 m. The original ore reserves are calculated to have been c. 5 million tons down to the 640 m level. Main sulphide minerals are pyrite, pyrrhotite, sphalerite, chalcopyrite, arsenopyrite, and galena in order of decreasing amounts.

Between 1960 and 1965 underground exploration was carried out. Underground development and surface plant erection started the following year, and production began in 1969. The annual production is around 200 000 tons of ore containing on average 1.3 g/t Au, 35 g/t Ag, 1.1 % Cu, 3.0 % Zn, 0.3 % Pb, 1.3 % As, and 29 % S.

A REVIEW OF SOME GEOLOGICAL INVESTIGATIONS WITHIN THE SKELLEFTE DISTRICT

The term "the Skellefte district" was introduced by A.G. Högbom in 1899. He was of the opinion that the oldest rocks of the district consisted of volcanics and fine-grained clastic sedimentary rocks, and that these two rock types were of about the same age, the volcanics dominating in the west and the sedimentary rocks in the east. The thick conglomerates in the northern parts of the district he regarded as younger rocks. Högbom supposed a gneissic granite, located to the south-east of the region, to be the substratum of the supracrustal rocks.

Eklund (1923) proposed a new stratigraphy for the Skellefte district, which according to him formed a border zone between a cratogen to the north and an orogen to the south. He was of the opinion that the volcanics, "the leptite formation", are the oldest rocks of the district, and that a separation into an elevated and downwarped area occurred at the end of, or already during the formation of the volcanics. During these movements, the Jörn- and Arvidsjaur granites were intruded, and Eklund supposed that these granites originated from the same magma that had earlier produced the volcanics. Within the downwarped area, the sedimentation was not interrupted, but there was a continuous transition from the formation of volcanics to purely clastic sedimentation. On the contrary, within the elevated area the sedimentation was interrupted and the granites were quickly exposed by weathering and erosion. Erosion debris formed conglomerates, for example "the Vargfors formation". Eklund was also of the opinion that the gneissic granite in the south-east was younger than, and intrusive into, the leptite formation.

In 1928 A. Högbom presented a hypothesis about the genesis of the sulphide ores in the Skellefte district. He thought that the ores were epigenetically deposited from solutions emitted from the Jörn granite magma, and that there was an intimate connection between sulphidization and other metasomatic transformations.

A few years later A. Högbom (1931) presented some new views on the geological development of the Skellefte district. He thought that the gneiss (earlier called gneiss granite) in the south-east was a strongly metamorphosed part of the Skellefte district. Furthermore, he thought that the intimate association of interstratified volcanic and clastic rocks should be considered as one formation. A. Högbom also distinguished the Vargfors formation as a considerably younger unit than the leptite formation.

In 1937 A. Högbom presented another description of the Skellefte district. He considered that only one period of folding of the supracrustal rocks had occurred, and that gently and steeply plunging fold axes had originated contemporaneously due to differences in the competency of the rocks. The folding was supposed to have occurred in connection with the intrusion of the syn-orogenic Jörn-Arvidsjaur granites.

Gavelin (1939) published an investigation of the central parts of the Skellefte district. He concluded that the degree of metamorphism was on the whole dependent on the Revsund granite, and that metamorphism increases towards the granite, which borders the rocks of the Skellefte district to the south.

The genesis of the sulphide ores of the Skellefte district had earlier been connected with the intrusion of the Jörn granite, but Gavelin associated their genesis with the formation of the Revsund granite. He was of the opinion that the metasomatic transformations associated with the sulphide ores were later than the regional metamorphism, and therefore supposed that the ores originated from the same source that produced the palingenic Revsund granite. According to Gavelin, metal-bearing solutions were "pushed" in front of an advancing migmatite front. Their metal and sulphur content was precipitated where structures, chemical environment and PT-conditions were favourable.

Grip (1941) thought that the gently plunging fold axes, normally striking WNW-ESE, had been formed in connection with folding during intrusion of the Jörn granite, and that the steep linear elements were formed somewhat later when the palingenic Revsund granite was generated.

In his description of the Precambrian rocks of Västerbotten County, Gavelin (1955) suggested a new stratigraphy for the Skellefte district (Fig. 1). This stratigraphy was considerably revised (Fig. 2) by Kautsky (1957), who had mapped the central parts of the district. The Skellefte volcanic "series" in Gavelin's stratigraphic scheme thus corresponds to Kautsky's Maurliden "series", which was divided into several formations containing both volcanics and sedimentary rocks. Gavelin's Skellefte phyllite "series" partly corresponds to Kautsky's Elvaberg phyllite. There is also a considerable difference in the two authors opinions concerning the stratigraphic position of the Revsund granite in relation to the unconformity and the Vargfors conglomerates (Figs. 1 and 2).

Helfrich (1971) presented a stratigraphy that, on the whole, corresponds to Kautsky's (1957). However, Helfrich postulated a more dynamic evolution of the Skellefte district involving the contemporaneous formation of volcanic and sedimentary rocks. Helfrich considered the Mensträsk conglomerate as being only a lithological facies rather than representing an uninterrupted stratigraphic level.

The most recent opinion regarding the genesis of the ores in the Skellefte district was put forward by Rickard and Zweifel (1975). They maintained that the ores were formed in a shallow marine environment in association with volcanic activity during the evolution of a geosyncline. The authors pointed out that the ores of the Skellefte district show the characteristics of deposits formed under similar conditions in other parts of the world during various geological epochs. The characteristics mentioned by them were: 1, the stratabound occurrence of the ores, 2, the close association with keratophyric and dacitic volcanics, 3, the lead isotope composition coincident with the primary "growth curve" (cf. Wickman *et al.* 1962), 4, the characteristic Pb:Cu:Zn and Pb:Zn ratios, 5, the remarkably homogeneous sulphur isotope ratios about the meteoritic standard. Furthermore, the ores show macroscopic metamorphic features including tight folding, brecciation, and boudinage. In addition, it was shown that the pyrite in the ores has been annealed and subsequently deformed.

Lundberg (1980) summarized the geological data collected in the Skellefte field and its surroundings by the Geological Survey of Sweden during the last decade. The stratigraphy that emerged is in many respects similar to that of Gavelin (1955), and is for comparison shown in Fig. 1. The only major difference is the age of the Vargfors conglomerates in relation to that of the Revsund granite.

GAVELIN (1955)	LUNDBERG (1980)
Adak granite series	
Sorsele granite series	Sorsele granitoids
Vargfors series	Dobblon Group (terrestrial)
UNCONFORMITY	UNCONFORMITY
Revsund granite series	Revsund granitoids
	Vargfors Group (terrestrial)
	UNCONFORMITY
Arvidsjaur – Jörn granite series	Jörn – Arvidsjaur granitoids
Arvidsjaur porphyry series	Arvidsjaur Group (terrestrial)
Skellefte phyllite series	Skellefte Group (marine)
Skellefte volcanite series	

Fig. 1. Simplified stratigraphic scheme of the Skellefte district (after Gavelin 1955, and Lundberg 1980).

According to Lundberg the rocks of the Skellefte Group were deposited in a marine environment and consist of acid to intermediate volcanics dominated by pyroclastics, which are conformably overlain mainly by greywackes and pelites. The volcanics of the Arvidsjaur Group, to the north of the Skellefte field proper, are of terrestrial origin and rest conformably on the rocks of the Skellefte Group. The Jörn granitoids intruded these formations. The Vargfors Group volcanics and conglomerates (Abborrtjärn and Dömanberg conglomerates) were deposited with marked unconformity on the folded Skellefte and Jörn Groups. The Revsund granitoids intruded all mentioned formations.

Interesting results have also been obtained from radiometric datings. Welin (1979) established a Rb-Sr age of 1745 ± 40 Ma for the Revsund granite, while the Arvidsjaur granite, which has been correlated with the Jörn type, gave a surprisingly low age of 1740 ± 30 Ma (Welin 1979, p. 316). U-Pb datings of zircons from Jörn granitoids gave a consistent age of $1891 \pm ^{14}_{12}$ Ma (Lundberg 1980, p. 164).

GEOLOGY OF THE NÄSLIDEN AREA

STRUCTURAL GEOLOGY

Economic maps (1:10 000) and aerial photographs (1:20 000) have been used for the field work. Geological field observations have been recorded using the

		Sorsele granite	
		Revsund granite	
Elvaberg series		Elvaberg phyllite	
	Mensträsk conglomerate	Dömanberg conglomerate Angular unconformity Abborrtjärn conglomerate	Vargfors conglomerate
	Considerable unconformity and hiatus		
	Jörn and Arvidsjaur granites		
Maurliden series	Skogsheden volcanics Petikträsk phyllite Maurliden volcanics Maurliden phyllite		Arvidsjaur porphyries

Fig. 2. Simplified stratigraphic scheme of the Skellefte district (after Kautsky 1957).

GEOMAP data system (Berner *et al.* 1971a, 1971b, 1972), and stereographic plots have been made by data computer.

Due to Quaternary deposits and swamps, outcrops are rare and unevenly distributed. Accordingly, the rock boundaries on the map (Fig. 3) are in many cases approximate. Geological interpretation has been considerably aided by regional magnetic, electromagnetic and gravimetric measurements performed by the Boliden Company. For example, carbonaceous and pyrrhotite-rich phyllites are readily distinguished on electromagnetic and magnetic maps, and can thus be discerned from volcanics, whose susceptibility and electric conductivity are considerably lower. Intrusions of gabbroic rocks have been rather well defined as they show gravity surplus in relation to the abovementioned rocks. The extension of the Revsund granite is also known from gravimetric measurements.

The eastern parts of the map area (Fig. 3) represent an anticlinorium which exposes the volcanic rocks of the Maurliden "series". To the east, south and west, these rocks are surrounded by carbonaceous phyllites belonging to the Elvaberg "series" (Helfrich 1971). These form a synclinorium in the west, and their substratum appears again in the westernmost parts of the mapped area, where the Revsund granite massif intrudes the supracrustal rocks (Fig. 3). Gravimetric measurements indicate that this intrusion reaches a considerable depth. At the few exposed places observable, the contacts are steep, about 80° NE (Malmqvist 1956), sharp and subparallel to the bedding and schistosity. This feature is also reflected on a regional scale with the supracrustal rocks curving round the granite massif.

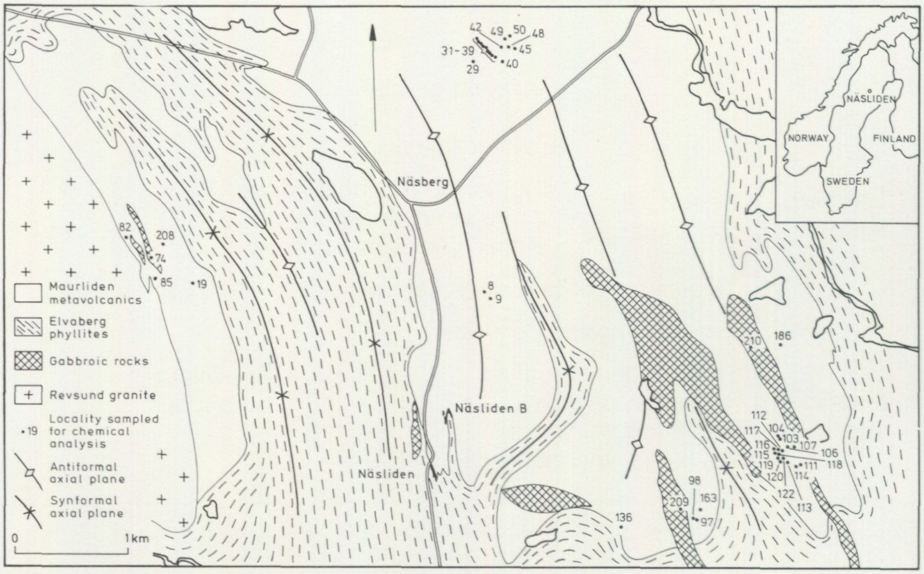

Fig. 3. Schematic geological map of the Näsliden area.

The Näsliden area is characterized by mostly isoclinally folded rocks with a steep westerly dip. However, as exposure is poor it is not possible to make any closer analysis of the structural geology.

The northern parts of the synclinorium contain Maurliden volcanics in a "minor" anticline whose extension has mainly been obtained from geophysical measurements. The compression in this area has not been intense enough to cause isoclinal folding.

The Skellefte district as a whole strikes WNW-ESE. This is also the orientation of the separate lithologic units which during a first folding phase were compressed around gently plunging fold axes in this direction. A second phase, in connection with the formation of the Revsund granite, folded and strongly compressed the rocks around steeply plunging axes (Grip 1941) resulting in a pronounced lineation (Fig. 4b). In the Näsliden area the predominant strike of the rocks is NNW–SSE (Figs. 3 and 4a) which is probably due to a distortion of the general strike associated with the intrusion of the Revsund granite. This style of folding will be further described below.

The mapped area is characterized by a well-developed schistosity whose distribution in space and frequency maximum at N16°W/77°W are shown in Fig. 4c. The schistosity planes coincide with the bedding planes and the lineation which mostly appears as a crenulation of the schistosity planes.

To judge from small scale structures there is also a fault tectonism, but no major movements have been proved to exist. However, some steep topographic structures have been interpreted as representing faults.

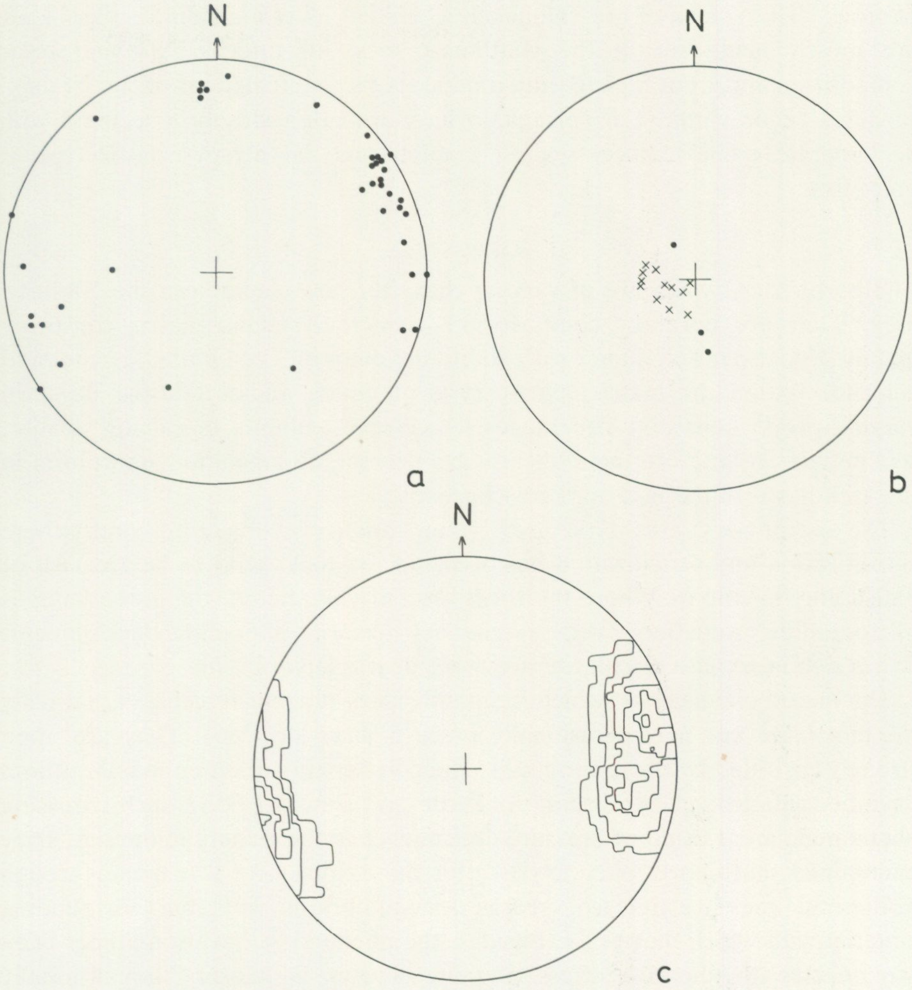

Fig. 4. Stereographic projections on the lower hemisphere: A. Poles of bedding planes. B. Lineations (x) and fold axes (·). C. Poles of schistosity planes. Contours at 25, 20, 15, 10, 5, and 1 %.

The regional metamorphism is of greenschist facies with quartz, albite, muscovite, chlorite, epidote, and biotite as characteristic minerals. Near the contact to the Revsund granite in the west, however, there are porphyroblastic amphibole needles in the metavolcanics.

MAURLIDEN "SERIES"

The volcanic rocks of the Näsliden area belong to the Maurliden "series" as defined by Helfrich (1971, p. 93). They constitute the oldest part of the bedrock. The volcanics are chemically classified as calc-alkaline rocks. They are mostly acid, but in the south-east rocks of intermediate and basic composition appear at higher stratigraphic levels. Intercalations of fine-grained phyllites occur within the volcanics which are often closely associated with agglomerates. The features suggest a submarine, largely pyroclastic type of volcanism.

PORPHYRIES

The porphyries, which are of varying character, are common in the Näsliden area. They are normally composed of a microcrystalline matrix consisting mainly of feldspar and quartz with additional quantities of biotite, sericite, and chlorite. Within the matrix, phenocrysts of quartz and/or feldspar occur in varying proportions and size ranges. Accessory amounts of calcite, apatite, sphene, zircon, and ore minerals are also present. Regional metamorphism in the area has resulted in a marked schistosity.

The porphyries are dark grey when relatively unaltered, but where chloritization and sericitization has occurred the rocks tend to be greenish or bluish grey in colour. Where the rocks are fairly unaltered, the groundmass is microgranitic, sometimes with a tendency towards pilotaxitic development. Types rich in sericite or chlorite are more or less lepidoblastic.

The quartz phenocrysts, which frequently show blue opalescence, are usually <2 mm large but may occasionally reach 5 mm (loc. 186). They are often strongly corroded by the groundmass, and consequently their euhedral outlines have been destroyed. According to Tuttle and Bowen (1958), such corrosion phenomena are a result of pressure dependence at the ternary minimum. They maintained that quartz phenocrysts after the extrusion of a magma, through isothermal pressure release, reach nonequilibrium with the surrounding material with which they react. Besides, the phenocrysts have sometimes been broken due to shearing stress and are always undulose. They normally constitute 2–5 % of the rock volume but may locally form about 10 %.

The feldspar phenocrysts usually consist of albitic plagioclase which is more or less altered to sericite. Sometimes, however, they have also been transformed to patchy antiperthites whose secondary potassium component is unaltered. The feldspar phenocrysts do not show corrosion phenomena like quartz, but may have granophyric reaction rims. They form square or lath shaped crystals rarely exceeding 2 mm, and occurring in roughly the same amounts as the quartz phenocrysts.

The porphyries are often Ca-rich with calcite present in aggregates, vesicles, disseminated in the groundmass or as an alteration product in plagioclase phenocrysts. Spherulites and quartz-filled amygdales occur rarely.

Porphyritic material forms an important matrix constituent in the agglomerates (e.g. in outcrops 1.5 km north-east of Näsberg and 2.3 km east of

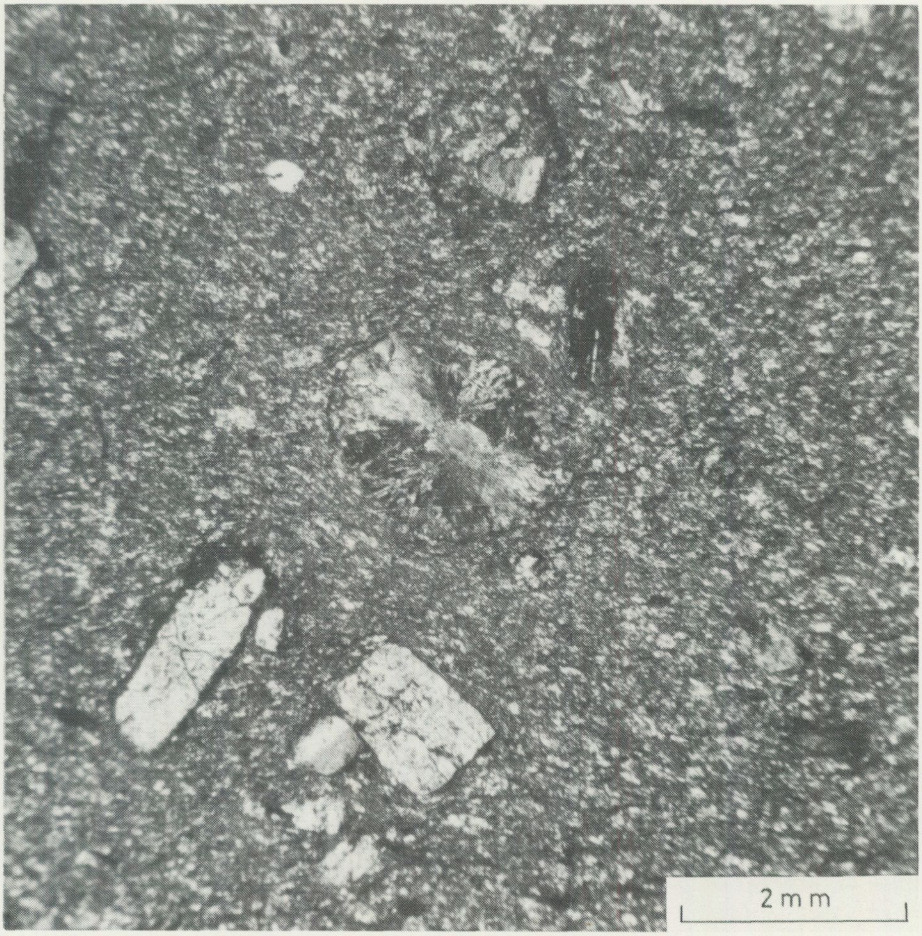

Fig. 5. Spherulite in porphyry. Loc. 103.

Näsliden). The rock fragments are felsitic, sometimes containing small aggregates of strongly sutured quartz.

At several places there are porphyries of a somewhat different appearance. Their chemical and mineralogical compositions are on the whole the same as those of the porphyries described above, but the size and amount of phenocrysts are less. A case in question concerns the south-eastern part of the mapped area. Here occur beds with quartz and quartz-feldspar porphyries whose phenocrysts seldom exceed 1 mm. Normally, the phenocrysts form only about 1 % of the rock volume, but locally may constitute as much as 5 %. Also these porphyries contain spherulites (Fig. 5) and quartz-filled vesicles. Around one such amygdale, 2 mm large, were gathered some 15 quartz phenocrysts which may have been due to a "collecting" effect of an ascending gas bubble.

At Näsberg and west of the phyllite synclinorium, porphyries with plagioclase phenocrysts outcrop. The phenocrysts, rarely larger than 1 mm, constitute around 1 % of the rock volume. In the last mentioned area the porphyry contains calcite-filled vesicles which are elongated in the direction of the lineation and may reach a length of a few centimetres.

Chemical analyses and Niggli values of the porphyries are given in Table 1:A–H. These metavolcanics are quartz-latitic to rhyodacitic in composition (Rittmann 1952), but the high *T* and *t* values clearly indicate that the original compositions have been altered. The changes were probably caused mainly by metasomatic alterations during the volcanic stage or by processes related to regional metamorphism. The porphyries 1.5 km north-east of Näsberg, which are the most strongly sericitized, also show the highest *T* values.

The porphyries are interpreted as being largely of pyroclastic origin. In favour of this hypothesis is their close association with agglomerates in which they commonly form the matrix. Intercalations of carbonaceous phyllite, which have also been observed in boreholes north-east of Näsberg, indicate deposition in a marine environment. The presence of spherulites, amygdales and corroded quartz phenocrysts suggest an ignimbritic type of eruptive mechanism (cf. Helfrich 1971, p. 26).

FELSITIC ROCKS

At several places within the mapped area felsitic rocks outcrop. The rocks are dark grey, aphanitic and schistose and are composed mainly of feldspar, quartz, sericite, chlorite, biotite, and calcite. The calcite often occurs in coarser aggregates. Sporadically the felsites also contain feldspar microlites.

In the field, it may sometimes be difficult to distinguish felsitic rocks and certain types of psammitic metasediments. However, the felsites have a distinctive brownish tint, and never occur banded.

The felsitic rocks are partly associated with agglomerates in which they form the groundmass (Fig. 6). The rock fragments, clearly seen on weathered surfaces, are either felsitic with coarser quartz aggregates, resembling the fragments in agglomerates associated with porphyries, or show a pilotaxitic appearance. On fresh surfaces the rock fragments are almost invisible.

The chemical compositions and Niggli values of the felsitic rocks are given in Table 1:I–L. The average composition is practically identical to the composition of the porphyries, with which they are probably related genetically. Consequently the felsites are also classified as quartz-latite or rhyodacite according to Rittmann (1952). When compared to the porphyries, the only difference of any significance is the somewhat higher *k* value among the felsitic rocks.

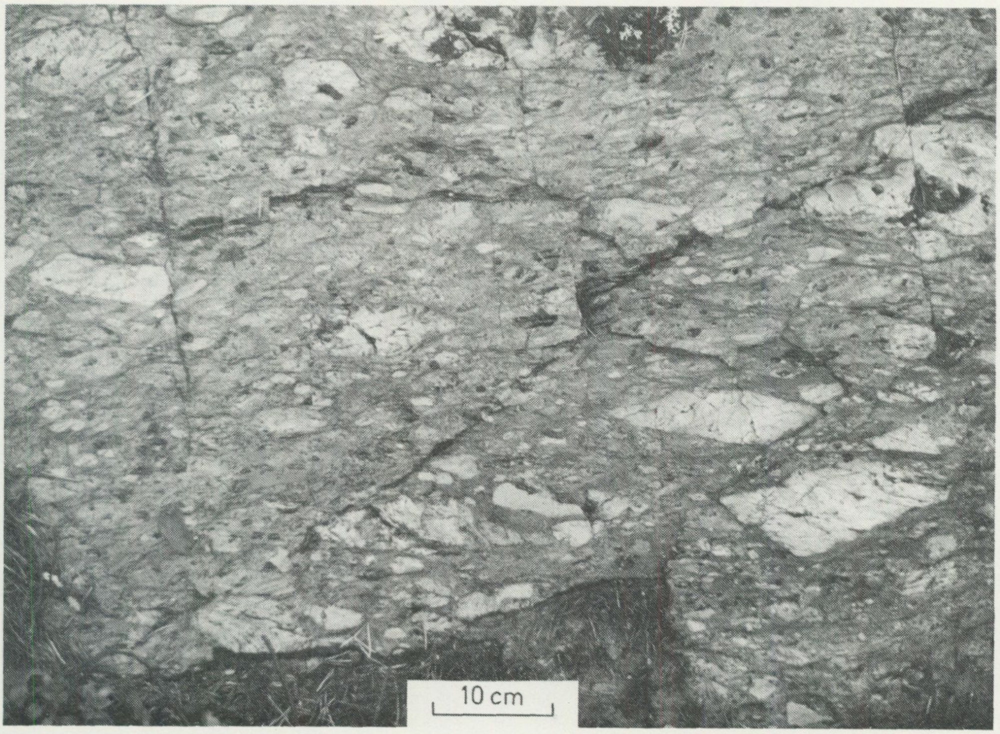

Fig. 6. Agglomerate with felsitic fragments and matrix. Loc. 29.

AMYGDALOIDAL ROCKS

Along the contact with the Revsund granite in the west, there occurs an acid amygdaloid rock, which is medium grey with a brownish or greenish tint. The essential minerals of the microcrystalline rock are feldspar, quartz and biotite with subordinate amounts of sericite, calcite and epidote. There is no tendency among the mica minerals to assume any preferred orientation, but the texture is massive and micrgranitic.

The amygdales are usually <0.5 cm large but may sometimes attain up to 27 cm in size (Fig. 7). They are usually filled with one or more of the minerals calcite, quartz and epidote. Often the amygdales show a zonal structure with epidote, occasionally together with hornblende, rimming calcite and quartz. The hornblende is partly transformed into biotite. Epidotization of the rock has also occurred along fissure veins of microscopic dimensions. These fissures are systematically filled from the centre to the margin with quartz, chlorite, and epidote.

The acid amygdaloidal rock has a chemical composition (Table 1:M) which is almost identical to the average porphyry and felsitic rock described above. The chemical analysis classifies the rock as a rhyodacite (Rittman 1952).

Fig. 7. Acid amygdaloidal rock. Loc. 82.

PORPHYRITES AND ASSOCIATED AGGLOMERATE

In the south-eastern parts of the mapped area there are also volcanics of a more basic chemical composition (Table 1:N–P). These rocks are, at least partly, overlain by a thin horizon of porphyry or a felsitic rock, but otherwise they form the uppermost parts of the volcanic pile.

The porphyrite is strongly schistose and usually bluish or greenish grey in colour. The plagioclase phenocrysts constitute 5–20 % of the rock volume and are 0.5–3.0 mm large. They are strongly altered to epidote, zoisite, chlorite, biotite, sericite, and calcite, but may sometimes have relatively unaltered rims.

The fine-grained and strongly altered matrix consists mostly of chlorite, biotite and epidote-zoisite. In the matrix there are also minor amounts of plagioclase microlites, calcite and occasionally quartz. The calcite occurs mostly in aggregates which are coarser grained than the matrix. Accessory minerals are sphene, opaques and apatite. Rarely does the porphyrite contain amygdales filled with quartz or epidote.

Stratigraphically upwards the porphyrite grades into an agglomerate, whose groundmass is identical with the porphyrite. Plagioclase microlites in the groundmass sometimes show a trachytic arrangement. The microlites are unaltered, possibly due to a more albitic composition as compared to the larger phenocrysts.

Fig. 8. Alternating tuff and agglomerate. Loc. 163.

The rock fragments of the agglomerate are somewhat lighter than the groundmass, and they almost invariably contain amygdales (0.5–2.0 mm large). The amygdales may occupy as much as 30–40 % of the volume of the fragments. Sometimes, two or even three gas bubbles have united into hourglass-shaped amygdales. They are filled with quartz, chlorite, calcite, epidote, and amphibole, most often in a zonal arrangement.

The matrix of the fragments is strongly altered to a semi-opaque admixture mainly consisting of epidote-zoisite, chlorite, and plagioclase. In the matrix there are also felsitic rock fragments and diffuse remnants of feldspar phenocrysts.

The agglomerate sometimes shows bedding structures with layers relatively rich in fragments (Fig. 8). Partly the fragments constitute as much as 60 % of the rock volume, but there are also layers which only contain few and small fragments. To the west and north from loc. 163 (Fig. 3) the fragments become more sparse and rounded, possibly reflecting mechanical deformation.

Thin intercalations of limestone (<3 cm) in the agglomerate suggest deposition in a shallow sea environment. Plagioclase microlites in a trachytic

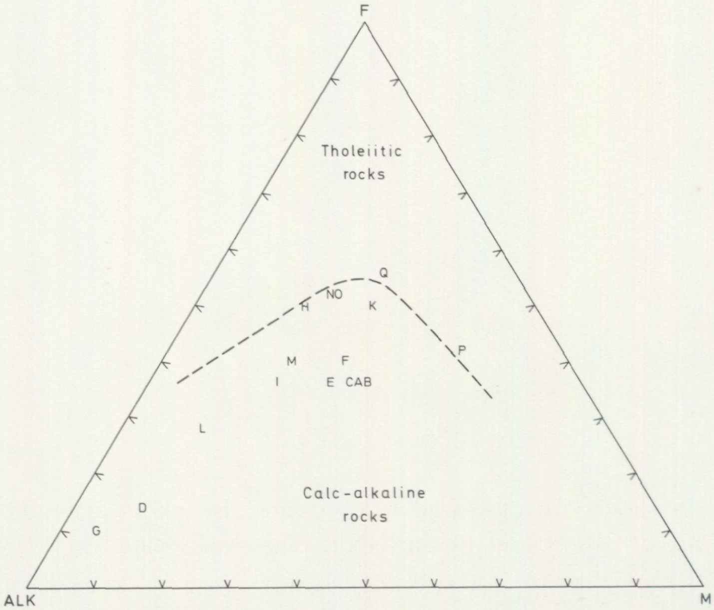

Fig. 9. AFM plots of metavolcanic rocks from the Näsliden area. Boundary line (dashed) is according to Irvine and Baragar (1971).

arrangement indicate flow movements, and the agglomerate was probably deposited from submarine pyroclastic flows. The calcareous porphyrite, which is so closely associated with the agglomerate, probably originated in a similar manner (Fiske 1936). Recognizable bedded tuff is indicated by a phenocryst-poor porphyrite in the easternmost parts of the area (loc. 114).

The larger SiO_2-content of the rock fragments in the agglomerate as compared to the groundmass (Table 1:N and O), is mainly due to secondary quartz in the amygdales. The porphyrites are classified as andesites according to Rittmann (1952) although it should be pointed out that the chemical composition of these rocks has been changed during post-magmatic alteration. The negative *t* values are explained by the calcareous character of the porphyries.

About 1.5 km NNE of Näsliden there also occurs a rock of basic composition (Table 1:Q), which shows intrusive contacts against the surrounding felsite. It is strongly schistose, has a well-developed lineation and is considered to be a pre-metamorphic subvolcanic intrusion. The rock is greenish black with a strongly altered, aphanitic matrix consisting mainly of chlorite, sericite and feldspar. Besides, it partly contains much calcite which mostly occurs as coarser aggregates within schistosity planes, together with small amounts of quartz. In the matrix there are plagioclase phenocrysts which are strongly altered to sericite. There are also amygdales filled with calcite, chlorite and quartz, indicating that the rock was intruded at shallow depth.

From their chemical compositions, the metavolcanics of the Näsliden area are classified in general as calc-alkaline rocks (Fig. 9). Classification of the altered varieties is, however, more open to question.

The metavolcanics are generally very poor in alkalis (cf. Table 1) which suggests that the rocks may have been redeposited or, most likely, leached. Suggestions that regional leaching of volcanic rocks is related to the formation of the "volcanic exhalative" class of ores have been put forward by several workers. The leaching is supposed to have occurred by convection of seawater through the volcanic pile. A convective cell may have been in the order of several km^3, with heat from active volcanic zones as the driving force.

ORES

Beside the Näsliden ore described below there also exists a minor deposit (Näsliden B-ore) 300–500 m to the NNE. This was located in 1923 and is situated in metavolcanics near the border between the Maurliden volcanics and Elvaberg phyllites. It occurs along a syncline of phyllites folded into the metavolcanics (Fig. 3). The deposit occurs as a stratabound body on both the eastern and western flank of the syncline. Both flanks dip about 70° to the west, and consequently the whole rock complex is isoclinally folded.

The Näsliden B-ore is surrounded by sericite and/or chlorite quartzites. Where less altered, the surrounding metavolcanics are recognizable as porphyries and felsites with only minor quantities of coarse pyroclastic rocks.

The Näsliden B-ore has been calculated to contain 0.8 million tons of ore down to the 110 m level. On an average it contains 0.9 g/t Au, 28 g/t Ag, 0.6 % Cu, 1.8 % Zn, 0.2 % Pb, 0.5 % As, and 29 % S. The main ore minerals are pyrite, pyrrhotite, sphalerite, chalcopyrite, arsenopyrite, galena, and magnetite. Näsliden B is rather similar to Näsliden but differs in having lower percentages of the valuable components and relatively larger quantities of pyrrhotite and magnetite (Grip and Wirstam 1952).

ELVABERG "SERIES"

Within the Näsliden area the Maurliden volcanics are overlain by fine-clastic sedimentary rocks of the Elvaberg "series". There are, however, also sedimentary rocks of the same type occurring as intercalations in the metavolcanics.

No direct contacts between the Maurliden and Elvaberg rocks occur in outcrops within the Näsliden area, but to judge from the conditions in the mine, the metasediments conformably overlie the volcanics.

Fig. 10. Load casts in graywacke. Loc. 132.

The phyllitic rocks are aphanitic to fine-grained and grey or black depending upon the content of carbonaceous material. The carbonaceous types also contain pyrrhotite. The phyllites show a very fine compositional layering, sometimes with a diffuse graded bedding. Intercalated within the phyllites are also psammites and calcareous rocks. Rocks of the graywacke type (Fig. 10) are characterized by about 1 mm large plagioclase and quartz grains together with up to 1 cm long phyllite fragments in a fine-grained matrix. Other rock types appear to represent rapidly redeposited porphyries (tuffites).

BASIC PLUTONIC ROCKS

Plutonic rocks of basic composition outcrop *inter alia* in the south-eastern parts of the area, where their extension has been largely determined from gravimetric measurements. Microscopically, a slight postcrystalline deformation can be observed, and these basic plutonics are probably older than the latest deformation in the area.

Hornblende, plagioclase, biotite, and actinolite are the main constituents of the plutonics, which are massive medium-grained and greenish or bluish grey in colour. The amphiboles are partly transformed into biotite and chlorite, and the plagioclase is strongly altered to poikilitic grains containing epidote, biotite, chlorite, sericite, and calcite.

In the metavolcanics and phyllites to the west (Fig. 3), there are also some minor basic intrusions. They are much finer grained here than in the south-east, and they show a widely varying appearance. Except for plagioclase, the main components are either hornblende, hornblende plus actinolite, actinolite, or clinopyroxene. The plagioclase is partly altered to sericite and epidote, and the amphiboles show alteration to biotite. In one type consisting mainly of plagioclase and hornblende, the feldspar partly occurs in 1–2 mm large aggregates which result in a porphyritic appearance. This type characteristically has a network of <1 mm broad quartz-filled fissures.

Chemical analyses and Niggli values of basic plutonics are given in Table 1:R–T. The last analysis represents the porphyritic variety mentioned above, and the other two are from plutonics in the south-east. The less basic character of the porphyritic rock is reflected in the relatively high *qz* value and low MgO content as compared to the intrusive rocks in the south-east. One of these is also undersaturated in silica (negative *qz*).

REVSUND GRANITE

The western parts of the mapped area are occupied by the Revsund granite, which is the youngest rock within the region. It is massive and light grey in colour with a medium-grained matrix consisting of microcline, plagioclase, quartz, and biotite. In the matrix there are 10–20 % of microcline megacrysts, which are 1–2 cm large and very characteristic for this granite.

The Revsund granite shows intrusive contacts, and it also contains xenoliths of the surrounding bedrock. Although the thermal influence on the intruded rocks is fairly weak, some recrystallization and the formation of amphibole needles in the metavolcanics has occurred. Besides, pegmatites are more common in these western parts of the area than elsewhere. As mentioned before (p. 10), the Revsund granite has also influenced the deformation of the supracrustal rocks, which curve round the granite massive.

GEOLOGY OF THE NÄSLIDEN MINE

STRUCTURE

In the Näsliden mine, rocks of the Elvaberg "series" conformably overlie the Maurliden volcanics. Within the Maurliden "series", dacitic tuffs are overlain by an agglomerate. These rocks show increasing alteration to sericite and/or chlorite schists towards the orebody, which is also partly underlain by a breccia

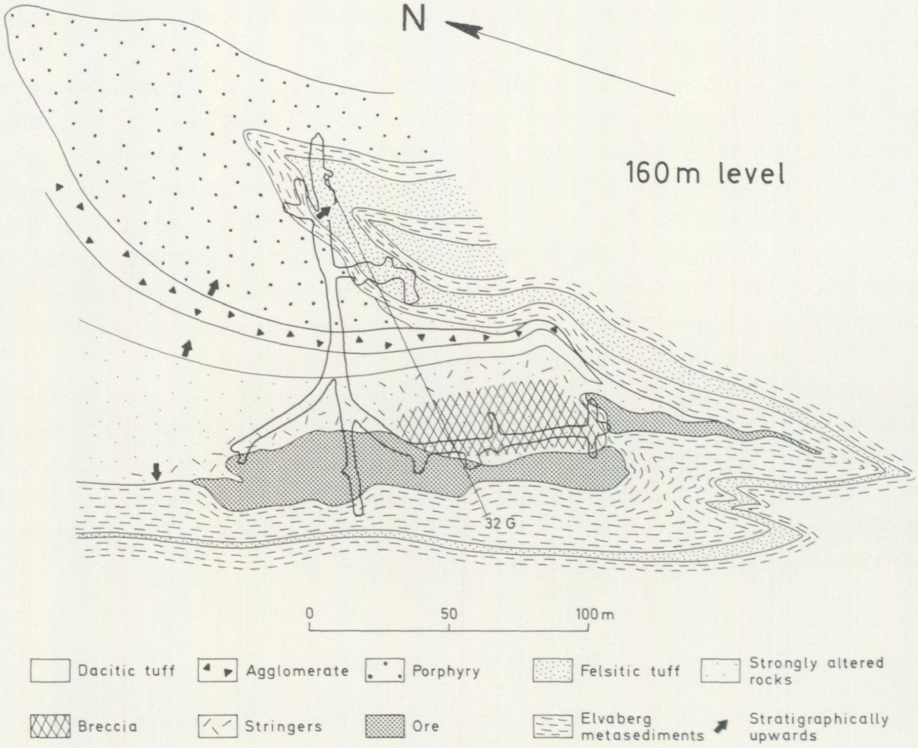

Fig. 11. Geology on the 160 m level in the Näsliden mine.

of uncertain origin (Fig. 11). Above the agglomerate there is a homogeneous but somewhat schistose porphyry with quartz and feldspar phenochrysts. In addition, felsitic tuffs occur in the lowermost part of the Elvaberg "series". The orebody is situated in the border zone between these two "series".

The structural picture in the mine area is complicated by intense, almost isoclinal folding. However, along the hanging wall the rocks strike N15°W while the predominant strike on the footwall side is about N–S (Figs. 11 and 12). The whole rock sequence dips 70°W (Figs. 13 and 14), which means that the folds are overturned to the east. The southernmost parts of the orebody are on higher levels situated in the core of a fold which is practically isoclinal (Fig. 11), and here the rocks in the footwall are not as strongly altered as they are elsewhere in the footwall.

All the rocks are characterized by a schistosity of varying intensity, generally parallel to the bedding planes. This schistosity (S_1) has developed prior to the last folding phase; the latter rarely observed as an axial plane schistosity.

Along the bedding planes there is a pronounced lineation best developed in carbonaceous phyllites and the chlorite schists in the footwall. The lineations

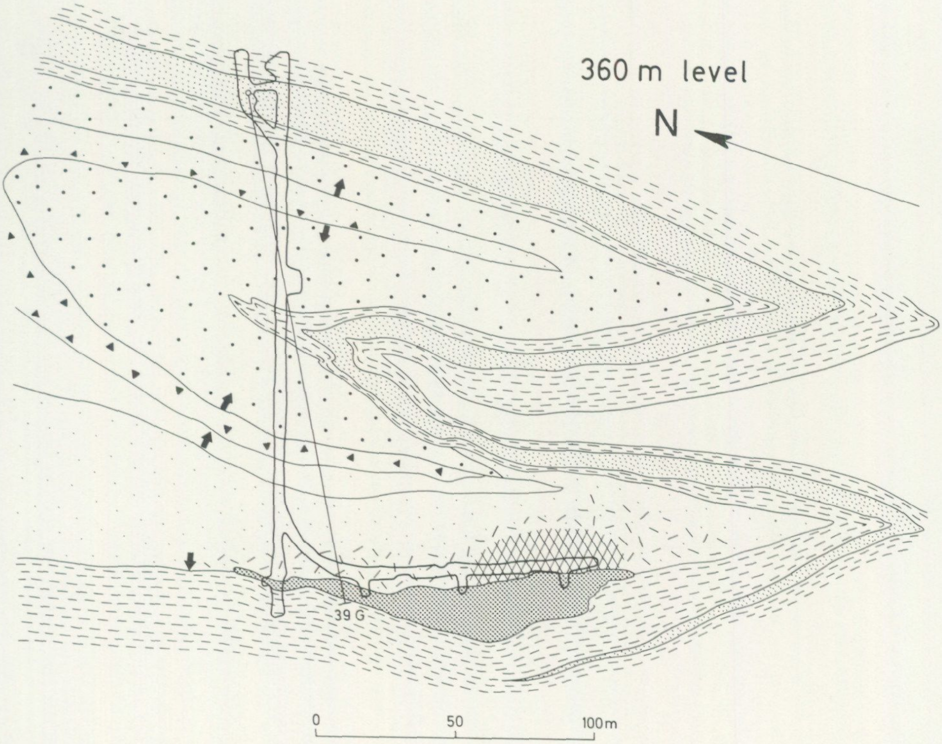

Fig. 12. Geology on the 360 m level in the Näsliden mine. Symbols as in Fig. 11.

which coincide with the fold axes (Fig. 14) indicate that an elongation has occurred in this direction (70° to S80°W). This effect is clearly shown by the agglomerate, whose rock fragments are all oriented with their longest axes in the direction of the lineation.

In the southern parts of the mine there is also a fold-fault with a dislocation of about 20 m (Fig. 11). This fault formed in connection with an anti-clockwise rotation around a steeply plunging fold axis (F_2). Finally the rotation proceeded far enough to cause rupturing which partly divided the ore into two bodies. During this folding and faulting the lamination in both the ore and the sedimentary rocks was almost completely destroyed in the area around the fold-fault. It seems as if the more plastic rocks such as ore, carbonaceous phyllite and calcareous metasediments were initially forced around the breccia in the footwall before the rupturing finally occurred. Due to its greater competency, the felsitic breccia possibly initiated this deformation structure in association with the folding.

A similar structure of smaller dimensions was also found in an intercalation of carbonaceous phyllite within the ore. The structure, which is shown in Fig.

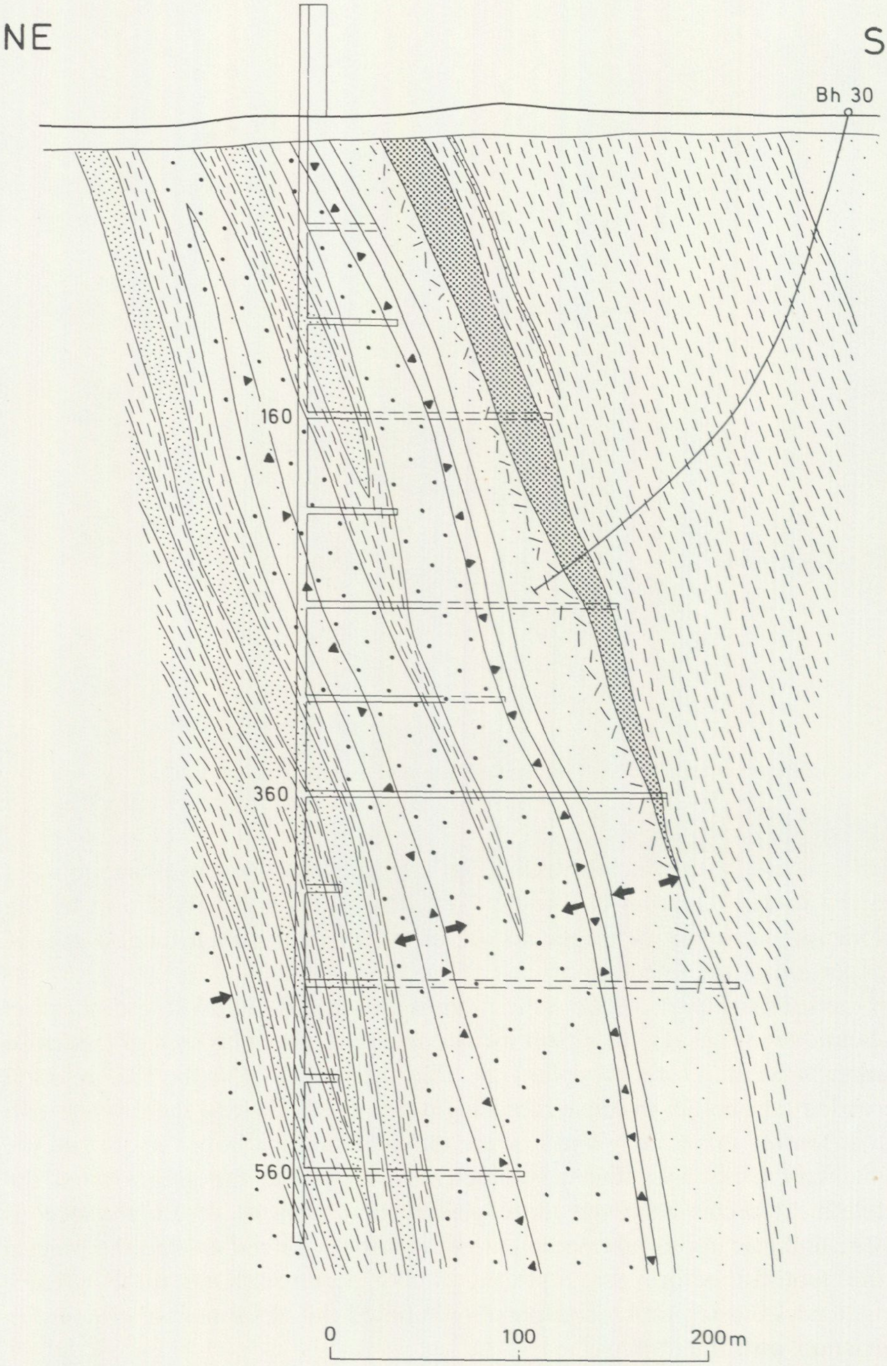

Fig. 13. Geology along a vertical section through the Näsliden mine. Symbols as in Fig. 11.

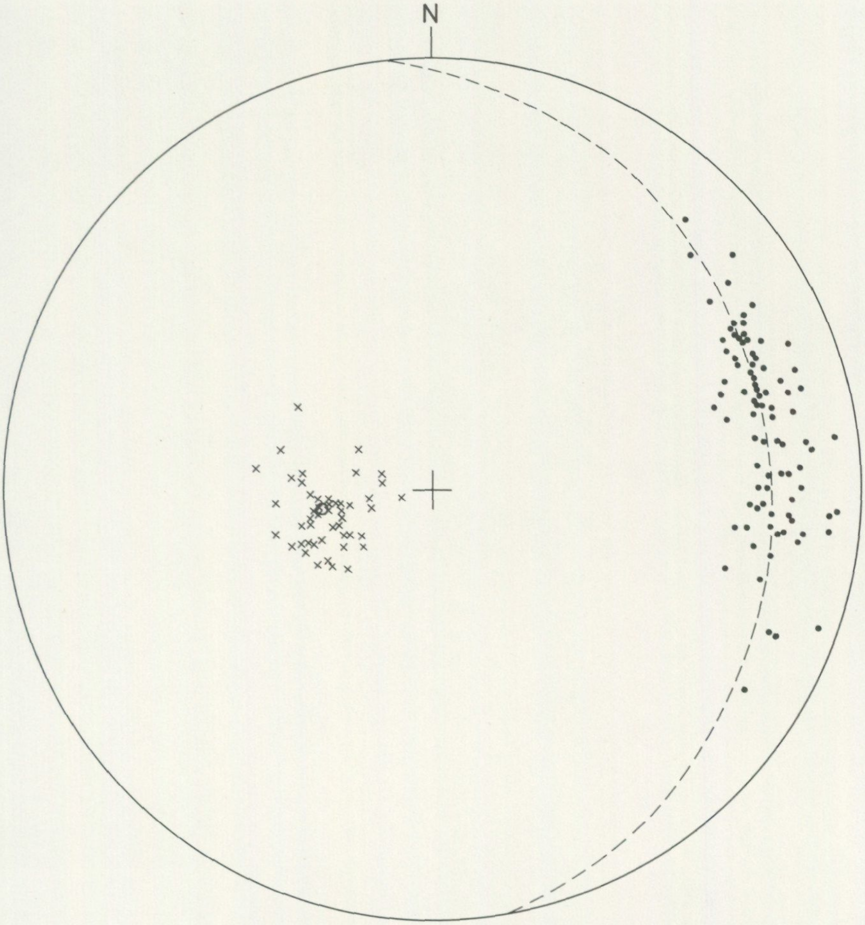

Fig. 14. Orientation diagram for bedding planes (·) and lineations (x) in the Näsliden mine. (o) = π-pole.

15, can be regarded as an intermediate step preceding a disruption (cf. Fig. 19). Except for the fold-fault mentioned above, no fault with any major dislocation has been observed, but faults with dislocations up to a few tens of centimetres are common.

The carbonaceous phyllite in the hanging wall and the chlorite schist in the footwall are often slickensided, probably due to shearing in connection with folding along the steeply plunging axes. The striae on the slickensides are most often oriented sub-horizontal, and the movements were preferentially released in these rocks owing to the small frictional resistance in them. However, it has not been possible to measure the amount of movement along these slickensides. Strike-slip movements in connection with shearing may also have affected the other country rocks, especially in areas of intense folding.

Fig. 15. Folded, pyrrhotite-banded, carbonaceous phyllite intercalation in the ore.

To judge from the mineral content in the country rocks at Näsliden (sodic plagioclase, quartz, chlorite, muscovite, biotite), metamorphism is of greenschist facies.

ROCKS OF THE MAURLIDEN "SERIES"

DACITIC TUFF AND AGGLOMERATE

Dacitic tuffs are the oldest known rocks in the mine. They are overlain by an agglomerate consisting of felsitic bombs and lapilli in a dacitic matrix. These rocks are strongly altered by chloritization and sericitization below the orebody.

The groundmass in the agglomerate is medium grey, aphanitic to very fine-grained, and consists mainly of feldspar, chlorite, biotite, quartz, sericite, and small amounts of ore. As usual, the biotite is often somewhat coarser than the other minerals. In the groundmass there are plagioclase phenocrysts and volcanic rock fragments. The fragments are usually acid and light grey, but there are also small, darker and more basic rock fragments; both types contain phenocrysts of plagioclase. In the light grey fragments there are only few phenocrysts and occasionally also aggregates of quartz up to 5 mm in diameter, which possibly represent original vesicles. The fragments may reach a size of 0.8 m and are oriented with their longest axes in the direction of the dominant regional lineation.

The dacitic tuff immediately below the coarser pyroclastic material has a mineral composition similar to the groundmass of the agglomerate. It also contains sericite and poikilitic plagioclase phenocrysts and, especially in its upper parts, small fragments of the types described above. Accessory minerals are apatite and calcite.

Parts of the tuff sequence show an alternation between lighter and darker, more and less acid layers. In one variety of this tuff, light coloured felsitic material forms thin, thread-like, irregular networks that partly unite.

PORPHYRY

The porphyry above the agglomerate is light to medium grey in colour with a yellowish or greenish tint due to sericitization or chloritization. Agglomerate with a porphyritic matrix occurs as a few thin horizons within the porphyry. In the aphanitic matrix of the porphyry there are 0.5–2.0 mm large phenocrysts of quartz and feldspar, each constituting some 5 % of the rock volume. The quartz phenocrysts characteristically show blue opalescence, and the rock is very similar to the porphyries 1.5 km north-east of Näsberg (p. 14).

The contacts between porphyry and other rocks such as carbonaceous phyllite and agglomerate are usually sharp. Close to the porphyry, the phyllites sometimes contain megacrysts of quartz which are of the same type as the quartz phenocrysts in the porphyry; the carbonaceous phyllites could thus be regarded as tuffites. On the whole the structural and lithological relations point to a pyroclastic, submarine origin of the porphyry.

The microcrystalline matrix of the porphyry consists mainly of feldspar, quartz and sericite with subordinate chlorite, biotite and calcite. The biotite commonly occurs as somewhat larger grains in the matrix, and the calcite often forms minor aggregates. Ore minerals, apatite and zircon are present in accessory amounts. The sericitization is partly irregular even within a single thin section, and sometimes it is intense enough to give the matrix a lepidoblastic appearance.

The quartz phenocrysts are usually more or less rounded, but dihexagonal forms and crystal fragments also occur. They always show undulose extinction and very often they are broken and joined together with matrix material, which frequently also corrodes them. Sometimes the quartz phenocrysts contain inclusions, which occupy only the central part of the host crystal, leaving a clear outer rim. The inclusions are also absent along cracks in the quartz grains and may have been removed during the regional metamophism.

The feldspar phenocrysts are generally subhedral and consist of plagioclase. They are always affected by sericitization and in the poikilitic crystals there is sometimes also chlorite, biotite and calcite. The alteration is in many cases crystallographically controlled and is commonly strongest in the kernel of the feldspars, indicating primary zoning with more Ca-poor margins. Partly, the metasomatic alteration of the plagioclase phenocrysts has proceeded far enough to make them almost unrecognizable.

FELSITE

The porphyry is overlain by carbonaceous phyllite and a felsitic rock, which is medium grey with a faint brownish tint. The felsite is homogeneous and consists mainly of feldspar, quartz, chlorite, sericite, and a little biotite. Ore minerals and calcite occur in accessory amounts. It has a grain size in the range of 0.02–0.03 mm, and occasionally contains about 0.5 mm large microlites of plagioclase and quartz. Like biotite in the porphyry, the biotite in the felsite is often somewhat coarser than the other constituents and has a porphyroblastic appearance.

The felsite occurs in association with carbonaceous phyllites which are found as intercalations thus proving the marine environment of deposition. Especially in the lower parts, fragments of phyllite have been incorporated in the felsite which sometimes also shows forms transitional towards the carbonaceous phyllites. Normally, the phyllite xenoliths occur as irregular bodies less than a few centimetres in size. The shape of the xenoliths indicates that the phyllite was still in a semi-consolidated state at the time of extrusion of the felsite.

The felsite has a chemical composition that is almost identical to the porphyry (cf. Table 9), which is an indication of its volcanic origin. It shows no bedding structures except when it grades into the phyllites. It is thus regarded as a submarine pyroclastic flow which is partly tuffite. Generally, it is very similar to the felsitic rocks described on p. 14 from other parts of the Näsliden area.

ALTERATION ZONES

Stratigraphically below the orebody there is a zone of strongly altered rocks. The zone extends some 20–30 m from the orebody, and rocks of this type also occur as "inclusions" in the ore. These strongly sericitized and chloritized rocks grade into relatively unaltered dacitic tuffs. In general, the volcanics in the mine always show some alteration although it is uncertain as to whether it is a result of the regional metamorphism or has been formed in connection with the formation of the ore.

There is also a zone of strongly altered rocks at the same stratigraphic level about 120 m from the orebody. Related to this zone there is, however, only a minor sulphide mineralization (Figs. 12 and 13).

The rocks of the alteration zones are mainly composed of sericite, chlorite and quartz, with minor or accessory amounts of sulphides, biotite, apatite, zircon, and remnants of feldspar. The biotite, which occurs more frequently in chlorite-rich rocks, often has a porphyroblastic appearance with anhedral or subhedral crystals sometimes oriented with their long axes across the schistosity of the rocks. Development of euhedral biotite porphyroblasts was prevented by the presence of quartz grains. The altered rocks are very fine-grained and can be classified as sericite and/or chlorite schists or quartzites. Chloritic schists have a tendency to predominate near the orebody.

In the altered rocks there are often secondary veins or schlieren characteristically containing sulphides (usually pyrite) with subsidiary quartz, muscovite, biotite, calcite, and feldspar. These secondary minerals are coarser than those in the host rocks, and they show no preferred orientation.

In the pure chlorite schists sporadic plagioclase grains (up to 1 mm in length) sometimes unite to aggregates. The feldspars are generally rounded showing a zonal texture caused by varying degrees of alteration. Typically, the central parts of the grains are strongly altered to sericite and calcite, followed outwards by a relatively unaltered zone and lastly a strongly altered rim (Fig. 16).

In the sericite quartzites there is sometimes a fragmentary structure resembling an agglomerate which is now represented by yellowish fragments in a grey, more chloritic matrix containing pyrite.

Within the alteration zone below the orebody there occurs a breccia of uncertain origin. It is confined to the southern and central parts of the zone (Figs. 11 and 12) which gives it a somewhat peculiar shape. The breccia consists of grey or yellowish grey fragments composed of microcrystalline sericite quartzite with minor amounts of pyrite, especially towards the margins, resulting in a diffuse zonation. Between the fragments, which fit together well, there is a matrix of quartz, calcite and pyrite with subordinate sphalerite and chalcopyrite (Fig. 17). The matrix material was probably deposited from hydrothermal solutions in open spaces. The boundaries of the breccia against the surrounding rocks are always diffuse.

The breccia was probably formed from silicified, rigid parts of the country rocks by fracturing in connection with volcanic eruptions. Afterwards, the fractures were penetrated by solutions related to later volcanic activity. Rocks

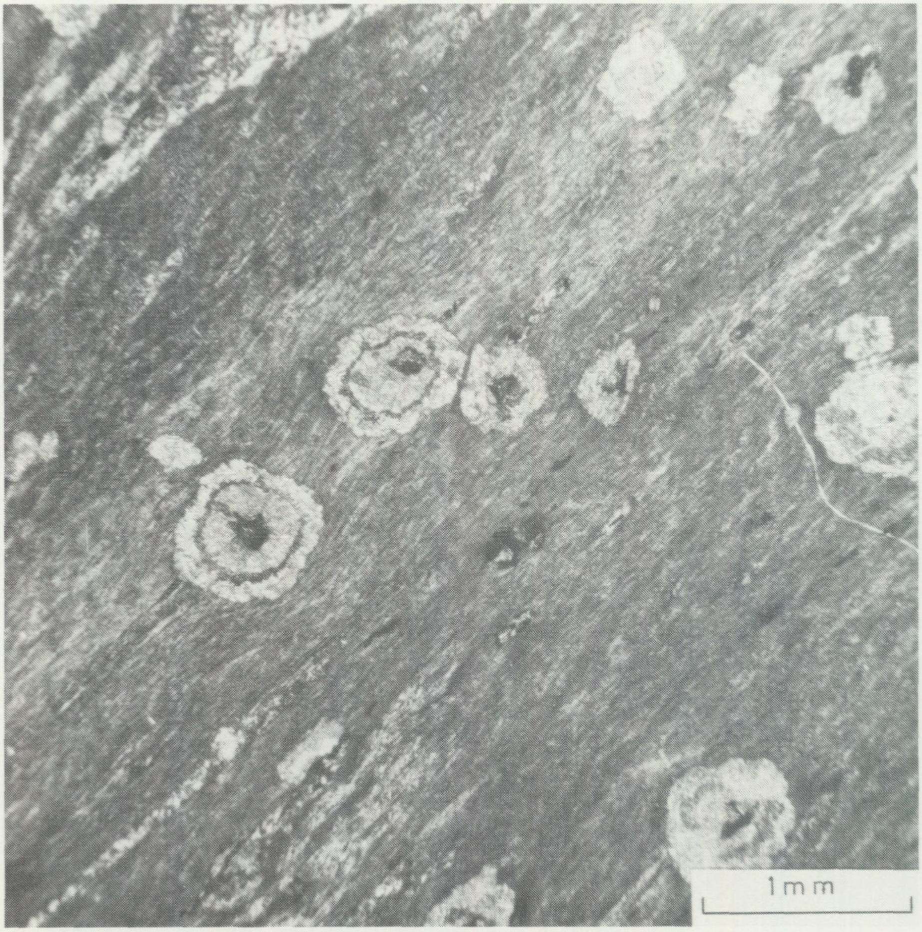

Fig. 16. Strongly altered plagioclase grains in chlorite schist.

of similar structure and composition at Mt. Lyell, Australia, were described by Markham (1968) who stated that "The chert of Crown Lyell No. 3 orebody is characterized by numerous crosscutting carbonate veinlets within which sulphide minerals occur" (p. 204). Furthermore: "The North Lyell and Lyell Comstock chert bodies are highly irregular to pipe-like in shape. Their structural configuration suggests therefore that they are not of sedimentary origin. In view of the extreme hydrothermal alteration to which the volcanic rocks have been subjected, it seems most probable that the chert bodies represent zones of completely silicified acid volcanics. Alternatively, they might represent siliceous sinter deposited within volcanic hot spring zones" (p. 205).

On the 460 m level, an adit traverses a similar breccia at the horizon of

Fig. 17. Breccia with fragments of sericite quartzite cemented by quartz, calcite and pyrite.

sericite quartzite about 120 m from the ore (Fig. 13). The breccia is underlain by an agglomerate and overlain by sericite quartzite and a minor massive sulphide body. The rock association and stratigraphy is the same below the major orebody, and consequently there seems to be a spatial and genetic connection between coarse pyroclastic rocks, sericite-chlorite alteration, breccias of the type described above, and the ore.

The sulphides of the alteration zones are completely dominated by pyrite occurring as a dissemination or in veins. On the whole, the zone has many characteristics in common with a "stringer ore", but it has not been possible to identify any volcanic pipe with certainty. This may possibly be due to scarce information and to the fact that the whole complex has been intensely deformed with the alteration zone running practically parallel to the ore.

However, in the central parts of the altered rocks north of the orebody (to the left in Figs. 11 and 12) there is a narrow, strongly chloritic zone with pyrite impregnation, which may represent the central parts of an alteration pipe originally perpendicular to the ore.

Within the alteration zone below the ore there is also a very light coloured, almost pure sericite schist "intruding" the other rocks. It occurs mainly along the schistosity which it, however, also traverses. The contacts are sharp, and inclusions of wall rocks are common.

ROCKS OF THE ELVABERG "SERIES"

Within the mine area, the rocks of the Elvaberg "series" (cf. p. 19) are dominated by grey and black carbonaceous phyllites, with subordinate amounts of psammitic rocks, calcareous rocks, tuffites, and metavolcanics.

The calcareous rocks are mainly confined to the lowermost parts of the sedimentary pile where they occur within a zone about 10 m above the ore. These rocks show a widely varying composition from relatively pure limestones, which grade through a greater admixture of detrital material into calcareous feldspar sandstones and tuffites. There are also beds of impure limestones containing angular fragments of carbonaceous phyllite, felsite and sericite quartzite. The fragments reach a few cm in size and were incorporated in the limestone by subaqueous slumping. Strongly sericitic rock fragments indicate that the alterations are an early feature in the geologic evolution, and that they were associated with hydrothermal volcanic processes. The mixture of various types of rock fragments in the limestone beds and absence of e.g. adjoining sericite quartzite precludes tectonic incorporation of the fragments.

As already mentioned, the limestones grade into feldspatic sandstones or tuffites (volcaniclastics; Fischer 1966, pp. 289–290) by increasing contents of feldspar, quartz, mica, and material mainly derived from unconsolidated volcanics. The psammitic rocks in addition to containing fragments of carbonaceous phyllites and metavolcanics (Fig. 18), normally contain 20–60 % plagioclase, together with minor amounts of quartz phenoclasts (0.5–1.0 mm in size) in a fine-grained matrix consisting of feldspar, quartz, biotite, chlorite, sericite, and subsidiary calcite and ore minerals.

Fine-grained phyllites, partly grading into psammitic rocks, form the major parts of the sedimentary pile, and they also occur as interstratifications within calcareous rocks and coarser metasediments. The grey phyllites have a very fine compositional layering which includes sandy and calcareous beds.

The Elvaberg metasediments were largely deposited from turbidity currents, and thus graded bedding is a common feature with individual beds measuring up to 3 m in thickness.

Fig. 18. Psammitic metasediment.

Some 175–200 m above the orebody are observed fine-grained, strongly schistose rocks composed mainly of talc and chlorite, the latter mineral partly occurring in about 1 mm large patches probably representing original fragments. In this rock (talc-schist) there are also beds of felsitic rocks, and the whole sequence is interpreted as metavolcanic.

THE OREBODY

GEOMETRY AND INTERNAL STRUCTURE

The Näsliden ore is situated along the border zone between the Maurliden and Elvaberg "series". Elvaberg metasediments conformably overlie the metavolcanics, and in broad outline the orebody is conformable with its surroundings. The orebody strikes NI5°–20°W and dips 65°–70°W (cf. Figs. 11 and 13).

In the open pit, the orebody has been exposed for 175 m along strike. Due to the thick overburden (12–15 m) and small width of the southernmost part of the ore, it has not been mined, but drillhole information reveals a total length of 220 m. At a depth of 150 m, the ore is 225 m long. It decreases in length downwards, being 140 m at the 350 m level. The ore is known down to 760 m. The width of the orebody does not exceed 25 m (Fig. 11), and its areal extents on the 153, 253 och 353 m levels are 2,610, 2,340 and 1,515 m^2 respectively.

As described on pp. 22 and 23, the southern part of the orebody was folded and faulted. The evolution of the fold-fault is schematically shown in Fig. 19. Due to this deformation the ore has partly been separated into two bodies. Observations show that below the 135 m level, the ore separates into two lenses, although at about the 200 m level, the ore consists of one body again owing to the fact that the southern, minor part wedges out successively.

From the forementioned it is clear that the Näsliden ore is a blanket shaped body with a length to width ratio of about 3.5:1. These two dimensions greatly exceed the thickness of the ore. Its longest dimension is parallel to the plunge of the lineation within the mine area. Sangster (1972, p. 12) stated that unmetamorphosed volcanogenic massive sulfide deposits, with some exceptions, are roughly circular in plan, and it can therefore be surmised that the Näsliden ore has been stretched in the direction of the lineation.

The contacts between ore and the wallrocks are very sharp. The altered rocks in the footwall are impregnated and contain stringers of sulphides, but there are no transitions into massive ore. Often the contact is made up of striated glide-faces, which are partly developed as harnesk surfaces (cf. p. 25).

Mostly the ore shows a compositional banding, which is caused by alternating layers of varying sulphide content and composition. Among the gangue minerals, carbonates (calcite and dolomite) dominate completely. However, especially within the stratigraphically upper parts of the orebody, more or less barren intercalations of carbonaceous phyllites and psammites occur more frequently than elsewhere. The layering in the ore is interpreted as sedimentary. The beds only rarely exceed a couple of centimetres in width and are normally not continuous for more than a few metres, which is due to Svecokarelian deformation. Pinch-and-swell structures are common and intercalations of phyllites and psammites are largely interrupted (Fig. 20). In connection with this tectonic deformation, accumulation of sulphides such as chalcopyrite, galena and sulphosalts in pressure shadows was common. The stratigraphically upper parts of the orebody also show the most distinct evidence of "Durchbewegung" due to larger differences in competency between the different beds.

The orebody is naturally most strongly tectonized in the crest area of the

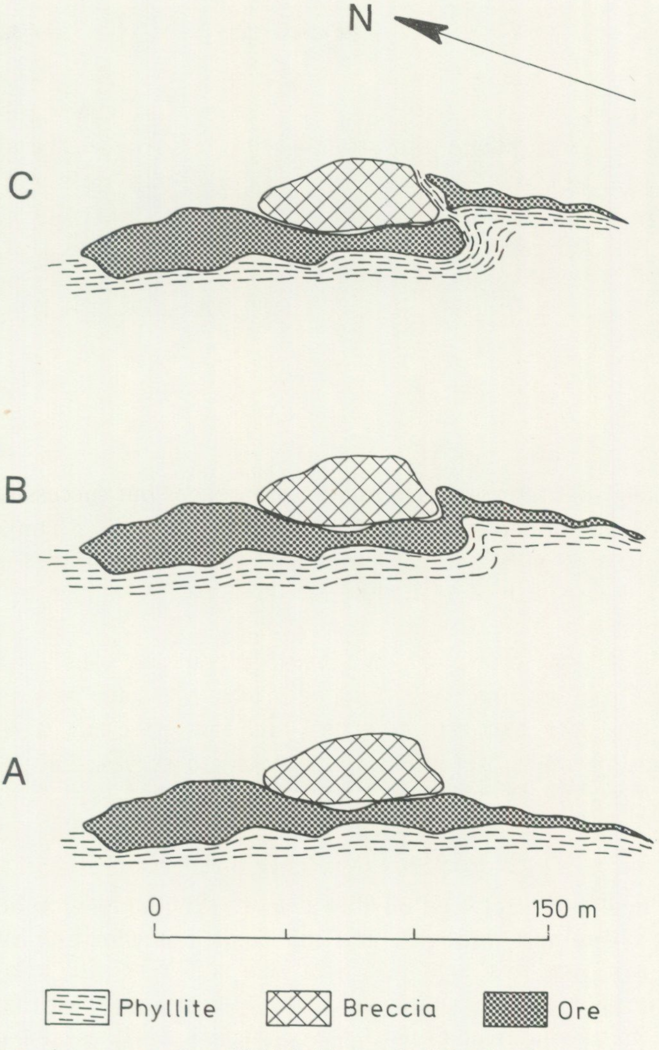

Fig. 19. Schematic representation of fold-faulting at the 153 m level.

major drag fold (and fold-fault), but it is only the larger body that has been affected so intensely that lamination is almost completely destroyed. Within the whole orebody dolomite occurs as large grains and aggregates, but this phenomenon is most pronounced in the area of the major drag fold where dolomite aggregates exceed 10 cm in size. This dolomite was probably derived from the carbonate in the orebody. In contrast to the "primary" carbonates in the ore, the "secondary" dolomite is pure white and free from carbonaceous pigmentation.

Small scale folds of a style which characterizes the entire mine area are rarely

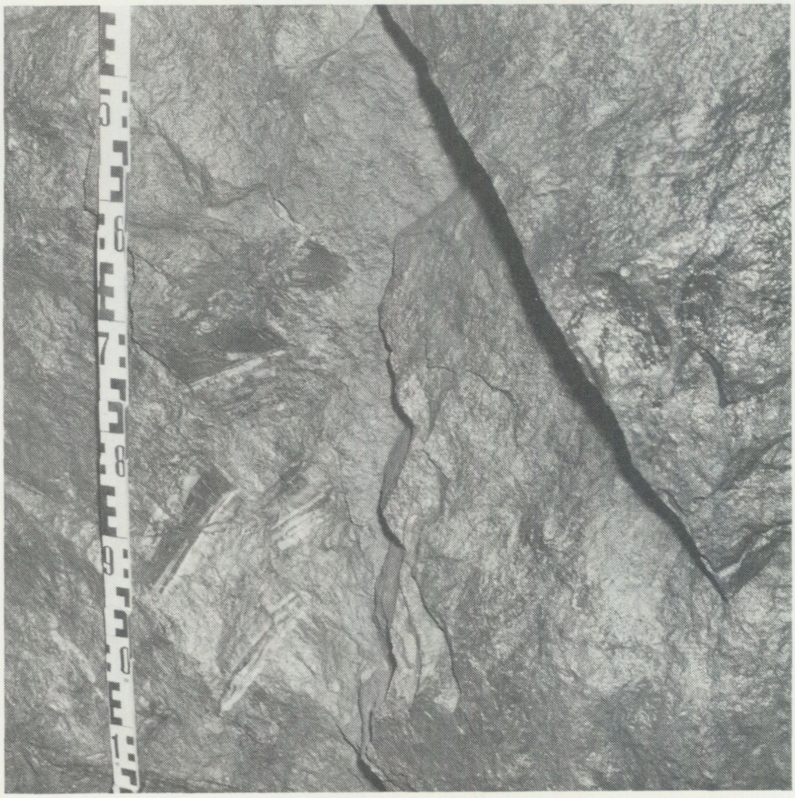

Fig. 20. Disrupted intercalation of psammite in massive ore.

observed at the contact between phyllite and ore. The lamination in the ore is destroyed at crests and throughs, and the banded phyllite is pronouncedly sheared in these areas.

Pyrite is by far the most abundant sulphide at Näsliden with subordinate amounts of pyrrhotite, sphalerite, chalcopyrite, galena, and arsenopyrite; antimony and bismuth minerals occur in trace amounts. Figs. 21 and 22 show the distribution of Cu, Zn and Pb on the 253 and 153 m levels. On both levels, the distribution of Cu is somewhat irregular especially towards the footwall. However, it is also evident that the proportion of Cu is higher in the stratigraphically lower parts of the ore. The irregular distribution within the lower parts of the orebody may, at least partly, be due to remobilization and to the fact that there was more primary Cu to be mobilized in these parts.

On the 253 m level, both Zn and Pb show increasing proportions towards the hanging wall, which are antipathetic to the distribution of Cu. On the 153 m level the Zn and Pb distribution indicates two cycles with increasing proportions towards the hanging wall (Fig. 22). The first cycle reaches the central parts of the orebody, and the second one occupies the upper parts. The ore on the 253 m level may possibly correspond to the first cycle on the 153 m level. The reason why the second cycle was not developed on the lower level may be that this level originally was farther from the centre of volcanic emanations.

In the vicinity of the fold-fault, where the lamination of the ore has been destroyed, the zonal distribution of Cu, Zn and Pb is absent (Fig. 21). Except for pure mechanical deformation of the laminae, remobilization has also occurred in this area producing increased concentrations of Pb and Zn and also of Cu, although the total sulphur content is lower than the average.

Chalcopyrite, sphalerite and galena are the principal phases reflecting the Cu, Zn and Pb content and distribution in the ore. Arsenic and antimony are mainly bound to arsenopyrite and the sulphosalts tetrahedrite, bournonite, boulangerite, and meneghinite.

A correlation matrix for all the elements mentioned above, plus gold and silver is presented in Table 2. The samples were taken from horizontal boreholes, drilled from exploration adits in the ore on the 153, 253 and 353 m levels.

Zn shows good correlation to Pb due to similar distributions of sphalerite and galena in the ore (cf. Figs. 21 and 22). In contrast, Cu is not significantly correlated to Zn or Pb, which reflects the tendency of chalcopyrite enrichment towards the footwall to be overlapped by local Zn and Pb maxima. The positive correlation between Pb and Ag depends of course on the silver content in galena. The antimony minerals (sulphosalts) mentioned above mostly occur intimately intergrown with galena, which results in good correlations of Sb to Pb and Ag. The sulphosalt tetrahedrite also contains between 7 and 18 wt. % silver (Vesterberg 1973). Arsenic is best correlated to Au and Cu which may indicate a tendency for arsenopyrite to be enriched towards the footwall.

MINERALOGY

Pyrite. In the Näsliden ore, pyrite is by far the most common of the sulphide minerals. In polished section, it shows distinct anisotropy with blue-green and brownish pleochroism. Anisotropy seems to be a normal feature in pyrite in spite of the fact that it is a cubic mineral. The reason may be that the lattice has undergone strain, or that pyrite has a low structural, as distinct from dimensional, symmetry (cf. Stanton 1957).

The grain size varies, but where the ore is rich in pyrite it is normally 0.1–0.2 mm. There is a tendency towards a reduction in grain size when pyrite occurs as impregnations within the gangue. According to Anger (1971, p. 9), carbon prevents the growth of pyrite crystals, and this may be the explanation in this case as the gangue often contains a little carbonaceous material. On the other

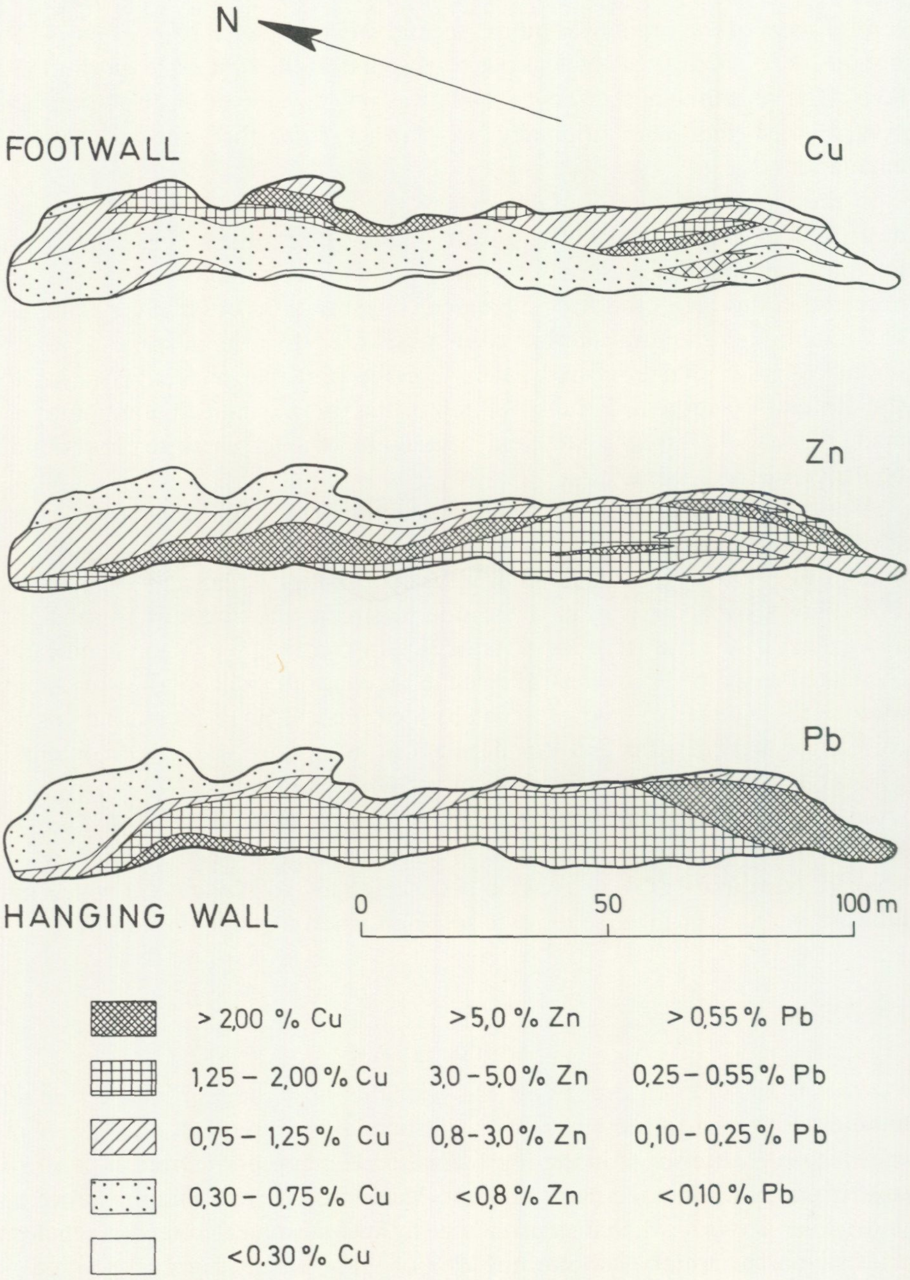

Fig. 21. Distribution of Cu, Zn and Pb (wt-%) on the 253 m level.

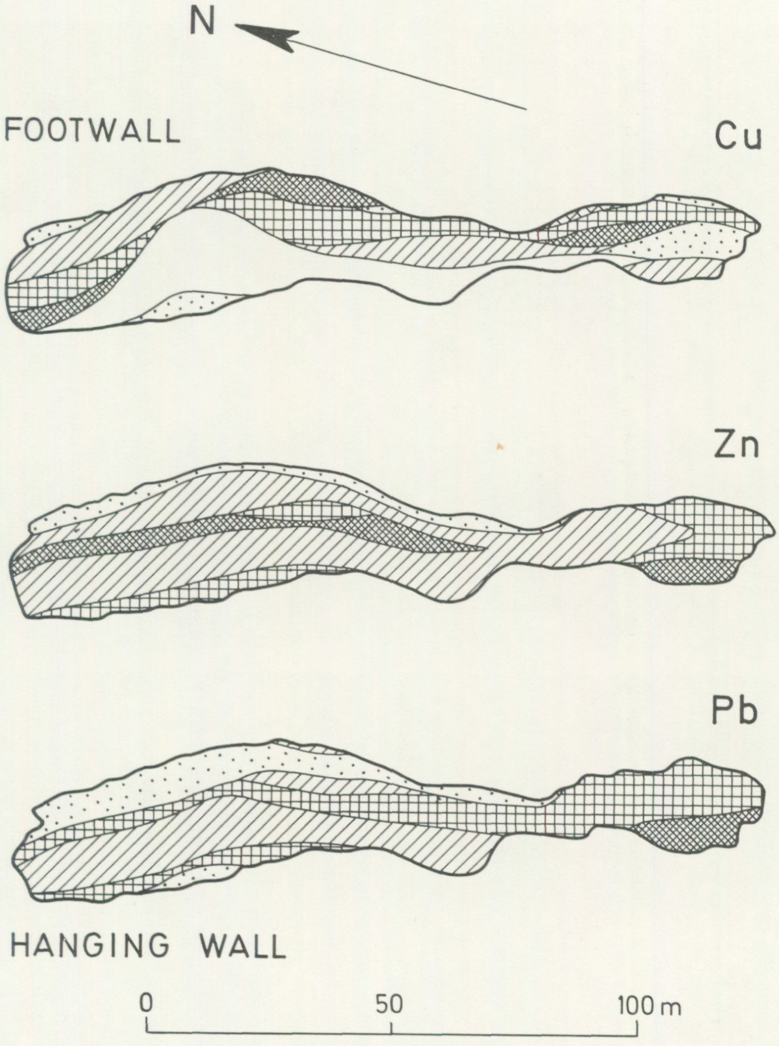

Fig. 22. Distribution of Cu, Zn and Pb (wt-%) on the 153 m level. Symbols as in Fig. 21.

hand, the chlorite-schist in the footwall often contains an impregnation, within which the pyrite forms cubes sometimes achieving sizes of 1 mm or more.

Etching of pyrite with concentrated nitric acid has revealed textures that may be interpreted as relic colloform. Some of these are reniform, botryoidal, or mammilary (Fig. 23 A–D). "The term colloform (implying colloid or gel-texture) is used to describe the texture of minerals that occur in a series of concentric curved or scalloped layers, in which the curvature is always convex towards the younger or free surface. A free surface, if present, is reniform, botryoidal, mammilary, or even stalactitic. These curved surfaces are

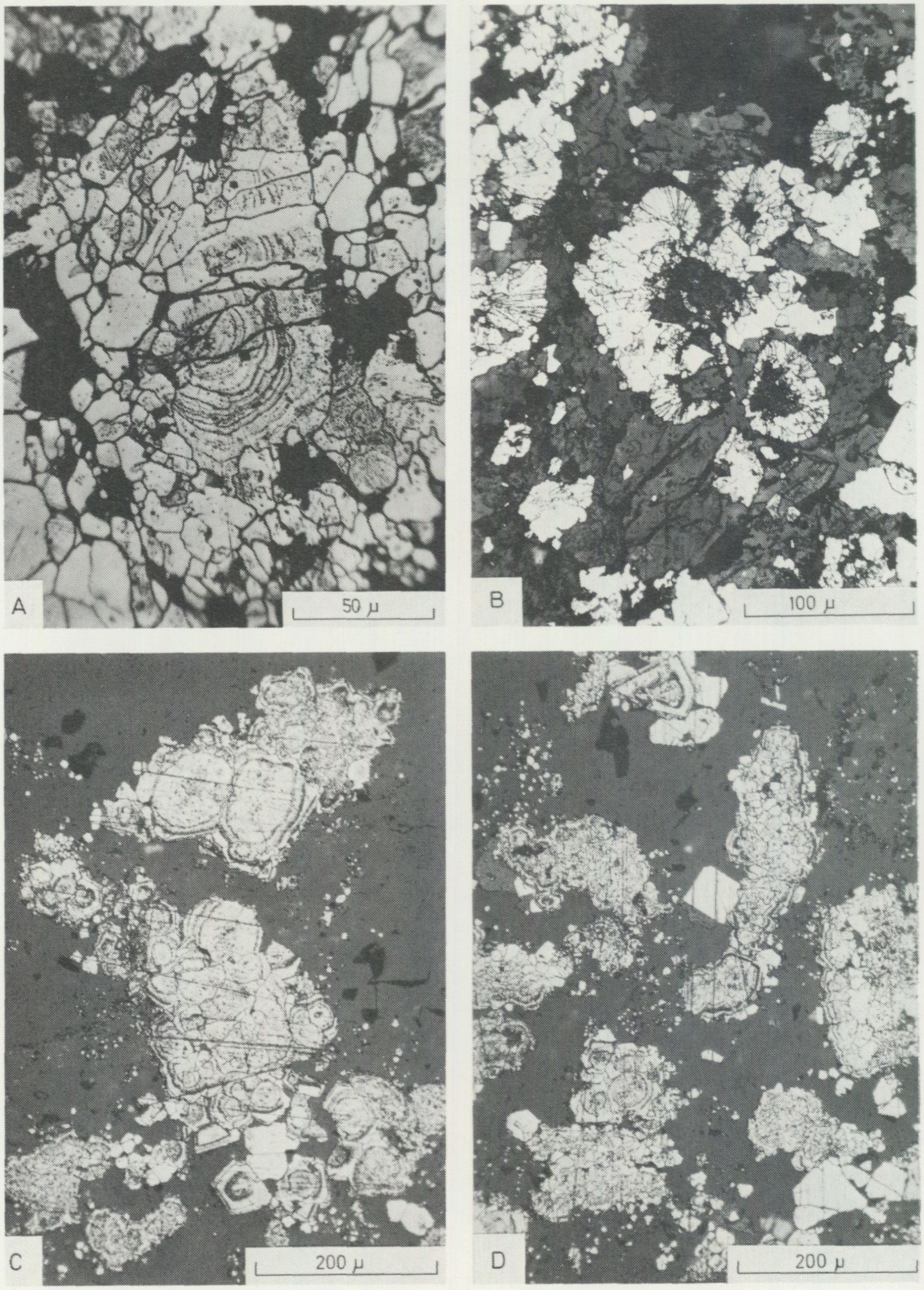

Fig. 23. Relic colloform pyrite etched with nitric acid. A. Reniform pyrite. B. Reniform pyrite. C. Botryoidal pyrite. D. Botryoidal and mammilary pyrite.

considered to be manifestations of surface tension effects in viscous material, and are therefore indicative, though not by any means exclusively, of colloidal origin" (Edwards 1954, p. 20).

In other cases, pyrite forms rounded aggregates with radiating columnar crystals emanating normally from nuclei consisting of chalcopyrite or sphalerite which are often accompanied by gangue minerals (Fig. 24 A–B). These radial textures are suitably explained by Edwards (1954, p. 20): "Where the original gel has crystallized, it results in the formation of radially arranged columnar crystals, whose long axes are normal to the outer (free) surface of the layer". In the Näsliden ore there are also examples of combinations of the textures described above (Fig. 25 A). "Colloidal masses that take on colloform shapes generally crystallize into clusters of radiating crystals trending normal to the periphery of the botryoids. Diffusion bands or colour variations may also be present in them. Radiating, columnar crystals are able to extend through the diffusion bands, because the crystallization was later than, and independent of, the formation of Liesegang rings" (Park and MacDiarmid 1970, p. 132).

Most of the best preserved colloform textures at Näsliden are more or less circular in cross-section. They range in size from about 0,03 to 0,3 mm and are in most cases entirely or partly surrounded by gangue minerals. If Anger's (1971) conception that carbon prevents growth of pyrite, is correct, it seems natural that the least recrystallized colloidal pyrite occurs in the carbonaceous gangue. Sangster (1972, p. 16) also stated: "Such features as colloform and framboidal pyrite are common, even in Archean orebodies, particularly those with high carbon (graphite) content".

Etching with conc. HNO_3 has revealed clusters of pyrite grains grouped into spheroidal masses (Fig. 25 B). The clusters, which are about 50 μ large, resemble what is known as framboidal (raspberry-like) pyrite, and they commonly occur in close connection with the colloform pyrite described above. Each framboid consists of approximately equidimensional grains 2–4 μ large.

Framboidal pyrite was earlier considered to have originated from colloidal deposition (e.g. Bastin 1950). The framboids were thought to have formed due to simultaneous crystallization from several centres within globules of gel. Other workers (e.g. Love 1962) related framboidal pyrite to micro-organisms. The framboids were suggested to represent the texture of fossilized bacteria. However, Berner (1966) found that framboidal pyrite could be synthesized in the laboratory under simulated sedimentary conditions without the participation of micro-organisms.

Naturally, the colloform pyrite was after diagenesis recrystallized further during regional metamorphism. There are examples where the concentric textures occur as helicitic traces within the recrystallized pyrite. In some cases, concentric textures have also been disrupted by recrystallization and intergranular movements (Fig. 23 A). Another interesting texture can be seen

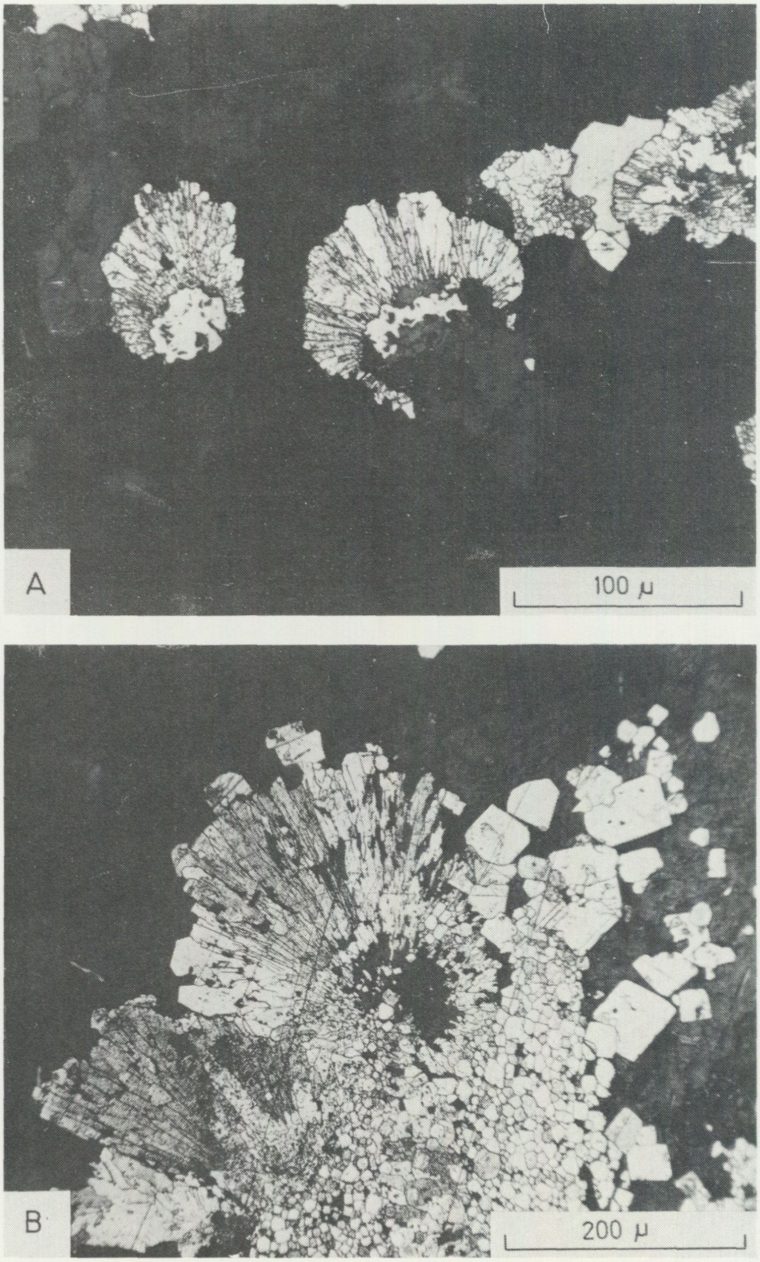

Fig. 24. A. Relic colloform pyrite aggregate. Columnar crystals, radially arranged around chalcopyrite in the centre. B. Relic colloform pyrite as in 24A, but with sphalerite in the centre and between the columnar crystals.

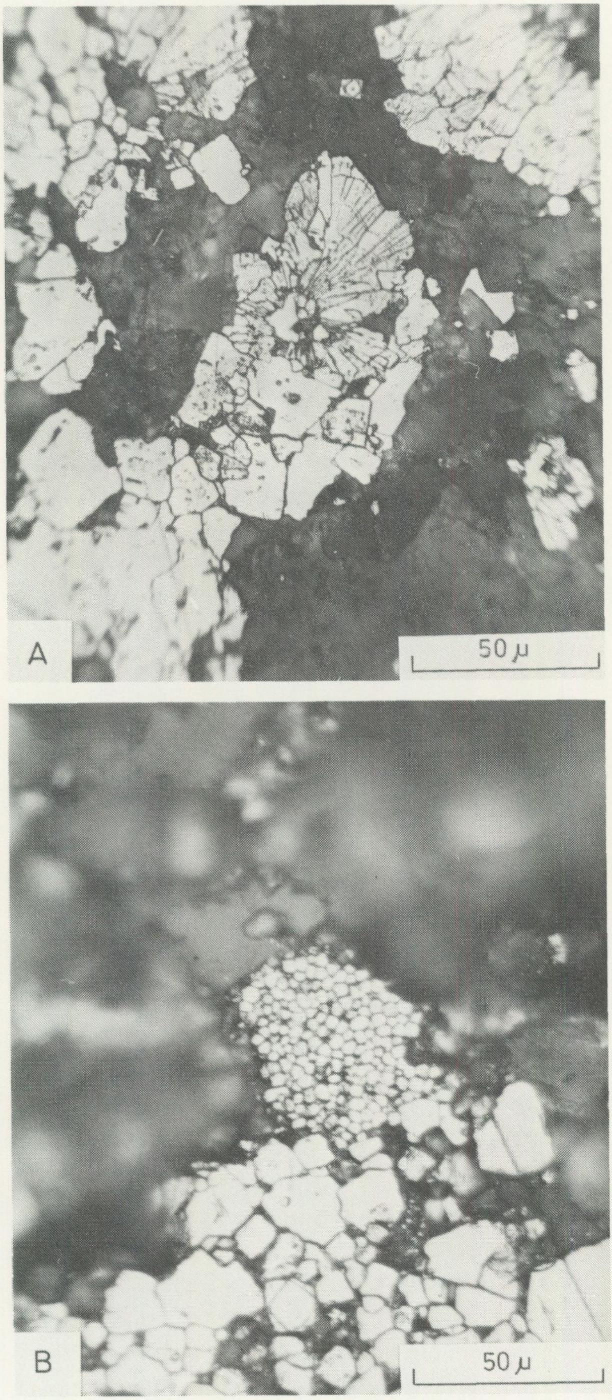

Fig. 25. A. Relic colloform pyrite etched with conc. HNO_3. Radiating, columnar crystals extend through the diffusion bands. B. Framboidal pyrite (?) etched with conc. HNO_3.

in Fig. 26 A, where the centre of the original colloform aggregate contains subconcentric scalloped layers. Towards the margin, these layers turn into planar surfaces comprising crystallographic faces of pyrite. This phenomenon is also interpreted as being due to recrystallization (cf. Markham 1968, p. 213).

A crystalloblastic series among sulphide minerals was proposed by Stanton (1959). This implies that minerals of high "form energy", e.g. pyrite and arsenopyrite, grow as metacrysts in a surrounding matrix of sulphides of lower "form energy". At Näsliden, pyrite shows well-developed crystal outlines against the other sulphides except arsenopyrite. Where it occurs as isolated grains within a matrix of sphalerite, pyrrhotite or chalcopyrite, euhedral and subhedral forms are common. However, the matrix sulphides, and above all sphalerite, also form "embayments" within the pyrite grains, a texture identical to the "caries texture" which was earlier regarded as proof of replacement. On the other hand, the pyrite grains also contain inclusions of "matrix sulphides", which suggests that the pyrite cubes must be regarded as porphyroblasts or poikiloblasts (cf. Fig. 26 B). Many of the "inclusions" are probably embayments that have been cut so as to give this effect. However, their number is large enough to make it likely that at least some of them are true inclusions. The embayments may also be the result of expulsion of inclusions from the growing pyrite grains (Roscoe 1971, p. 1130, Fig. 6).

At places where the ore consists almost exclusively of pyrite, this sulphide forms a micromosaic of anhedral grains. This texture (foam-texture), where polygonal grains meet at angles close to 120° at triple junctions (Fig. 27 A), may be due to recrystallization (Stanton 1964), and has for long been recognized as such in metals (Carpenter and Fisher 1930). Also in metamorphic silicate rocks the same type of granoblastic texture occurs. To achieve this texture "the essential requirements are that grains pack together in the most economical manner, that surface free-energy is minimal – this being related to surface area of individual grains, and that surface tensions between juxtaposed grains are in balance" (Lawrence 1973, p. 217). "The relative size of the different faces of a crystal can be influenced by its environment – variation in temperature, pressure, speed of growth and particularly by the incorporation of impurities" (Stanton 1964, p. 50). The crystal form that fulfills the space requirements best is the pentagonal dodecahedron, which has 12 faces, 5 edges per face and angles of 120° between the faces.

Rickard and Zweifel (1975) investigated pyrite micromosaics from *inter alia* Näsliden. They measured the triple junction angles which yielded an approximately normal unimodal distribution. The kurtosis of the curve is weakly platycurtic ($K_s=2.85$) and the distribution slightly rightskewed ($S_k=+0.06$). "Closer inspection of the Näsliden micromosaic shows that the weak schistosity of the pyrite developed by the merging of the grain boundaries of pairs of apparently similar-size pyrite crystals normal to the strike of the

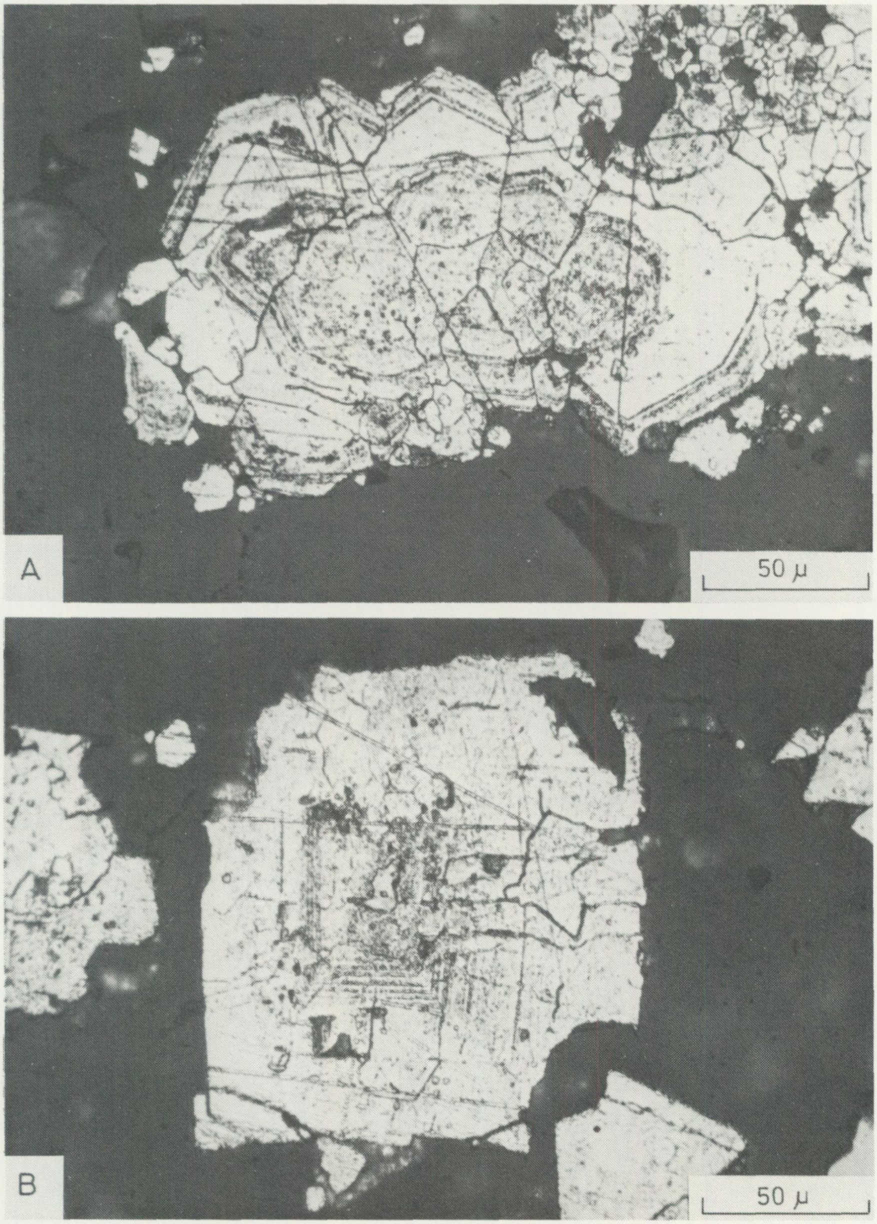

Fig. 26. A. Relic colloform pyrite aggregate showing increasing degree of recrystallization towards the margin. Etched with conc. HNO_3. B. Growth zonation in pyrite etched with conc. HNO_3.

schistosity. That is, the Näsliden pyrite was first annealed and then deformed" (Rickard and Zweifel 1975, p. 268).

The pyrite sometimes shows signs of deformation in the form of irregular fractures which are filled with chalcopyrite, sphalerite or, particularly, pyrrhotite. In part, pyrite porphyroblasts have been cataclastically deformed along cleavage planes (Fig. 27 B), but sometimes the deformation has resulted in a network of irregular fractures traversing the porphyroblasts. These fractures are often filled with pyrrhotite in spite of the fact that the pyrite lies within a matrix of sphalerite and gangue minerals.

Under the microscope, a more thorough fragmentation of pyrite can also be observed being most evident where relic colloform aggregates have been fragmented. The separate pieces of an original aggregate are often randomly oriented and impossible to trace back to their "original" position (Fig. 27 C). This kind of fragmentation may be interpreted to have occurred in connection with transportation and redeposition from local submarine slumping (cf. Watanabe 1974, p. 347).

Arsenopyrite comprises about 3 % of the Näsliden ore and shows a very slight concentration towards the footwall. It is very fine-grained, normally 0.01–0.07 mm, and occurs as single grains scattered in the other sulphides or in the gangue; it also tends to be clustered in aggregates or in non-continuous bands.

Arsenopyrite shows a strong tendency to develop euhedral crystals. Where it occurs as single grains within the other sulphides, it is usually developed as rhomb-shaped crystals, and therefore should be placed before pyrite in the "crystalloblastic series".

In exceptional cases arsenopyrite, in contact with gangue minerals, shows crystallographically oriented inclusions of the gangue which were probably incorporated into growing arsenopyrite crystals during recrystallization. Otherwise, arsenopyrite is normally free from inclusions or "caries" textures of the type so common in pyrite.

Berglund and Ekström (1978) investigated arsenopyrites from the Näsliden mine. Five samples with 31.1–32.3 mol. % As indicated an equilibrium temperature in the interval 360–420°C.

Pyrrhotite occurs as interstitial grains in pyrite or in aggregates with the other sulphides where it normally has a grain size of 0.1–0.3 mm. Inclusions of chalcopyrite, sphalerite and arsenopyrite are common. In single-phase pyrrhotite aggregates, the development of triple junction points has resulted in "foam-textured" pyrrhotite.

Due to deformation, pyrrhotite grains have been divided into a number of smaller units, subgrains, which differ slightly in orientation. This is readily seen between crossed nicols as the pyrrhotite is strongly anisotropic. There is no

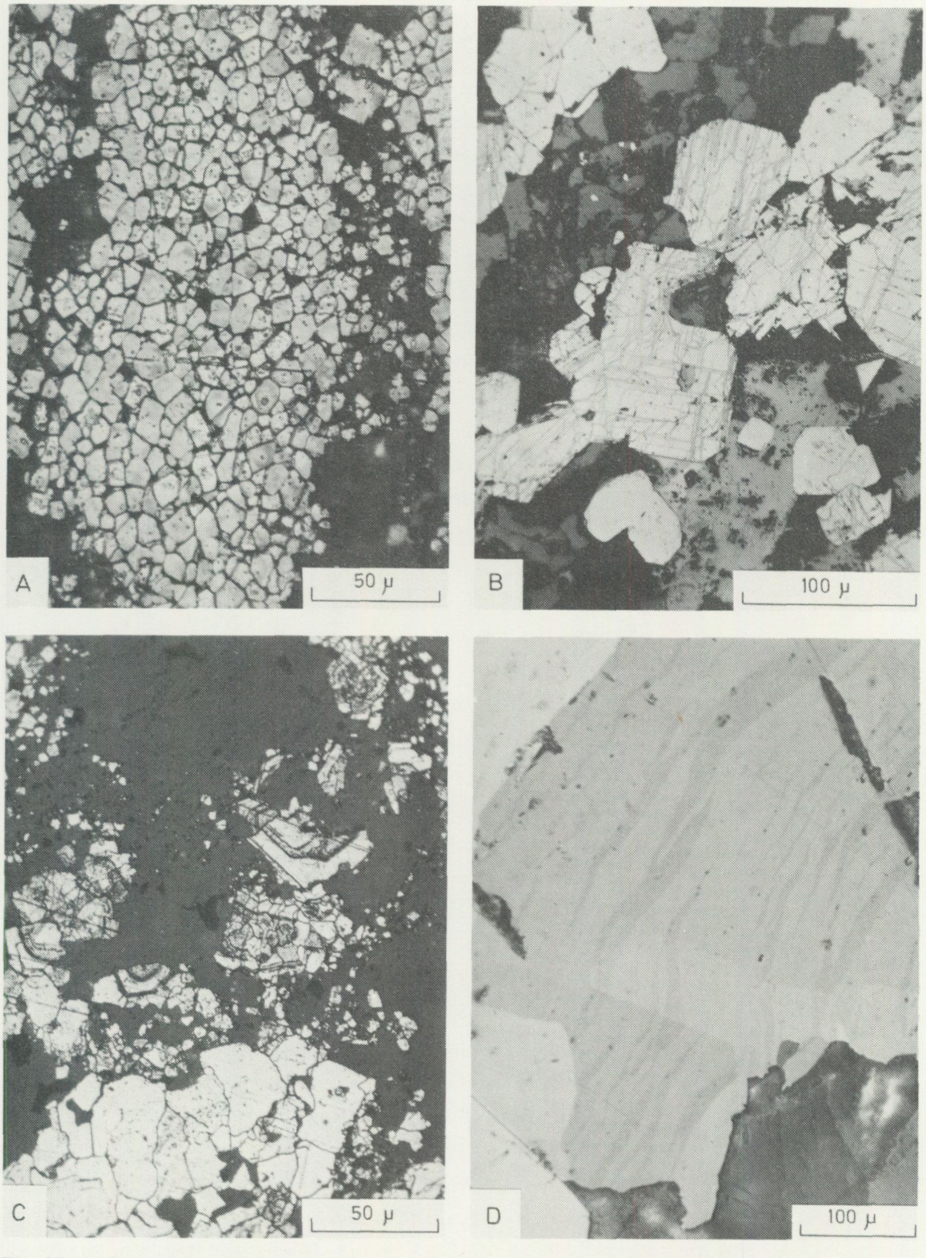

Fig. 27. A. Pyrite micromosaic (foam pyrite) etched with conc. HNO_3. B. Cataclastically deformed pyrite. C. Fragmentation of relic colloform pyrite. Etched with conc. HNO_3. D. Sinuous lenses of an exsolved phase in pyrrhotite traversing subgrain boundaries.

doubt that sometimes we are concerned with deformed pyrrhotite grains as they often contain subparallel, sinuous lenses of an exsolved phase traversing the boundaries between subgrains (Fig. 27 D, cf. Richards 1966, pp. 15–16). The subgrain development was probably due to annealing, i.e. deformed pyrrhotite lattices of high energy were reconstructed into lower energy configurations. In this case, reordering implies formation of unstrained blocks and subgrains. The process of reordering during annealing is also known as polygonization. This texture is reminiscent of the porphyries at Näsliden, where the quartz phenocrysts are granulated or show undulose extinction. Etched polished sections have also revealed bent cleavage planes in pyrrhotite.

As mentioned above, cataclastically deformed pyrite is often healed with pyrrhotite. Fracturing of the "matrix sulphides" or the gangue is very rarely observed in this connection. The pyrrhotite fills minute fractures in the pyrite and some replacement has also occurred. Especially where the pyrrhotite-healed, cataclastic pyrite is surrounded by sphalerite, or chalcopyrite the pyrrhotite seems to be a product of pyrite breakdown.

Sphalerite. The Näsliden ore contains about 4,5 % sphalerite occurring as interstitial grains in pyrite mosaics or as anhedral grains, 0.1–0.3 mm large, in aggregates together with pyrrhotite or chalcopyrite. Etched sphalerite has also been found to form aggregates of nearly equidimensional grains in a "foam texture."

The sphalerite often contains <50 μ long rod-shaped exsolution grains of crystallographically oriented pyrrhotite. It also contains inclusions of pyrrhotite and chalcopyrite.

In the Näsliden ore, the sphalerite is almost invariably twinned. The twins are mostly irregularly spaced within the grains and there may be twins of different orientation in the same grain. The twins, which are frequently bent, do not always persist across the whole grain, and may also vary in thickness along their length. These twin qualities (Fig. 28 A–B) are all characteristic of deformation twins although many are a result of annealing. If Rickards' and Zweifel's (1975, p. 268) statement that the Näsliden pyrite was first annealed and then deformed is correct, then the annealing twins in sphalerite should have formed prior to the deformation twinning.

Berglund and Ekström (1978) investigated co-existing sphalerite, arsenopyrite, pyrite, and pyrrhotite. They found contents of 11.3 to 13.4 mol % FeS in the sphalerite, which was regarded as a possible indication of pressure variation during metamorphism. Interpretation of the data using the sphalerite geobarometer of Scott (1973) indicated metamorphic pressures of about 5.5–7 Kb for the Näsliden ore, which would appear to be too high. Additional data suggested an equilibrium temperature in the interval 360°–420°C.

Supplementary analyses of sphalerite have been carried out by the present author using an ARL SEMQ electron microprobe. Co-existing sphalerite, pyrite and pyrrhotite were analyzed for Zn, Fe, and S (Table 3). Each analysis represents an average of 3–4 points within the grain. The content of FeS in the sphalerites was found to vary between 10.9 and 12.1 mol. % with an average of 11.5 mol. %, compared to 12.5 mol. % in the investigation by Berglund and Ekström who analyzed only the Fe-contents.

Chalcopyrite is similar to sphalerite and pyrrhotite in grain size and textural appearance. It constitutes about 3.5 wt. % of the orebody and is preferentially concentrated towards the footwall.

Fractures in sphalerite may be healed with chalcopyrite, but the opposite situation also occurs. However, the chalcopyrite has normally had the greatest mobility and thus is often concentrated in pressure shadow zones around fragments of broken phyllite intercalations in the ore.

In unetched, polished sections, chalcopyrite seems to occur as more or less uniformly distributed irregular grains in the sphalerite. However, after etching with HBr, an overwhelming majority of the minute chalcopyrite grains are revealed to be localized along grain boundaries and at triple junction points in the sphalerite. Edwards (1954, p. 41) concluded: "If the temperature of recrystallization is high, which makes for a rapid rate of solid diffusion, and the period of auto-annealing is prolonged, the precipitated minerals tend to escape from the recrystallized mineral and segregate in its grain boundaries". This phenomenon may be due to the easier diffusion of chalcopyrite at grain boundaries, and to the fact that it moved along with the surfaces of the recrystallizing sphalerite. The shape of chalcopyrite grains in sphalerite aggregates is mainly determined by the shape of the latter mineral which has a greater "crystalloblastic force".

Sporadically, the chalcopyrite contains creamy grey exsolution lamellae of cubanite ($CuFe_2S_3$). "At high temperature much FeS is soluble in $CuFeS_2$ producing a "cubic high-temperature chalcopyrite", upon cooling this breaks up as follows: ordinary chalcopyrite + cubanite. . . The existence of cubanite shows thus in any case that originally the temperature of formation must have been over ~ 250°C". (Ramdohr 1969, p. 621).

Berglund (1979) found the mobility sequence of ore minerals at Näsliden to be pyrite $<$ sphalerite $\simeq$ pyrrhotite $<$ chalcopyrite.

Galena, sulphosalts and Bi-minerals. Galena is the third most frequent base metal sulphide at Näsliden, constituting about 0.3 % of the ore. It occurs as anhedral grains dispersed in the other sulphides or in aggregates together with sphalerite or sulphosalts. In these aggregates, the galena often shows a well developed "foam texture" with triple junction angles close to 120°.

Four different sulphosalts have been identified. They are bournonite ($PbCuSbS_3$), boulangerite ($Pb_5Sb_4S_{11}$), meneghinite ($CuPb_{13}Sb_7S_{24}$), and

Fig. 28 A. Deformation twins in sphalerite. Etched with HBr.

tetrahedrite ($Cu_{12}Sb_4S_{13}$), and they occur preferentially in the lead- and zinc-rich parts of the ore. They also seem to be enriched in the major fold and rupture structures of the orebody. Vesterberg (1973) investigated sulphosalts *inter alia* from Näsliden. He found that, except for tetrahedrite, they correspond very well to the idealized compositions given above. Two tetrahedrites, however, were found to contain 1.2–1.5 % Zn, about 5.5 % Fe and 15.4–17.9 % Ag. The sulphosalts are intimately associated with galena, and these minerals almost always occur in myrmekitic intergrowths.

In close association with the above-mentioned minerals there is also

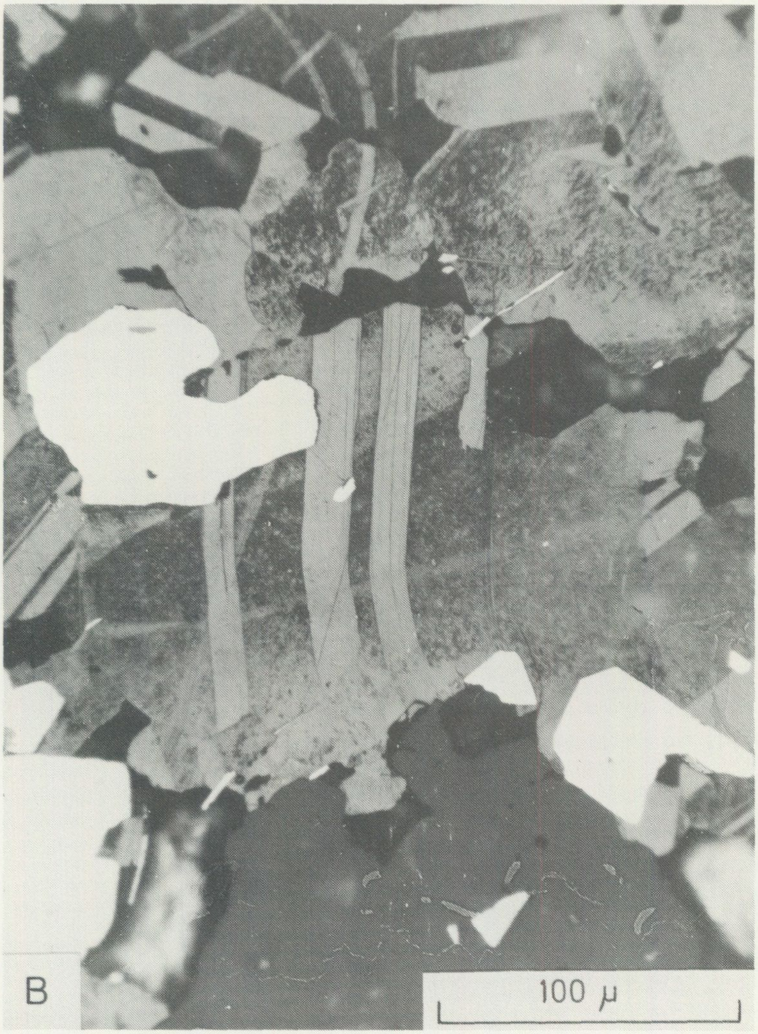

Fig. 28 B. Deformation twins in sphalerite. Etched with HBr.

tellurobismuthite (Te_3Bi_2) which occurs sporadically as small (0.05 mm) anhedral grains or as romb-shaped, euhedral crystals. In one instance bismuthinite (Bi_2S_3) has been observed as approximately 0.5 mm large grains showing well-developed cleavage. It has a distinct bireflectance, strong anisotropy and is bluish to brownish-grey in colour.

Magnetite is a very minor component in the ore. It usually occurs as 0.2–0.3 mm large anhedral grains sometimes having a poikilitic appearance with inclusions of pyrite, sphalerite and gangue minerals.

Supergene alteration minerals. The weathering of the ore has, in general, been very slight. However, limonite alteration was widespread in the surficial parts of the ore in the open pit. In polished sections from the uppermost parts of the orebody there is also covellite (CuS), chalcocite (Cu_2S) and tenorite (CuO). These minerals have been due to supergene alteration and occur mostly at grain boundaries in association with chalcopyrite which has become replaced. Where covellite occurs together with the other secondary minerals in the "intergranular veins", it often rims around the "host mineral".

Gangue minerals. The dominating gangue minerals in the Näsliden ore are calcite and dolomite except for the stratigraphically upper parts which frequently contain intercalations of carbonaceous phyllites composed mainly of quartz, feldspar and mica. The carbonates are dark grey due to finely disseminated carbonaceous material. There are, however, also larger crystals or crystal aggregates which are greyish white and free from carbon. These were probably formed from the recrystallization of pre-existing carbonates during the regional metamorphism. Particularly in the more strongly tectonized parts around the major fold-fault (Fig. 11), these processes generated up to 0.2 m large aggregates of dolomite.

Quartz, chlorite and muscovite occur as disseminated grains in the ore and also constitute the main components of the chlorite schist which occurs as "inclusions" in the stratigraphically lower parts of the ore.

FISSURE VEINS

In the mine there are fissure veins of several types. They were all formed relatively late in the geological evolution, probably from hydrothermal solutions generated during the regional metamorphism.

Quartz-calcite veins are the most common of the fissure veins and usually occur as less than 0.2 m broad tabular bodies oriented in the direction of the schistosity, but veins in other directions are not uncommon. Except for quartz and calcite, these veins occasionally also contain biotite, chlorite and pyrite. In one vein of this type along the footwall of the ore, greyish-white sepiolite was observed; it partially forms thread-like fibres but mostly occurs as compact porous masses.

One vein composed partly of fragments of the enclosing chlorite schist, contained more than 50 % sphalerite occurring as approximately 1 mm large subhedral crystals. As opposed to the sphalerite in the orebody, the sphalerite in this case did not exhibit any secondary twins, although etching with concentrated nitric acid revealed concentric growth textures indicating that the sphalerite formed in "open" space conditions.

On the 250 m level two *zeolite veins* were observed in the ore. They were 3–5 m long, 2–5 cm wide and oriented nearly perpendicular to the lamination in the orebody. Along the contacts existed a thin coating of blue talc. The major parts of the fissure veins were made up of thaumasite $Ca_3Si(OH)_6(H_2O)_{12}(SO_4)(CO_3)$, a zeolite that was identified by X-ray diffraction. It formed <1 mm large, acicular, white crystals that trended roughly perpendicular to the walls.

Two *"sulphosalt veins"* have also been recorded, both occurring at the contact between ore and the wall rocks. The minor one was observed in the strongly tectonized area around the fold-fault on the 150 m level. The other one is an irregular subhorizontal vein, about 10 m long, in the footwall at the 340 m level. The constituents in the two sulphosalt veins are the same although they vary in proportion. In the minor vein, sulphosalts and galena predominate completely, whereas in the larger vein, chalcopyrite is also a major component. The sulphosalts usually occur together with quartz, calcite and biotite.

Thirteen different ore minerals have thus been identified and, as they are often arranged zonally, it has been possible to establish their sequence of crystallization. The first mineral to crystallize was arsenopyrite, which forms relatively large, scattered, euhedral crystals sometimes showing growth structures parallel to the crystal faces. Chalcopyrite, like pyrrhotite, often forms larger homogeneous parts. These two minerals have crystallized approximately simultaneously as they both include aggregates of each other. The chalcopyrite is usually twinned, and beside lanceolate twins, there are also sets of finely lamellar polysynthetic twins. Cubanite occurs as exsolution lamellae cutting the twins in several directions.

After the chalcopyrite had formed, sphalerite started to crystallize. It normally occurs along the margins of chalcopyrite aggregates into which it also forms enbayments. The sphalerite also contains small exsolution blebs of chalcopyrite.

The sulphosalts tetrahedrite, bournonite and boulangerite plus meneghinite crystallized after sphalerite. Galena was formed along with all the sulphosalts, and chalcopyrite has been observed occurring with bournonite. Tetrahedrite sometimes occurs overgrown by the other sulphosalts and galena.

In the "sulphosalt veins" there are also small, probably late-stage interstitial grains of altaite (PbTe), tellurbismuth (Te_3Bi_2) and a silver-telluride. These minerals and the sulphosalts have been verified by microprobe analyses (Vesterberg 1973). The sequence of crystallization in the "sulphosalt veins" can thus be written: arsenopyrite → chalcopyrite + pyrrhotite → sphalerite → tetrahedrite + galena → bournonite + galena → boulangerite + meneghinite + galena → altaite + tellurbismuth + silver-telluride.

DISCUSSION OF ORE GENESIS

In the Skellefte district, the ore-genetic hypothesis of Gavelin (1939) was almost universally accepted until the 1960's. In short, his ideas imply that the formation of the palingenic Revsund granite "pushed" a front of hydrothermal solutions in advance of a "migmatite front" progressing towards the north. The "ore solutions" were supposed to have been enriched in iron, base metals and sulphur derived mainly from the sedimentary rocks undergoing migmatization and palingenesis. Particularly, the fine-grained, carbonaceous phyllites, which are relatively rich in the elements mentioned, were ascribed an important role as "feeders" to the hydrothermal solutions. Gavelin thought that the solutions then deposited metasomatical ores in suitable chemical environments at places where there occurred favourable PT conditions. Fold structures and tectonized areas were envisaged as particularly effective controls of ore deposition. Due to differences of rock competency, such structures developed especially along the contacts between the volcanics and the phyllite-carbonate rocks. Gavelin thus explained why many of the ores are located close to the boundary between the Maurliden volcanics and the Elvaberg phyllites.

New opinions regarding the genesis of the ores of the Skellefte district have been recently asserted. These hypotheses, which relate the ore formation to volcanism, are not new as such but have not been applied to the district before. They maintain that the volcanics and the sulphide material had a common source, the metals having been concentrated in a hydrothermal phase formed at the end of a volcanic cycle or during a break in the volcanic activity. The Näsliden case is an instance of such ores associated with calc-alkaline, acid or intermediate submarine pyroclastic rocks. An exhalative-sedimentary or volcanic hydrothermal mode of deposition is suggested. The ores have consequently been formed at or near the bottom of a sea. The depositional process has been direct ore sedimentation or the metasomatic replacement of still unconsolidated pyroclastics or sediments.

Ores of the above-mentioned type occur as massive, lens-shaped bodies having their long axes parallel to the bedding of the surrounding rocks. Such ores have been described from many parts of the world, e.g. the Noranda-Matagami area in Canada, Broken Hills in Australia, and the Kuroko district of Japan.

Similar to Näsliden, most of the ores of the Skellefte district are located in the uppermost parts of the Maurliden metavolcanics or in sedimentary rocks immediately above these volcanics. Occasionally, however, orebodies formed lower down in the volcanic pile (e.g. Kristineberg). No orebodies have been found in the Elvaberg metasediments. As mentioned above, this localization was interpreted by Gavelin (1939) to have been tectonically controlled. On the other hand, ores formed in connection with submarine volcanism most often occur in acid volcanics near the top of a volcanic pile, or in similar volcanics at the top of an individual cyclic sequence in multicyclic volcanic accumulations (Sangster 1972).

At Näsliden, the metavolcanics comprising the footwall are strongly altered to sericite- and/or chlorite-quartzites or schists. Under the orebody, this extreme alteration has a width of 20 to 30 m, the altered rocks then successively grading into less altered dacitic tuffs. In contrast, the carbonaceous phyllites and calcareous metasediments of the hanging wall show no or only minor alteration even very close to the orebody. If the ore had been deposited epigenetically, the almost unaltered state of the hanging wall rocks appears surprising. This writer therefore suggests that the alteration took place in connection with a fumarolic or solfataric activity, which also generated the ore. The alteration may have been caused by the subsurface convection of sea water mixed with solutions of magmatic origin.

Due to the intensive isoclinal folding in the Näsliden mine, the original configuration of the altered rocks is somewhat obscure. The information presently available suggests that the alteration zone extends almost parallel to the ore and to the boundary between the volcanic and the sedimentary rocks. Most of the alteration zone is dominated by sericite although chlorite schists occur next to the orebody and as a narrow, pyritiferous zone in the middle part of the alteration area. This chloritic zone, which has hitherto been traced for only approximately 100 m below the orebody, possibly represents the central parts of an alteration pipe.

In the altered footwall of the ore, sulphides, mostly pyrite, form veins and irregular impregnation reminiscent of the "stringer ores" that are found in many volcanogenic massive sulphide deposits.

Gavelin (1939) maintained that the grade of metamorphism in the Skellefte district increases towards the Revsund granite. Biotite, which was employed as an index mineral, is said to be regionally replaced by chlorite, this replacement defining an isograd delimiting a low-grade region in the north.

One of Gavelin's main arguments for the hypothesis of ore deposition from solutions generated in connection with the formation of the Revsund granite was the alleged virtual absence of biotite from altered rocks associated with the ores, whilst other country rocks were said to contain this mineral. Because Gavelin regarded the development of biotite as being related to the formation of the Revsund granite, it was indicated that the scarcity of biotite in the strongly altered rocks was due to its destruction by the ore-bearing solutions advancing after the peak of metamorphism.

At Näsliden, all the various country rocks contain biotite which normally forms sub- or anhedral, porphyroblastic grains. Biotite is most abundant in carbonaceous phyllite. It is more abundant in the felsitic tuff than in the porphyry, thus reflecting the higher content of ferrous (and total) iron in the felsitic tuff. In the strongly altered rocks, biotite is less common than in the other country rocks; it is particularly sparse in the sericite-rich types. In these rocks, the biotite also shows the lowest degree of idiomorphism.

The reason for the insignificant development of biotite in the sericite-quartzites may be the low iron and magnesium contents of that rock. On the other hand, in the more chloritic alteration rocks the chemical requirements for the formation of biotite appear to have been fullfilled. However, magnesian chlorites are stable under higher metamorphic conditions than chlorites of low Mg/Mg+Fe ratios, which may explain the scarcity of biotite in the alteration zone.

Primary ore features. Macro-banding is a conspicuous feature of the Näsliden ore. In the stratigraphically upper parts of the ore, intercalations of calcareous and carbonaceous phyllites are common. In the lower parts, the gangue is mainly composed of carbonate. The banding is here expressed by variations in the amount of sulphides and/or different proportions of the sulphide minerals. The macro-banding, which is sometimes clearly visible in hand specimen, is interpreted as a primary structural feature. In the opinion of this writer, the banding of sulphides in an almost monomineralic "matrix" is incompatible with an epigenetic-metasomatic mode of ore formation as there appear to exist no distinctive chemical or physical differences to cause a selective replacement of the wall rock that could have led to the extensive fine lamination occurring in the ore. It is proposed instead that the cause of the banding was rhythmical chemical precipitation of materials derived from seawater (mainly carbonates) and from repeated volcanic exhalations. The precipitation of carbonate from the sea could have been facilitated by submarine volcanic activity heating the water.

The Näsliden deposit also shows a stratigraphic compositional zonation, copper being concentrated in the lower and lead and zinc in the upper parts of the ore. This is a feature commonly found in Kuroko-type deposits and in many volcanogenic Precambrian ores.

Relic colloform textures, such as reniform, botryoidal and mammilary pyrite, have been observed in Näsliden ore specimens etched with concentrated nitric acid. These textures suggest that the sulphides were at least partly precipitated in open space from a gel or a supersaturated solution. The concentric colloform textures, sometimes found in combination with radially arranged columnar crystals, are the best examples of primary textures in the ore. There are also small spherical aggregates of pyrite crystals, which may be interpreted as recrystallized framboids. However, the origin of the pyrite aggregates and the framboids is dubious. Nevertheless, they occur in close connection with other colloform textures and may possibly represent a primary feature.

The colloform textures at Näsliden have been found in the stratigraphically upper parts of the ore where the sulphides occur in carbonaceous phyllites. In the Kuroko deposits of Japan, colloform textures preferentially occur in the "black ore" characterized by high zinc and lead contents. In the Precambrian, relic colloform pyrite occurs especially in ores rich in graphite which may have inhibited recrystallization.

Secondary ore features. The banding in the Näsliden orebody shows many signs of deformation. There are numerous small-scale pinch and swell structures in the thin bands of the ore. Dynamometamorphism has also caused boudinage which sometimes occurs in combination with a rotation of more competent intercalations. Tight folding of the macro-banding has also been observed. In the major fold characterizing the southern part of the orebody, the banding has been almost completely destroyed by intense folding and subsequent fold-faulting.

Etched specimens show that the pyrite is largely developed as a grain micromosaic. Rickard and Zweifel (1975) investigated pyrite micromosaics from some ores in the Skellefte district, among them the Näsliden deposit. They measured the triple junction angles which yielded an approximately normal unimodal distribution with a mean angle of 119.8° and a modal value of 129°. The ideal angle between pyrite grains recrystallized to form such a micromosaic is 120°. The kurtosis (K_s) of the curve was found to be slightly platycurtic (K_s=2.85), the distribution being slightly right-skewed (S_k=+0.06). "Closer inspection of the Näsliden micromosaic shows that the weak schistosity of the pyrite developed by the merging of grain boundaries of pairs of apparently similar-size pyrite crystals normal to the strike of the schistosity. That is, that the Näsliden pyrite was first annealed and then deformed. This is further borne out by the mean triple junction angle for the Näsliden micromosaic, which is very near the equilibrium 120°"(Rickard and Zweifel 1975, p. 268).

The relic colloform textures also show evidence of deformation and strong recrystallization. Minor displacements in the colloform pyrite aggregates are indicated by broken concentric layers. Along the new grain margins developed by displacement, the concentric layers have sometimes been completely destroyed by recrystallization. Some colloform pyrite aggregates have subconcentric scalloped layers in their central parts. Towards the margins, however, these layers change into planar crystallographic surfaces formed by stronger marginal recrystallization. There are also euhedral or subhedral pyrite crystals in a matrix of other sulphides. They are interpreted as porphyroblasts.

The development of subgrains in pyrrhotite is another indication of deformation in the orebody. The formation of subgrains may have been triggered by the bending of the pyrrhotite lattices. As deformation continued, the lattice was disrupted by the formation of dislocations. The annealing of deformed lattices is an alternative explanation of subgrain formation.

The Näsliden sphalerite is almost invariably twinned. Most of the twins appear to be annealing twins, but there are also numerous instances of deformation twinning. The latter twins are often bent and commonly tail off in an irregular manner.

GEOCHEMISTRY OF THE COUNTRY ROCKS

The chemical analyses presented in Tables 4–8 were made on samples from two horizontal boreholes (32G and 39G) drilled from the shaft on the 153 and 353 m levels, and one borehole (30) drilled from the surface (cf. Figs. 11–13). Each sample normally represents 5 m of the core from which 10 cm per metre was collected for chemical analysis.

The iron content was analyzed as total Fe and as Fe^{2+} soluble in HF + H_2SO_4 ($Fe^{3+}=Fe_{tot}-Fe^{2+}$). For the "unaltered" volcanics low in sulphur, Fe^{2+} and Fe^{3+} were recalculated to FeO and Fe_2O_3 respectively. In the strongly altered rocks, Fe_{sulph} represents iron in pyrite, the dominating sulphide in these rocks. The excess iron was recalculated to FeO. In the sedimentary rocks Fe_{sulph} represents iron in pyrrhotite. The strongly altered rocks are often particularly rich in sulphur, some of which escaped as SO_2 during ignition. Consequently, there was a double determination of sulphur resulting in a too high loss on ignition, and a sum of components exceeding the sum normally obtained for samples low in sulphur.

Plots of the commonly altered metavolcanics in AFM diagrams (Fig. 29) demonstrate calc-alkaline compositions (cf. Fig. 9). The various rock types, however, cluster within fairly distinct areas with the porphyry concentrated towards the alkali corner as compared to the other rocks. The felsite has lower MgO contents than the dacitic tuff, which is probably partly due to chloritization of the latter rock.

The mean SiO_2 values for felsitic tuff (72.7 %) and porphyry (75.3 %, Table 9) and their normative feldspar compositions ($Or_{28}Ab_{48}An_{24}$ and $Or_{32}Ab_{44}An_{24}$), classify these rocks as rhyodacites. However, it should be noted that the sericite alteration and calcite content of especially the porphyry have affected the normative feldspar composition. The partly altered tuff below the porphyry contains on an average 63.7 % SiO_2, and its dacitic character (labradorite-trachyandesite; Rittmann 1952) is also reflected in the normative feldspar composition $Or_{21}Ab_{47}An_{32}$. Observations in the mine and under the microscope reveal that the agglomerate overlying this tuff has a matrix which is practically identical to the tuff. The higher SiO_2 content (68.9 %) of the agglomerate is mainly caused by its felsitic rock fragments.

Mean values of main and trace elements for the porphyry and felsitic tuff show a practically identical composition of the two rock types (Table 9). The

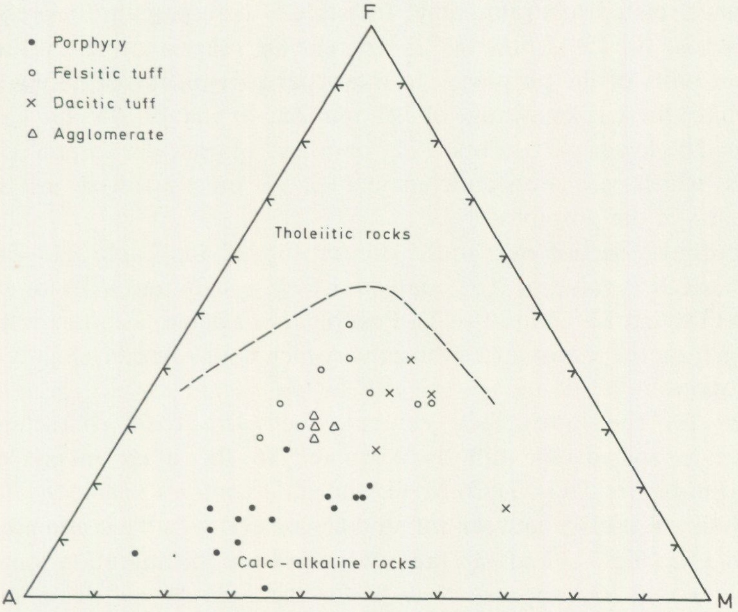

Fig. 29. AFM plots of metavolcanics from the Näsliden mine.

only difference of major significance is the higher Fe^{2+} (and total Fe) content in the felsite. It is expressed mineralogically by a greater abundance of biotite.

Compared to the felsite, the porphyry is more strongly altered to sericite and chlorite, which is reflected in *k* and *mg* values of 0.43 and 0.68 for the porphyry, and 0.34 and 0.45 for the felsite (Table 9). The strongly positive Niggli *t* values for the metavolcanics from Näsliden reflect their altered state. In the felsitic tuff, which is altered least, the strongly positive *t* is also a criterion for mixing with sedimentary material (cf. p. 28). The average Niggli values for the metavolcanics and strongly altered rocks are presented in Table 9.

Borehole 32G traverses a felsitic tuff obliquely to the bedding (Fig. 11). Eight chemical analyses with corresponding Niggli values, taken from the middle and upper parts towards the base of the felsite, are shown in Table 6:25–32. The *T* and *t* values increase markedly towards the base of the felsite. This is partly due to the incorporation of material from the underlying phyllite during the extrusion of the felsite (cf. p. 28). Another reason is a slight increase in chloritization and sericitization towards the lowermost parts of the felsite. These alterations are also reflected in increasing MgO, *mg* and *k,* and decreasing Na_2O and *alk*/*al* (breakdown of plagioclase).

Because of the folding in the mine area (Fig. 12), the porphyry was intersected three times on the 360 m level by bh 39G. Enrichment of Zn, Pb, Cu, and As in the upper part of the porphyry is the only geochemical pattern of significance related to stratigraphy. In Table 5 these parts are represented by analyses nos. 10, 15–17 and 18–21, whereas the other analyses correspond to the lower parts of the porphyry. In the upper parts of the porphyry (towards the phyllite) there is an average of 295 ppm Zn, 40 ppm Pb, 75 ppm Cu, and 19 ppm As. The lower parts contain 115 ppm Zn, 13 ppm Pb, 29 ppm Cu, and 7 ppm As, which means an enrichment of 2.5–3 times of these metals in the upper parts of the porphyry.

The porphyry section next to the ore (cf. Fig. 12 and Table 5:18–24) has an average Niggli k value of 0.51 compared to $k = 0.36$ and 0.39 for the other sections (Table 5:12–17 and 10–11). Possibly this is due to a certain influence of solutions from the major alteration zone, which have caused a slightly stronger sericitization.

Except for the lower SiO_2 content, the more basic character of the agglomerate and dacitic tuff as compared to the other metavolcanics is reflected in higher TiO_2, FeO, MgO, and CaO contents (Table 9). The same relationships also exist between tuff and agglomerate. In the sections cut by bh 32G and 39G (Figs. 11 and 12), the tuff is closest to the alteration zone, and its *alk/al* ratio is 0.36 compared to 0.49 for the agglomerate. This suggests a slightly stronger alteration of plagioclase in the tuff (Table 4).

Among the trace elements, the concentrations of Cu, As and Sb are somewhat higher in the dacitic tuff and agglomerate than in the more acid metavolcanics (Table 9). This may be due to the proximity of the alteration zone. On the other hand, the content of Zn and Pb is lower in the dacitic tuff, although it is nearest to the strongly altered rocks in the sampled boreholes (Figs. 11 and 12).

According to the present interpretation of the structural geology of the Näsliden mine, the dacitic tuff and agglomerate constitute the original rocks of the alteration zone below the ore (Figs. 11–13). The described chemical changes caused by alteration processes must be regarded as approximate owing to uncertainties regarding the exact chemical composition of the original rocks and their change of volume. However, some general trends can be established fairly well when comparing relatively unaltered dacitic tuff and agglomerate to strongly altered rocks. The average chemical composition of the two rock complexes can be estimated from Table 9, which also includes analyses from the alteration zone some 120 m from the orebody. The most obvious changes characterizing the alteration zone are depletion in Na_2O and CaO, and addition of Fe_{tot}, MgO, and S. Apart from these changes, sulphurization is accompanied by the addition of Zn, Pb, Cu, As, Sb, Bi, and Ag. Combined with the higher *t, k, mg,* and *qz* and lower *c* and *alk/al* Niggli values (cf. Table 9) in the alteration zone, these changes demonstrate the addition of pyrite and various other sulphides together with the chloritization and breakdown of plagioclase by sericitization during the alteration process.

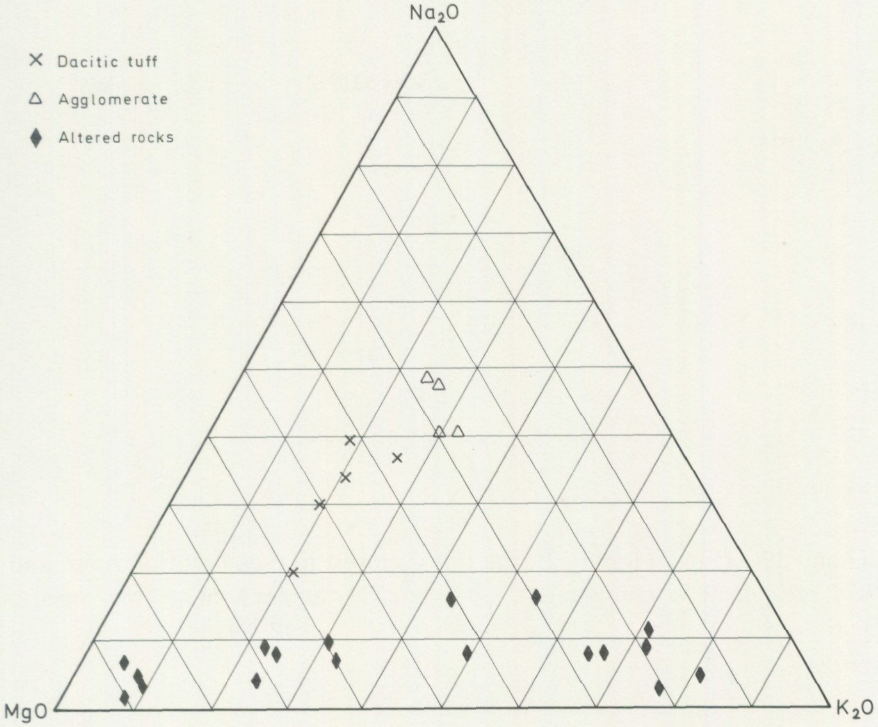

Fig. 30. Diagram illustrating metasomatic alteration and differentiation of metavolcanic rocks.

Some of the chemical changes mentioned above are plotted in Figs. 30 and 31. These figures also show the metasomatic differentiation of the metavolcanics into rocks relatively rich in potassium (sericite) or magnesium (chlorite). The differentiation furthermore implies depletion of SiO_2 (Fig. 32) and addition of Al_2O_3, MnO and TiO_2 (cf. Tables 4 and 7) in the chloritic rocks compared to the dacitic tuff and agglomerate. Among the sericite quartzites the corresponding chemical relations to the unaltered volcanics are the opposite (cf. Tables 4 and 7). However, as is clear from Figs. 30–32, there are gradual transitions from sericite quartzite via sericite-chlorite quartzite to chlorite schist poor in quartz.

The partly quartz poor character of the chloritic (Mg-rich) rocks is reflected in the low *qz* values, one of which is even negative. These rocks are also low in *k, alk* and *mg* compared to the more sericitic rocks, whose surprisingly high *mg* depends on a very low FeO content.

Concerning the distribution of trace elements within the alteration zone, the mean contents of Zn, Pb, As, Sb, and Ag are highest in the sericite quartzite. On the other hand there is greater affinity of Cu and Bi for the chlorite schist.

Due to the finely laminated character of the metasediments and

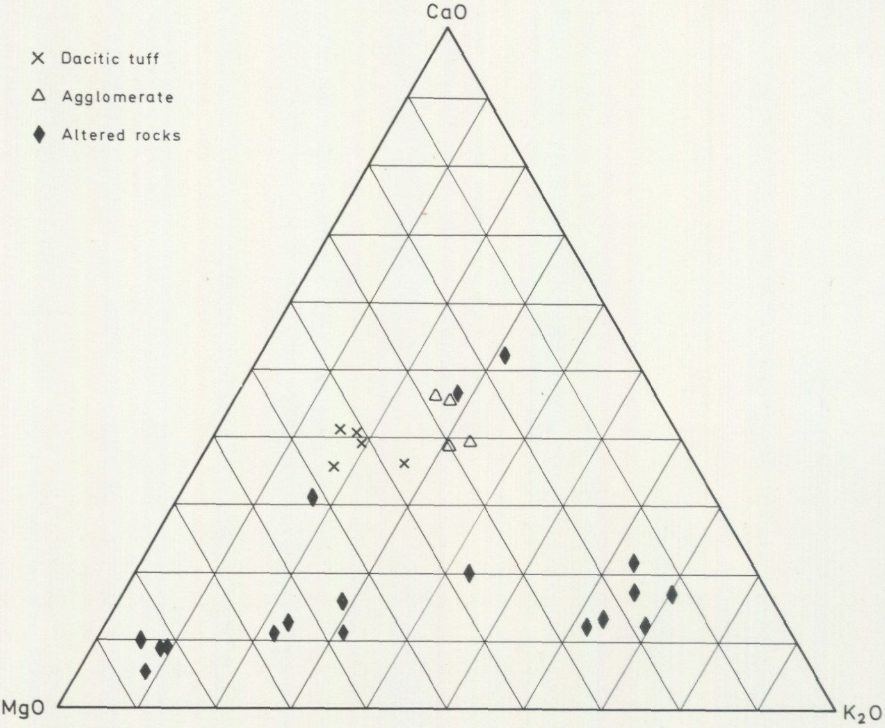

Fig. 31. Diagram illustrating metasomatic alteration and differentiation of metavolcanic rocks.

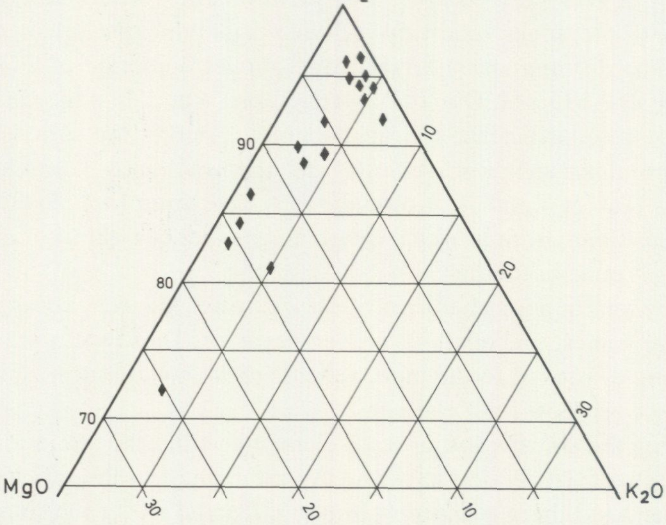

Fig. 32. Diagram illustrating differentiation among strongly altered rocks.

compositional variation between the laminae, chemical trends and possible alterations in relation to the ore are on the whole not possible to detect. However, similar to the altered rocks below the ore, the metasediments immediately above the ore are enriched in sulphur and the chalcophile elements Zn, Pb, Cu, As, and Sb. There is also a depletion of Na in the metasediments within a few metres above the ore. These conditions indicate that fumarolic activity probably occurred later than the formation of what is today regarded as ore.

CONCLUDING STATEMENT

STRATIGRAPHIC CONCLUSIONS

There have been two important schools of thought on the stratigraphy of the Skellefte district. Gavelin (1955) envisaged the sequence as follows: Skellefte supracrustals including Elvaberg sediments (oldest) – Jörn-Arvidsjaur granites – Revsund granite plus folding and metamorphism – Vargfors conglomerates (youngest). The model of Kautsky (1957) differs by the relative chronological arrangement of the supracrustals and plutonics. From oldest to youngest, Kautsky's succession is: Maurliden "series" – Jörn-Arvidsjaur granites and folding – Mensträsk/Abborrtjärn conglomerates and Elvaberg "series" – Revsund granite. The stratigraphy of the Skellefte district was summarized by Lundberg (1980).

From information available in the Näsliden area and the central parts of the Skellefte district, the present writer concludes that towards the end of its period of formation, the Maurliden "series" was uplifted, weathered and partly eroded. The Mensträsk conglomerate (breccia) was formed in the process. However, in the Näsliden area, this conglomerate is found neither in outcrop nor in the shape of boulders in till. It therefore appears that the Mensträsk conglomerate does not form a regional lithological unit (cf. Helfrich 1971, p. 93) but is restricted to local occurrences. In the Näsliden area, the contact between the Maurliden and Elvaberg series is only exposed in the mine where there is no intervening angular unconformity as proposed by Kautsky (1957). It is therefore suggested that there is no major age difference between the Mensträsk conglomerate and Elvaberg phyllites, the lithologically different semi-coeval rocks being the result of different erosional and sedimentary environments.

In an island arc environment, the Mensträsk conglomerate was formed at places where the rocks were elevated above sea level. At the same time greywackes and other sediments were deposited subaquatically between the islands and in deeper water. The Abborrtjärn conglomerate was formed close to a basement block in the north, and was deposited unconformably onto the folded rocks mentioned above.

As to the Jörn granite, it is regarded as approximately coeval with the Maurliden metavolcanics, whereas the Revsund granite is a younger palingenic granite migmatizing the supracrustal rocks.

The geologic evolution of the Näsliden area can thus be described as follows.

1. Calc-alkaline Maurliden volcanics, which are probably mainly of pyroclastic origin, were extruded onto an unknown basement.
2. Carbonaceous phyllites were deposited during episodes of relative volcanic quiescence.
3. Towards the close of the volcanic period, greywackes, psammites, carbonaceous phyllites and calcareous rocks were formed, the latter comprising particularly the lower parts of the sedimentary pile.
4. At Näsliden, "exhalative sedimentary" ores were deposited close to the boundary between the volcanic and sedimentary rocks.
5. The supracrustal rocks were then folded around subhorizontal axes.
6. In connection with the formation of the Revsund granite there followed a later phase of folding around steeply dipping axes.
7. Gabbroic rocks were intruded at a late stage.

ORE-GENETIC CONCLUSIONS

Rickard and Zweifel (1975) asserted the opinion that the genesis of the ores of the Skellefte district is directly related to the volcanic activity in the area. Similar ore-genetic hypotheses have earlier been applied to e.g. the Kuroko ores of Japan and to ores from the Noranda-Matagami area in Canada. These hypotheses maintain that metals are concentrated during a hydrothermal phase at the end of a volcanic cycle or during a break in the volcanic activity. Furthermore, as is the case in Näsliden, the ores thus formed are normally associated with calc-alkaline, acid or intermediate, submarine pyroclastic volcanism.

An exhalative sedimentary or volcanic hydrothermal mode of deposition is suggested for the Näsliden ore, which was formed during a waning stage of the volcanism. The footwall metavolcanics are partly strongly altered to sericite and chlorite. In this alteration zone, sulphides occur as veins and irregular disseminations reminiscent of the "stringer ores" that are found in many volcanogenic massive sulphide deposits. The alteration can have been caused by the subsurface convection of sea water mixed with solutions of magmatic origin.

It is proposed that the conspicuous banding of the Näsliden ore was caused by rythmical chemical precipitation of materials derived from repeated volcanic exhalations. The carbonate-rich matrix of the ore may largely have originated from the precipitation of carbonate from seawater in this connection. The precipitation was facilitated by submarine volcanic activity heating the water.

The Näsliden deposit also shows a stratigraphic compositional zoning with lead and zinc concentrated in the upper and copper in the lower parts of the ore. On the 153 m level a repeated zoning of lead and zinc occurs.

A variety of relic colloform textures, such as reniform, botryoidal, mammilary, and possibly also framboidal pyrite, have been observed in Näsliden ore specimens etched with concentrated nitric acid. These textures suggest that the sulphides were at least partly precipitated in open spaces from a gel or a supersaturated solution. The colloform textures have been found in the stratigraphically upper parts of the ore. The Kuroko deposits of Japan are also characterized by compositional zoning with colloform textures preferentially occurring in the upper "black ore" containing high lead and zinc proportions.

Dynamometamorphism of the Näsliden ore has occasionally caused tight folding of the banding. Development of pinch and swell structures, boudinage and a fold-fault also occurred during this phase.

Rickard and Zweifel (1975) investigated pyrite micromosaics from the Näsliden deposit and concluded that the pyrite was first annealed and then deformed. The sphalerite is almost invariably twinned with most of the twins appearing to be due to annealing, although there are also numerous deformation twins. The development of subgrains in pyrrhotite is another indication of deformation of the orebody. The relic colloform pyrite textures also show evidence of deformation and varying degrees of recrystallization.

In summary, Näsliden has many characteristics found in other Precambrian volcanogenic ores and in the Miocene Kuroko deposits. All these ores are associated with calc-alkaline volcanics, particularly acid or intermediate coarse pyroclastic rocks, and they are mostly underlain by zones of strong alteration. In the vicinity of the massive ore, the alteration zones contain a stringer-type mineralization that sometimes reaches ore grade. The massive ores are banded and roughly conformable with the surrounding rocks. They also show compositional zoning with copper concentrated at the footwall, and zinc and lead towards the hanging wall.

ACKNOWLEDGEMENTS

The author would like to acknowledge Dr. Hans Zweifel, chief of the Prospecting department of Boliden Mineral AB, for initiating this investigation and for his encouraging discussions. The author also wants to convey his thanks to Professor Roland Gorbatschev at the Department of Mineralogy and Petrology in Lund, for his valuable suggestions during the accomplishment of the work. The mine geologist Christian Trepka-Bloch presented constructive criticism and has been very helpful. The English text was corrected by Dr. John Smellie, Geological Survey of Sweden, who also read the manuscript critically. The drawings were prepared by Barbro Lindström. Finally, the author wishes to express his gratitude to the management of Boliden Mineral AB for various contributions and for the permission to publish this paper.

REFERENCES

ANGER, G., 1971: Microfabrics in geosynclinal sulphide deposits. – Clausthaler Hefte zur Lagerstättenkunde und Geochemie der Mineralischen Rohstoffe, 10.

BASTIN, E.S., 1950: Interpretation of ore textures. – Geol. Soc. America Mem. 45.

BERGLUND, S., 1979: A textural study of the mobility of some common sulfides. – UUDMP Research report no. 14.

BERGLUND, S., and EKSTRÖM, T.K., 1978: Arsenopyrite and sphalerite as T and P indicators in sulfide ores from northern Sweden. – UUDMP Research report no. 13.

BERNER, H., EKSTRÖM, T., LILLJEQUIST, R., STEPHANSSON, O., and WIKSTRÖM, A., 1971a: Data storage and processing in geological mapping. I. Field data sheet. – Geol. Fören. Stockh. Förh. 93, 85–101. Stockholm.

– 1971b: Data storage and processing in geological mapping. II. Data file. – Geol. Fören. Stockh. Förh. 93, 693–705. Stockholm.

– 1972: Geomap – A data system for geological mapping. – Int. Geol. Congr. Montreal 1972, 3–11.

BERNER, R.A., 1969: The synthesis of framboidal pyrite. – Econ. Geol. 64, 383–384.

BURRI, C., 1959: Petrochemische Berechnungsmethoden auf äquivalenter Grundlage. – Birkhäuser Verl., Basel-Stuttgart.

CARPENTER, C.H., and FISHER, M.S., 1930: A study of crystal structures of native copper. – Trans. Inst. Mining Met. 39, 238–284.

EDELMAN, N., 1967: Stratigraphy and metamorphism in the Kristineberg area, northern Sweden. – Sver. Geol. Unders., C 622.

EDWARDS, A.B., 1954: Textures of the ore minerals and their significance. – Aust. Inst. Mining Met., Melbourne.

EKLUND, J., 1923: Skelleftefältets geologi. – Geol. Fören. Stockh. Förh. 45, 219–223. Stockholm.

FISCHER, R.V., 1966: Rocks composed of volcanic fragments and their classification. – Earth. Sci. Rev. 1, 287–298.

FISKE, R.S., 1936: Subaqueous pyroclastic flows in the Ohanapecosh formation, Washington. – Geol. Soc. America Bull. 74, 391–406.

GAVELIN, S., 1939: Geology and ores of the Malånäs district, Västerbotten, Sweden. – Sver. Geol. Unders. C 424.

– 1955: Beskrivning till berggrundskarta över Västerbottens län. Urbergsområdet inom Västerbottens län. – Sver. Geol. Unders. Ca 37.

GRIP, E., 1941: Die Tektonik und Stratigraphie der zentralen und östlichen Teile des Skelleftefeldes. – Bull. Geol. Inst. Univ. Ups. XXX, 67–90.

GRIP, E., and WIRSTAM, Å., 1952: Näslidenmalmerna. – Unpublished report. Boliden Company.

HELFRICH, H.K., 1971: Stratigraphie, Tektonik, Petrochemie und Montangeologische Zeuge am Nordrand der zentralen "Norrlandgeosynklinale". – Sver. Geol. Unders. C 654.

HÖGBOM, A., 1928: On the relations between syntectonic granites and ore-formation in Sweden. – Fennia 50, No. 21.

– 1931: Nya iakttagelser inom Norr- och Västerbottens urberg. – Geol. Fören. Stockh. Förh. 53, 415–438. Stockholm.

– 1937: Skelleftefältet med angränsande delar av Västerbottens och Norrbottens län. – Sver. Geol. Unders. C 389.

Högbom, A.G., 1899: Skellefteåfältets geologi och bergarter. – Geol. Fören. Stockh. Förh. 21, 636–638. Stockholm.

Iijima, A., 1974: Clay and zeolitic alteration zones surrounding Kuroko deposits in Hokuroko district, northern Akita, as submarine hydrothermal-diagenetic alteration products. – Soc. Mining Geol. Japan, Spec. Issue 6, 267–289.

Irvine, T.N., and Baragar, W.R.A., 1971: A guide to the chemical classification of the common volcanic rocks. – Can. J. Earth Sci. 8, 523–548.

Kautsky, G., 1957: Ein Beitrag zur Stratigraphie und dem Bau des Skelleftefeldes, Nordschweden. – Sver. Geol. Unders. C 543.

Lawrence, L.J., 1973: Polymetamorphism of sulphide ores of Broken Hills, N.S.W., Australia. – Mineral. Deposita 8, 211–236.

Love, L.G., 1962: Biogenic primary sulphide of the Permian Kupferschiefer and Marl Slate. – Econ. Geol. 57, 350–366.

Lundberg, B., 1980: Aspects of the geology of the Skellefte field, northern Sweden. – Geol. Fören. Stockh. Förh. 102, 156–166. Stockholm.

Malmqvist, D., 1956: Sammanställning av prospekteringsresultat från Näsliden. – Unpublished report, Boliden Company.

Markham, N.L., 1962: Some genetic aspects of the Mt. Lyell mineralisation. – Mineral. Depoita 3, 199–221.

Mason, B., 1966: Principles of geochemistry. – John Wiley & Sons Inc., New York.

Mukaiyama, H., Mononobe, S., and Yoshida, T., 1974: Genesis of the ore deposits of the Iwami mine, Shimane prefecture, Japan. – Soc. Mining Geol. Japan, Spec. Issue 6, 221–234.

Park, C.F. Jr., and Mac Diarmid, R.A., 1970: Ore Deposits. – San Francisco.

Ramdohr, P., 1969: The ore minerals and their intergrowths. – Pergamon Press.

Richards, S.M., 1965: Mineragraphy of fault-zone sulphides, Broken Hill, N.S.W.– Australia Commonwealth Sci. Ind. Res. Organ., Mineragraphic Invest. Paper 5, 1–24.

Rickard, D.T., and Zweifel, H., 1975: Genesis of Precambrian sulphide ores, Skellefte district, Sweden. – Econ. Geol. 70, 255–274.

Rittmann, A., 1952: Nomenclature of volcanic rocks. – Bull. Volcanol. 12, 75–102.

– 1960: Vulkane und ihre Tätigkeit. 2. Aufl. – Ferdinand Enke Verlag, Stuttgart.

Roscoe, W.E., 1971: Geology of the Caribou deposit, Bathurst, New Brunswick. – Can. J. Earth Sci. 8, 1125–1136.

Rouhunkoski, P., 1968: On the geology and geochemistry of the Vihanti zink ore deposit, Finland. – Bull. Comm. Geol. Finl. 236.

Sangster, D.F., 1972: Precambrian volcanogenic massive sulphide deposits in Canada: A review. – Geol. Surv. Can., Paper 72–22.

Stanton, R.L., 1957: Studies of polished surfaces of pyrite, and some implications. – Can. Mineralogist 6, 87–118.

– 1959: Mineralogical features and possible mode of emplacement of the Brunswick Mining and Smelting orebodies, Gloucester County, N.B. Symposium on the genesis of massive sulfide deposits. – Trans. Can. Inst. Min. Metall. 62, 339–351.

– 1964: Mineral interfaces in stratiform ores. – Trans. Inst. Mining Met. 74. (2), 45–79.

– 1972: Ore petrology. – Mc Graw-Hill, New York.

Tuttle, O.F., and Bowen, N., 1958: Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$ – $KAlSi_3O_8$ – SiO_2 – H_2O. – Geol. Soc. America Mem. 74.

UTADA, M., MINATO, H., ISHIKAWA, T., and YOSHIZAKI, Y., 1974: The alteration zones surrounding Kuroko-type deposits in Nishi-Aizu district, Fukushima Prefecture, with emphasis on the analcime zone as an indication in exploration for ore deposits. – Soc. Mining Geol. Japan, Spec. Issue 6, 291–302.

UYTENBOGAARDT, W., and BURKE, E.A.J., 1971: Tables for microscopic identification of ore minerals. – Elsevier Publishing Company, Amsterdam.

VESTERBERG, K., 1973: Antimonsulfomineral från några sulfidmalmer i Skelleftefältet. – Unpublished Report. Boliden Company.

WATANABE, M., 1974: On the textures of ores from the Daikoku ore deposit, Ainai mine, Akita prefecture, northeast Japan, and their implications in ore genesis. – Soc. Mining Geol. Japan, Spec. Issue 6, 337–348.

WELIN, E., 1979: Tabulation of recalculated radiometric ages published 1960–1979 for rocks and minerals in Sweden. – Geol. Fören. Stockh. Förh. 101, 309–320. Stockholm.

WICKMAN, F.E., BLOMQVIST, N.G., GEIJER, P., PARWEL, A., VON UBISCH, H., and WELIN, E., 1962: Isotopic constitution of ore lead in Sweden. – Ark. Mineralogi Geologi 3, 193–257.

TABLE 1. Chemical analyses (wt %) and Niggli values of rocks from the Näsliden area. Nomenclature according to Rittmann (1952).

	A	B	C	D	E	F
SiO_2	69.0	70.5	71.0	75.2	74.6	71.2
TiO_2	0.4	0.35	0.35	0.1	0.3	0.3
Al_2O_3	13.8	14.0	13.2	13.0	12.8	13.1
Fe_2O_3	0.54	0.36	0.49	0.3	0.64	0.79
FeO	2.68	3.09	2.91	0.9	2.64	3.60
MnO	0.05	0.06	0.06	0.03	0.05	0.09
MgO	1.6	1.8	1.6	0.5	1.4	1.7
CaO	2.3	1.8	2.1	1.25	1.1	2.0
Na_2O	1.3	1.1	2.0	2.7	1.2	2.0
K_2O	1.9	1.2	1.1	4.8	2.6	1.7
S	–	–	0.1	–	–	–
LOI	3.4	3.1	2.8	1.2	1.6	1.5
Sum	97.0	98.2	97.7	100.0	98.9	98.0
si	381	383	400	458	458	373
qz	+226	+226	+241	+219	+288	+209
al	46	45	44	47	46	40
fm	28	31	29	11	29	33
c	14	10	13	8	7	11
alk	14	14	15	35	17	16
mg	0.47	0.47	0.47	0.42	0.43	0.40
k	0.49	0.29	0.26	0.53	0.58	0.35
ti	1.7	1.4	1.5	0.5	1.4	1.2
w	0.14	0.10	0.14	0.23	0.17	0.16
T	+ 31	+ 31	+ 29	+ 12	+ 29	+ 25
t	+ 18	+ 20	+ 16	+ 4	+ 22	+ 13

A. Porphyry with quartz phenocrysts. Loc. 39, 40 (Labradorite – rhyodacite).
B. Porphyry with quartz and feldspar phenocrysts. Loc. 45, 48. (Light labradorite – dacite).
C. Porphyry with quartz and feldspar phenocrysts. Loc. 49, 50. (Light labradorite – dacite).
D. Porphyry with large quartz and feldspar phenocrysts. Loc. 186. (Quartz – latite).
E. Porphyry with small quartz phenocrysts. Loc. 106, 112, 115, 118, 119, 120 (Quartz – latite).
F. Porphyry with small quartz and feldspar phenocrysts. Loc. 103, 104, 113, 122. (Labradorite – rhyodacite).

TABLE 1 continued.

	G	H	I	K	L	M
SiO_2	78.3	72.2	70.0	70.7	76.6	72.8
TiO_2	0.25	0.45	0.4	0.35	0.25	0.3
Al_2O_3	12.1	11.7	14.4	12.7	12.5	12.7
Fe_2O_3	0.24	0.66	0.80	0.77	0.26	0.30
FeO	0.88	5.33	2.24	4.32	2.02	3.27
MnO	0.03	0.15	0.04	0.07	0.02	0.07
MgO	0.15	1.1	0.9	1.5	0.56	1.0
CaO	0.7	1.1	1.6	1.4	0.9	2.1
Na_2O	2.2	2.9	1.5	0.36	2.5	1.7
K_2O	2.4	1.2	2.6	2.7	2.6	2.6
S	0.3	0.1	0.1	–	0.1	–
LOI	0.16	1.3	2.4	1.9	0.8	1.1
Sum	97.7	98.2	97.0	96.8	99.1	97.9
si	647	397	413	403	511	414
qz	+425	+218	+239	+256	+302	+239
al	59	38	50	43	49	43
fm	5	36	22	37	17	26
c	6	6	10	9	6	13
alk	30	20	18	12	27	19
mg	0.39	0.24	0.36	0.34	0.32	0.32
k	0.41	0.21	0.53	0.83	0.40	0.50
ti	1.6	1.9	1.8	1.5	1.3	1.3
w	0.47	0.10	0.26	0.14	0.13	0.07
T	+ 29	+ 18	+ 32	+ 31	+ 22	+ 24
t	+ 22	+ 12	+ 22	+ 22	+ 15	+ 11

G. Porphyry with small feldspar phenocrysts. Loc. 19, 208. (Rhyodacite).
H. Porphyry with small feldspar phenocrysts. Loc. 4, 5, 6, (Dacite).
I. Felsitic rock. Loc. 31–38. (Labradorite-rhyodacite).
K. Felsitic rock. Loc. 112, 116, 117, 123. (Quartz-latite).
L. Felsitic rock. Loc. 136. (Quartz-latite).
M. Amygdaloidal rock. Loc. 82, 86, 87. (Labradorite-rhyodacite).

TABLE 1 continued.

	N	O	P	Q	R	S	T
SiO_2	51.8	58.4	46.7	49.1	49.3	44.8	53.6
TiO_2	1.0	1.05	0.75	0.75	0.7	0.5	0.95
Al_2O_3	15.7	17.5	17.7	18.5	14.5	11.0	18.5
Fe_2O_3	1.55	1.37	0.90	1.73	5.6	5.7	1.32
FeO	5.30	3.46	8.65	7.32	4.6	3.8	9.56
MnO	0.17	0.12	0.20	0.16	0.15	0.13	0.22
MgO	1.5	1.1	5.8	2.3	8.3	13.3	2.0
CaO	12.2	10.8	7.2	6.3	9.4	9.85	7.7
Na_2O	2.9	2.1	2.4	1.8	2.3	1.9	3.5
K_2O	1.1	0.30	1.3	1.4	0.9	0.2	0.74
S	–	–	–	0.1	–	–	–
LOI	5.9	3.7	5.8	7.8	3.7	6.5	0.73
Sum	99.1	99.9	97.4	97.3	99.5	97.7	98.8
si	153	196	123	158	117	157	152
qz	+ 11	+ 66	– 10	+ 24	– 9	+ 29	+ 8
al	27	35	27	25	20	23	31
fm	24	19	44	35	49	33	35
c	39	39	20	22	24	37	23
alk	10	7	8	8	7	7	11
mg	0.27	0.28	0.51	0.31	0.60	0.20	0.24
k	0.19	0.08	0.26	0.33	0.20	0.06	0.12
ti	2.2	2.6	1.5	1.8	1.3	1.3	2.0
w	0.21	0.26	0.08	0.17	0.52	0.57	0.10
T	+ 17	+ 27	+ 19	+ 27	+ 14	+ 16	+ 20
t	– 22	– 12	– 1	+ 5	– 10	– 21	– 3

N. Matrix in agglomerate associated with porphyrite. Loc. 97, 98, 163. (Andesite).
O. Fragments in agglomerate associated with porphyrite. Loc. 97, 98, 163. (Light labradorite-dacite).
P. Porphyrite poor in phenocrysts. Loc. 107, 111, 114. (Olivine-andesite).
Q. Porphyrite. Loc. 8, 9. (Pigeonite-labradorite-andesite).
R. Gabbroic rock (porphyritic variety). Loc. 209.
S. Gabbroic rock. Loc. 210.
T. Gabbroic rock. Loc. 74.

TABLE 2. Matrix of correlation coefficients (r) for metals in the Näsliden ore. N = 147 except for Sb where N = 79. The significance at the 95 p.c. probability level is 0.22 for Sb and 0.17 for the other correlations.

	Cu	Zn	Pb	As	Sb	Ag
Cu	–					
Zn	–0.10	–				
Pb	–0.06	0.58	–			
As	0.37	0.20	0.08	–		
Sb	–0.13	0.25	0.70	–0.12	–	
Ag	0.30	0.54	0.85	0.16	0.57	–
Au	0.27	0.49	0.44	0.49	–0.06	0.52

TABLE 3. Electron-microprobe analyses of sphalerites from Näsliden.

Sample no.	Weight-%		Atomic %	Mol-% FeS
7539	Zn	59.72	44.34 ± 0.21	11.4
	Fe	6.55	5.70 ± 0.16	
	S	33.00	49.96 ± 0.23	
		99.27	100.00	
7543	Zn	60.00	44.92 ± 0.07	10.9
	Fe	6.20	5.44 ± 0.02	
	S	32.52	49.64 ± 0.07	
		98.72	100.00	
7807	Zn	59.59	43.94 ± 0.04	11.6
	Fe	6.74	5.82 ± 0.02	
	S	33.42	50.24 ± 0.04	
		99.75	100.00	
7809	Zn	58.75	43.58 ± 0.06	12.1
	Fe	6.96	6.05 ± 0.03	
	S	33.30	50.37 ± 0.08	
		99.01	100.00	
7810	Zn	59.49	44.02 ± 0.18	11.4
	Fe	6.56	5.68 ± 0.09	
	S	33.34	50.30 ± 0.14	
		99.39	100.00	

TABLE 4. Chemical analyses and Niggli values of dacitic tuff (1–5) and agglomerate (6–9) from the Näsliden mine.

%	1	2	3	4	5	6	7	8	9
SiO_2	60.8	62.0	63.4	61.8	70.6	67.1	68.9	68.0	71.7
TiO_2	0.75	0.75	0.85	0.85	0.60	0.45	0.50	0.55	0.40
Al_2O_3	14.2	15.0	16.0	15.6	13.8	15.1	15.0	15.0	13.6
Fe_2O_3	2.0	0.4	–	–	–	0.4	–	0.1	–
FeO	5.0	6.8	5.7	5.9	2.8	2.9	3.5	3.5	2.9
MnO	0.10	0.10	0.08	0.08	0.05	0.06	0.06	0.06	0.04
MgO	4.7	3.6	3.2	4.0	2.4	2.0	1.7	2.1	1.6
CaO	4.5	3.4	3.1	3.0	2.3	2.9	2.8	2.7	2.7
Na_2O	1.6	2.7	3.1	2.4	2.4	3.1	3.1	2.9	2.9
K_2O	1.7	1.7	1.4	1.5	1.7	2.4	1.5	2.1	1.6
S	2.2	0.1	0.2	0.4	0.5	0.5	0.2	0.5	0.3
LOI	3.6	2.6	2.3	2.8	1.9	1.9	1.2	1.7	1.3
ppm									
Zn	330	145	165	130	150	230	170	180	380
Pb	31	13	9	9	24	27	22	40	12
Cu	145	110	105	100	65	105	55	44	75
As	100	30	13	10	14	18	90	12	40
Sb	5	5	5	5	5	5	5	10	5
Bi	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	<0.5	<0.5	<0.5
Sn	3	2	2	2	2	2	2	3	2
In	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5	1	0.5
Ga	22	21	21	18	14	21	21	22	24
Mo	2	2	3	2	2	2	2	<2	3
Ag	0.3	0.3	<0.3	<0.3	0.4	0.3	0.3	0.3	0.3
Ge	1.7	1.2	1.0	0.9	0.9	1.7	1.2	1.6	1.5
Ba	100	<100	300	100	200	200	100	200	200
Sum %	101.2	99.2	99.4	98.4	99.1	98.9	98.5	99.3	99.1
si	249	224	242	232	334	301	332	308	366
qz	+106	+ 71	+ 82	+ 83	+169	+120	+155	+133	+188
al	34	32	36	35	44	40	43	40	41
fm	35	41	37	41	28	26	27	28	25
c	20	13	13	12	12	14	12	13	15
alk	11	13	15	12	16	20	19	19	20
mg	0.81	0.46	0.49	0.54	0.60	0.51	0.45	0.50	0.49
k	0.41	0.29	0.22	0.29	0.31	0.33	0.24	0.32	0.26
ti	2.3	2.0	2.4	1.0	2.1	1.5	1.8	1.9	1.5
w	1.00	0.05	–	–	–	0.11	–	0.02	–
T	+ 23	+ 19	+ 21	+ 22	+ 28	+ 20	+ 23	+ 21	+ 21
t	+ 4	+ 5	+ 8	+ 10	+ 16	+ 6	+ 12	+ 8	+ 7

1. Bh 30, 296.6–304.3 m
2. Bh 32 G, 68.0– 75.3 m
3. Bh 39 G, 123.2–129.0 m
4. Bh 39 G, 129.0–134.0 m
5. Bh 39 G, 134.0–138.4 m
6. Bh 32 G, 54.8– 60.0 m
7. Bh 32 G, 60.0– 65.0 m
8. Bh 32 G, 65.0– 68.0 m
9. Bh 39 G, 118.6–123.2 m

TABLE 5. Chemical analyses and Niggli values of porphyry from the Näsliden mine.

%	10	11	12	13	14	15	16	17
SiO_2	68.1	76.9	77.3	76.3	74.6	76.6	74.9	73.7
TiO_2	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.25
Al_2O_3	14.4	12.2	12.3	12.1	13.0	12.4	12.0	11.7
Fe_2O_3	0.4	–	–	0.3	–	–	–	0.6
FeO	1.4	1.3	0.8	0.8	0.8	0.8	1.5	1.0
MnO	0.05	0.03	0.04	0.04	0.04	0.04	0.04	0.04
MgO	2.3	1.7	1.1	0.8	0.9	1.0	1.7	2.0
CaO	1.7	1.5	1.5	1.7	2.4	2.0	2.5	2.1
Na_2O	2.1	1.7	1.9	2.5	2.6	2.5	2.5	2.2
K_2O	2.2	1.7	2.2	2.4	2.6	2.1	1.5	1.5
S	1.1	0.1	0.1	0.1	0.1	0.2	0.4	0.7
LOI	1.8	1.3	1.5	1.8	1.7	1.1	1.5	1.4
ppm								
Zn	450	100	100	130	100	180	170	510
Pb	21	18	12	12	12	29	25	65
Cu	70	30	26	26	24	46	47	110
As	80	25	6	5	6	10	11	25
Sb	5	5	<5	5	<5	<5	5	5
Bi	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sn	3	2	2	2	2	2	2	2
In	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ga	19	17	17	18	20	18	17	16
Mo	<2	2	<2	<2	<2	<2	2	3
Ag	0.3	<0.3	<0.3	<0.3	<0.3	3	3	6
Ge	1.4	1.2	1.0	1.2	1.4	1.2	1.3	1.4
Ba	300	300	400	600	700	500	100	100
Sum %	95.9	98.1	99.0	99.1	99.0	99.0	98.8	97.3
si	364	510	535	508	453	495	442	446
qz	+191	+337	+345	+302	+252	+297	+262	+271
al	45	48	50	47	47	47	42	42
fm	26	24	16	14	12	15	23	26
c	10	9	11	12	16	14	16	14
alk	18	18	22	26	25	24	20	19
mg	0.69	0.69	0.69	0.56	0.65	0.65	0.66	0.69
k	0.40	0.39	0.43	0.38	0.39	0.35	0.28	0.30
ti	1.2	1.0	1.0	1.0	0.9	1.0	0.9	1.1
w	0.20	–	–	0.25	–	–	–	0.35
T	+ 27	+ 30	+ 28	+ 21	+ 21	+ 23	+ 22	+ 23
t	+ 17	+ 20	+ 17	+ 9	+ 6	+ 9	+ 6	+ 9

10. Bh 39 G, 14.2–20.0 m
11. Bh 39 G, 20.0–24.5 m
12. Bh 39 G, 45.0–50.0 m
13. Bh 39 G, 50.0–55.0 m
14. Bh 39 G, 55.0–60.0 m
15. Bh 39 G, 60.0–65.0 m
16. Bh 39 G, 65.0–70.0 m
17. Bh 39 G, 70.0–74.5 m

TABLE 5 continued.

%	18	19	20	21	22	23	24
SiO_2	72.1	76.0	77.4	76.2	78.5	71.8	78.5
TiO_2	0.25	0.20	0.20	0.20	0.20	0.20	0.15
Al_2O_3	12.5	11.9	11.0	11.7	11.2	13.2	10.8
Fe_2O_3	1.1	0.3	–	–	–	0.1	–
FeO	1.1	0.1	0.3	2.1	0.5	1.2	1.0
MnO	0.03	0.03	0.03	0.03	0.03	0.03	0.03
MgO	1.2	0.8	0.8	1.1	0.9	1.9	1.0
CaO	2.5	2.1	1.9	1.7	1.9	2.3	1.9
Na_2O	1.6	1.5	1.5	1.3	1.6	1.7	2.4
K_2O	3.0	3.1	2.4	2.9	2.7	3.2	1.7
S	0.6	0.4	0.5	0.9	0.2	0.5	0.1
LOI	2.5	2.3	1.8	2.0	1.8	2.5	1.3
ppm							
Zn	195	80	170	650	75	145	180
Pb	32	13	28	60	8	14	16
Cu	85	31	70	125	20	42	33
As	3	7	6	12	<3	<3	<3
Sb	10	<5	<5	5	<5	<5	<5
Bi	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sn	2	<2	<2	2	2	2	2
In	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ga	17	17	16	17	16	20	15
Mo	<2	<2	2	2	<2	2	2
Ag	0.3	<0.3	0.3	0.3	<0.3	<0.3	0.3
Ge	1.3	1.4	1.1	1.3	0.9	1.2	1.3
Ba	400	500	500	500	500	600	300
Sum %	98.6	98.8	97.9	100.3	99.6	98.7	98.9
si	422	534	633	565	573	402	554
qz	+241	+334	+435	+373	+378	+219	+358
al	43	49	53	51	48	44	45
fm	21	11	6	12	13	22	17
c	16	16	17	14	15	14	14
alk	20	24	24	23	24	21	24
mg	0.50	0.78	0.61	0.98	0.75	0.71	0.63
k	0.55	0.57	0.51	0.59	0.52	0.55	0.31
ti	1.1	1.1	1.2	1.1	1.1	0.8	0.8
w	0.47	0.72	–	1.00	–	0.06	–
T	+ 23	+ 25	+ 29	+ 28	+ 24	+ 23	+21
t	+ 7	+ 9	+ 12	+ 15	+ 9	+ 9	+ 7

18. Bh 39 G, 85.4– 91.0 m
19. Bh 39 G, 91.0– 96.0 m
20. Bh 39 G, 96.0–101.0 m
21. Bh 39 G, 101.0–106.0 m
22. Bh 39 G, 106.0–111.0 m
23. Bh 39 G, 111.0–115.0 m
24. Bh 39 G, 115.0–118.6 m

TABLE 6. Chemical analyses and Niggli values of felsitic tuff from the Näsliden mine.

%	25	26	27	28	29	30	31	32	33
SiO_2	73.8	75.3	70.1	73.7	75.0	72.7	70.9	70.6	72.5
TiO_2	0.25	0.25	0.35	0.30	0.30	0.35	0.35	0.40	0.35
Al_2O_3	11.0	11.0	12.8	12.6	12.2	12.0	12.8	14.0	12.9
Fe_2O_3	0.6	0.4	1.0	0.7	–	0.3	0.6	0.3	–
FeO	2.6	2.6	2.0	3.4	3.8	3.4	4.0	3.6	4.2
MnO	0.09	0.07	0.05	0.07	0.08	0.07	0.05	0.04	0.06
MgO	1.1	1.0	1.5	1.4	1.4	2.0	3.1	2.9	1.2
CaO	2.4	1.9	1.7	1.4	1.8	1.6	1.5	1.1	2.0
Na_2O	2.6	3.2	2.8	2.3	1.9	1.8	1.9	1.1	1.5
K_2O	1.8	1.0	1.9	1.8	1.0	1.9	1.9	2.2	1.4
S	0.3	0.2	0.9	0.1	0.1	0.2	0.2	0.2	0.3
LOI	2.1	1.8	2.5	1.6	1.2	1.8	2.0	2.3	1.1
ppm									
Zn	190	190	220	200	190	185	200	230	380
Pb	26	42	27	19	30	24	16	15	35
Cu	41	37	210	25	21	28	27	27	60
As	30	15	160	7	3	6	3	3	20
Sb	<5	<5	<5	<5	<5	<5	<5	<5	5
Bi	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5
Sn	2	2	3	3	2	2	2	2	4
In	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5
Ga	19	17	22	21	21	19	22	23	22
Mo	2	2	3	<2	2	2	2	2	2
Ag	0.3	<0.3	0.4	<0.3	<0.3	<0.3	<0.3	<0.3	0.4
Ge	1.3	1.1	1.2	1.3	1.4	1.2	1.2	1.2	1.7
Ba	200	300	500	400	300	400	500	600	400
Sum %	98.7	98.8	97.7	99.4	98.8	98.2	99.4	98.8	97.6
si	432	477	396	414	443	407	343	362	416
qz	+246	+282	+207	+238	+284	+241	+184	+212	+262
al	38	41	41	42	42	40	37	42	44
fm	25	22	27	31	31	34	41	39	31
c	15	13	10	8	11	10	8	6	12
alk	21	24	22	19	15	17	15	13	13
mg	0.37	0.42	0.47	0.37	0.39	0.48	0.54	0.56	0.33
k	0.31	0.17	0.30	0.33	0.25	0.40	0.39	0.56	0.38
ti	1.1	1.2	1.5	1.3	1.3	1.5	1.3	1.5	1.5
w	0.17	0.15	0.31	0.15	–	0.07	0.11	0.06	–
T	+ 16	+ 17	+ 19	+ 23	+ 28	+ 23	+ 22	+ 30	+ 30
t	+ 1	+ 5	+ 9	+ 14	+ 16	+ 13	+ 14	+ 24	+ 18

25. Bh 32 G, 2.0– 7.0 m
26. Bh 32 G, 7.0–12.0 m
27. Bh 32 G, 12.0–17.0 m
28. Bh 32 G, 17.0–22.0 m
29. Bh 32 G, 22.0–27.0 m
30. Bh 32 G, 27.0–32.0 m
31. Bh 32 G, 32.0–37.0 m
32. Bh 32 G, 37.0–41.5 m
33. Bh 39 G, 3.0– 7.3 m

TABLE 7. Chemical analyses and Niggli values of strongly altered rocks from the Näsliden mine.

%	34	35	36	37	38	39	40	41	42
SiO_2	69.0	70.1	66.7	59.0	73.8	77.7	76.9	70.8	67.5
TiO_2	0.35	0.55	0.40	0.65	0.45	0.30	0.30	0.35	0.35
Al_2O_3	11.0	11.8	11.6	12.3	10.0	9.2	8.9	12.8	11.0
Fe_{sulph}	5.9	5.5	4.1	3.6	2.1	1.8	3.6	3.0	2.0
FeO	–	0.1	0.4	4.8	2.3	1.3	0.5	1.5	5.8
MnO	0.05	0.04	0.07	0.10	0.05	0.06	0.05	0.05	0.06
MgO	0.6	0.5	1.3	5.2	1.8	1.3	0.7	1.4	4.1
CaO	0.9	0.5	4.1	3.2	1.0	2.4	1.0	0.7	1.2
Na_2O	0.21	0.08	0.73	0.66	0.35	0.54	0.47	0.43	0.70
K_2O	3.6	1.9	2.4	1.7	2.1	1.4	2.9	3.4	2.1
S	6.9	6.3	4.7	4.1	2.4	2.1	4.1	3.5	2.3
LOI	5.6	5.2	5.2	5.6	2.8	2.3	3.4	4.1	3.9
ppm									
Zn	820	2200	210	350	1000	140	210	530	260
Pb	140	290	36	230	300	30	30	35	19
Cu	380	300	60	650	250	110	550	150	330
As	2300	3100	150	500	3000	550	1800	460	90
Sb	50	110	15	40	160	50	400	45	10
Bi	<0.5	<0.5	<0.5	1	2.5	0.5	<0.5	0.5	3
Sn	3	8	3	3	3	2	3	4	2
In	<0.5	0.5	<0.5	0.5	1	<0.5	1	0.5	<0.5
Ga	14	18	17	17	15	13	11	17	17
Mo	3	2	4	<2	<2	2	3	3	4
Ag	2.5	6	0.7	2.2	2.3	0.6	1.4	0.4	0.4
Ge	2.3	1.9	1.2	0.9	1.2	1.1	1.7	2.1	3.1
Ba	400	300	100	<100	200	100	100	400	200
Sum %	104.5	103.2	101.8	101.1	99.6	100.5	103.1	102.2	101.1
si	634	733	431	270	620	664	786	520	366
qz	+442	+579	+273	+138	+464	+516	+592	+344	+222
al	60	73	44	33	50	46	54	55	35
fm	9	8	13	43	27	20	12	20	47
c	9	6	28	16	9	22	11	6	7
alk	23	13	14	8	14	12	24	19	11
mg	0.95	0.95	0.97	0.81	0.82	0.84	0.89	0.76	0.70
k	0.91	0.93	0.68	0.62	0.79	0.63	0.80	0.83	0.66
ti	2.4	4.3	1.9	2.2	2.8	1.9	2.3	1.9	1.4
w	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93
T	+ 37	+ 59	+ 30	+ 25	+ 35	+ 34	+ 30	+ 36	+ 24
t	+ 28	+ 54	+ 1	+ 10	+ 26	+ 12	+ 19	+ 31	+ 17

34. Bh 30, 282.0–287.0 m
35. Bh 30, 287.0–292.0 m
36. Bh 30, 292.0–296.6 m
37. Bh 32 G, 75.0– 80.0 m
38. Bh 32 G, 80.00– 85.0 m
39. Bh 32 G, 85.0– 90.0 m
40. Bh 32 G, 90.0– 95.0 m
41. Bh 32 G, 95.0– 99.0 m
42. Bh 32 G, 99.0–102.6 m

TABLE 7 continued.

%	43	44	45	46	47	48	49	50	51
SiO_2	53.2	31.9	39.2	62.7	56.5	64.9	56.0	55.9	63.5
TiO_2	0.8	1.15	1.15	0.90	0.95	0.55	0.65	0.70	0.50
Al_2O_3	14.1	19.8	19.8	15.3	18.4	16.5	17.9	17.0	16.0
Fe_{sulph}	1.7	5.4	7.1	5.3	6.3	0.8	0.3	1.1	0.3
FeO	13.0	13.3	8.5	0.8	0.5	3.1	5.5	6.5	4.0
MnO	0.09	0.11	0.08	0.03	0.02	0.05	0.10	0.12	0.06
MgO	7.8	11.3	6.7	1.2	1.0	4.8	10.8	9.4	6.0
CaO	0.9	1.2	1.3	0.7	0.7	0.9	0.6	1.0	1.0
Na_2O	0.65	0.62	0.79	0.39	0.50	0.54	0.16	0.40	0.35
K_2O	0.47	1.1	2.4	3.3	3.9	2.6	0.98	0.98	2.0
S	2.0	6.2	8.2	6.1	7.2	0.9	0.3	1.3	0.3
LOI	5.1	9.9	9.2	5.8	6.8	3.7	5.6	5.2	3.6
ppm									
Zn	250	400	380	2000	5300	175	240	420	215
Pb	19	75	50	90	140	20	14	65	21
Cu	215	500	630	110	95	150	55	80	70
As	120	70	500	370	360	105	40	15	50
Sb	10	50	30	80	170	5	5	5	15
Bi	2.5	50	12	1.5	0.5	1	1	2	2.5
Sn	<2	2	2	3	3	2	<2	2	2
In	<0.5	0.5	<0.5	<0.5	0.5	<0.5	<0.5	0.5	<0.5
Ga	18	30	21	17	21	18	21	25	20
Mo	2	<2	2	<2	<2	2	<2	2	3
Ag	1.0	2.0	1.6	1.4	1.6	1.0	0.3	0.9	1.1
Ge	0.5	0.8	0.6	0.5	1.0	1.2	1.1	1.0	0.8
Ba	<100	<100	200	400	500	500	400	300	400
Sum %	99.9	102.1	104.6	102.8	103.4	99.4	99.0	99.7	97.7
si	173	87	153	446	350	299	318	184	263
qz	+ 61	− 27	+ 17	+275	+176	+158	+200	+ 71	+136
al	27	31	44	64	67	45	60	33	39
fm	67	62	41	13	10	41	32	60	50
c	3	4	5	5	5	4	4	4	4
alk	3	4	9	18	18	10	4	3	7
mg	0.56	0.74	0.94	0.98	0.94	0.80	0.21	0.76	0.74
k	0.32	0.53	0.66	0.84	0.83	0.76	0.80	0.61	0.78
ti	2.2	2.4	3.4	4.8	4.4	1.9	2.8	1.7	1.6
w	0.16	1.00	1.00	1.00	1.00	0.04	0.10	–	0.09
T	+ 24	+ 28	+ 35	+ 46	+ 49	+ 35	+ 55	+ 30	+ 32
t	+ 21	+ 24	+ 30	+ 41	+ 44	+ 30	+ 52	+ 26	+ 28

43. Bh 39 G, 138.4–144.0 m
44. Bh 39 G, 144.0–149.0 m
45. Bh 39 G, 149.0–154.0 m
46. Bh 39 G, 154.0–159.0 m
47. Bh 39 G, 159.0–164.0 m
48. Bh 39 G, 24.5–30.0 m
49. Bh 39 G, 30.0–35.0 m
50. Bh 39 G, 35.0–40.0 m
51. Bh 39 G, 40.0–42.3 m

TABLE 8. Chemical analyses and Niggli values of sedimentary rocks from the Näsliden mine.

%	52	53	54	55	56	57	58
SiO_2	67.8	53.7	53.2	57.0	50.9	35.5	50.0
TiO_2	0.40	0.55	0.55	0.45	0.50	0.50	1.20
Al_2O_3	10.1	15.7	15.6	14.1	15.0	11.9	16.0
Fe_{sulph}	5.0	4.5	5.7	6.1	5.0	5.7	2.3
FeO	2.6	3.7	4.1	1.8	2.6	–	6.2
MnO	0.10	0.22	0.15	0.07	0.18	0.25	0.21
MgO	2.8	4.6	4.7	3.4	4.1	2.0	3.9
CaO	2.1	4.8	3.3	5.0	6.4	21.2	9.2
Na_2O	1.1	1.0	0.51	1.1	1.3	1.1	1.2
K_2O	1.5	2.7	3.0	2.8	3.2	2.5	1.3
S	2.9	2.6	3.3	3.5	2.9	3.3	1.3
LOI	2.9	4.5	3.9	3.1	4.9	13.2	5.0
ppm							
Zn	800	1200	640	800	710	1100	240
Pb	110	75	45	75	50	95	13
Cu	150	160	230	320	210	180	75
As	80	30	13	13	5	60	35
Sb	10	5	10	10	10	20	5
Bi	0.5	0.5	0.5	<0.5	<0.5	<0.5	<0.5
Sn	3	2	3	2	3	3	<2
In	0.5	0.5	0.5	0.5	0.5	<0.5	0.5
Ga	14	17	17	16	17	9	20
Mo	5	2	3	4	2	2	<2
Ag	1.2	1	0.8	1.3	0.9	0.9	<0.3
Ge	1.5	2.0	1.5	1.5	1.6	1.4	1.8
Ba	100	400	600	500	500	300	<100
Sum %	99.4	98.8	98.2	98.6	97.1	97.3	97.8
si	433	198	209	248	187	99	154
qz	+281	+ 58	+ 71	+ 98	+ 39	– 31	+ 30
al	38	34	36	36	33	20	29
fm	35	37	41	28	30	9	34
c	14	19	14	23	25	64	30
alk	13	10	9	12	12	7	6
mg	0.63	0.68	0.67	0.78	0.74	0.93	0.52
k	0.47	0.63	0.79	0.62	0.61	0.59	0.41
ti	1.9	1.5	1.6	1.5	1.4	1.1	2.8
w	–	0.15	0.06	–	0.43	1.00	–
T	+ 25	+ 24	+ 27	+ 24	+ 20	+ 12	+ 23
t	+ 11	+ 5	+ 13	0	– 5	– 52	– 8

52. Bh 32 G, 41.5– 47.0 m, grey phyllite
53. Bh 32 G, 47.0– 51.0 m, grey phyllite
54. Bh 39 G, 7.7– 14.2 m, grey phyllite
55. Bh 39 G, 74.5– 80.0 m, grey phyllite with sandy and limy intercalations
56. Bh 39 G, 80.0– 85.4 m, grey phyllite, limy
57. Bh 32 G, 122.1–126.8 m, impure limestone
58. Bh 32 G, 126.8–132.1 m, limy sandstone and phyllite

TABLE 8 continued.

%	59	60	61	62	63	64	65	66	67
SiO_2	52.8	56.0	57.0	48.5	22.3	49.2	45.4	46.5	55.4
TiO_2	0.45	0.60	0.65	0.70	0.55	0.55	0.40	1.25	0.65
Al_2O_3	12.5	14.5	17.6	12.6	7.2	14.9	14.1	17.8	16.4
Fe_{sulph}	4.2	8.2	3.7	14.3	2.6	10.3	9.3	3.0	6.4
FeO	2.1	–	2.7	–	0.1	–	–	7.9	1.4
MnO	0.26	0.12	0.16	0.08	0.40	0.07	0.06	0.20	0.08
MgO	2.5	2.7	2.6	2.7	2.8	3.2	4.3	4.6	3.0
CaO	9.8	3.4	4.9	2.4	32.8	3.3	5.9	6.8	3.4
Na_2O	1.1	1.9	2.3	1.7	0.65	0.90	0.86	1.3	1.2
K_2O	1.0	1.5	2.6	2.5	1.8	3.5	2.2	0.79	2.3
S	2.4	5.1	2.1	11.9	1.5	8.8	7.5	1.7	3.7
LOI	7.7	3.8	2.3	8.9	24.6	7.3	7.8	3.7	4.2
ppm									
Zn	200	270	250	2300	200	1800	920	310	480
Pb	310	140	60	180	90	150	300	37	38
Cu	105	135	190	420	80	350	1000	155	220
As	60	35	20	80	180	80	450	55	40
Sb	5	10	<5	120	5	60	60	10	10
Bi	0.5	0.5	<0.5	0.5	<0.5	<0.5	0.5	<0.5	<0.5
Sn	2	2	2	5	13	4	4	2	2
In	<0.5	<0.5	<0.5	0.5	<0.5	0.5	<0.5	<0.5	<0.5
Ga	15	20	19	18	10	22	15	20	17
Mo	4	5	3	9	<2	7	3	2	4
Ag	0.4	0.4	0.3	2.7	0.3	2.7	1.9	0.3	0.5
Ge	1.3	1.3	1.3	1.2	0.9	5.3	1.8	1.4	0.9
Ba	100	300	300	100	100	100	200	<100	400
Sum %	96.9	97.9	98.7	106.6	97.4	102.3	98.1	95.6	98.2
si	205	272	221	279	48	229	176	140	262
qz	+ 78	+117	+ 61	+105	− 67	+ 71	+ 42	+ 19	+112
al	29	41	40	43	9	41	32	32	46
fm	24	27	24	24	11	28	34	41	25
c	41	18	20	15	76	16	25	22	17
alk	7	14	15	19	4	14	9	5	12
mg	0.60	0.71	0.61	0.97	0.85	0.78	0.72	0.50	0.86
k	0.37	0.34	0.42	0.50	0.64	0.71	0.62	0.28	0.55
ti	1.3	2.2	1.9	3.1	0.9	1.9	1.2	2.8	2.3
w	1.00	1.00	0.66	0.41	1.00	1.00	1.00	0.14	0.35
T	+ 22	+ 28	+ 25	+ 24	+ 5	+ 26	+ 24	+ 26	+ 33
t	− 19	+ 10	+ 5	+ 9	− 71	+ 10	− 1.0	+ 4	+ 16

59. Bh 30, 231.0–236.0 m, grey and black phyllite with limestone intercalation
60. Bh 30, 236.0–241.0 m, black phyllite
61. Bh 30, 241.0–246.0 m, grey phyllite
62. Bh 30, 246.0–250.2 m, grey and black phyllite, greywacke
63. Bh 30, 250.2–256.3 m, limy turbidite with fragments of felsite, phyllite and sericite quartzite
64. Bh 30, 256.3–261.8 m, black phyllite
65. Bh 39 G, 171.5–176.3 m, grey phyllite
66. Bh 39 G, 176.3–180.8 m, turbidite, limy
67. Bh 39 G, 180.8–185.3 m, grey phyllite

TABLE 9. Average chemical composition and average Niggli values of metavolcanics and strongly altered rocks from the Näsliden mine.

%	Felsitic tuff (25–33)	Porphyry (10–24)	Agglomerate (6–9)	Dacitic tuff (1–5)	Aggl. + dacite (1–9)	Strongly altered rocks (34–47)
SiO_2	72.7	75.2	68.9	63.7	66.0	62.0
TiO_2	0.30	0.20	0.50	0.75	0.65	0.60
Al_2O_3	12.4	12.2	14.7	14.9	14.8	14.1
Fe_{tot}	3.4	1.5	3.3	4.8	4.1	7.0
MnO	0.06	0.04	0.06	0.08	0.07	0.07
MgO	1.7	1.3	1.9	3.6	2.8	4.2
CaO	1.7	2.0	2.8	3.3	3.1	1.3
Na_2O	2.1	2.0	3.0	2.4	2.7	0.48
K_2O	1.7	2.3	1.9	1.6	1.7	2.2
S	0.3	0.4	0.4	0.7	0.6	3.8
LOI	1.8	1.8	1.5	2.6	2.1	5.2
ppm						
Zn	220	215	240	185	210	840
Pb	26	24	25	17	21	90
Cu	53	52	70	105	89	260
As	27	13	40	33	36	755
Sb	<5	<5	6	5	5	70
Bi	<0.5	<0.5	<0.5	<0.5	<0.5	4.5
Sn	2	2	2	2	2	3
In	<0.5	<0.5	0.5	<0.5	<0.5	<0.5
Ga	21	17	22	19	20	18
Mo	2	<2	2	2	2	2
Ag	<0.3	<0.3	0.3	<0.3	<0.3	1.5
Ge	1.3	1.2	1.5	1.1	1.3	1.3
Ba	400	400	200	200	200	300
si	410	496	327	256	288	405
qz	+240	+307	+149	+102	+123	+258
al	41	47	41	36	38	48
fm	31	17	27	36	32	32
c	10	14	14	14	14	8
alk	18	22	20	13	16	12
mg	0.45	0.68	0.49	0.58	0.54	0.80
k	0.34	0.43	0.29	0.30	0.30	0.72
ti	1.3	1.0	1.7	2.0	1.8	2.6
w	–	–	0.03	0.21	–	0.74
T	+ 24	+ 24	+ 21	+ 23	+ 22	+ 36
t	+ 13	+ 11	+ 8	+ 9	+ 8	+ 27

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Tryck: Offsetcenter ab, Uppsala 1982

ISBN 91-7158-256-8
ISSN 0082-0024