

RUDYARD FRIETSCH

A LATE-METASOMATIC IRON
MINERALIZATION IN THE NARKEN
AREA AND ITS OCCURRENCE
AS GLACIAL BOULDERS AT KIHLANKI,
BOTH IN NORTHERN SWEDEN



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Abstract

Near Narcken village, between Luleå and Kiruna in Northern Sweden, there are some quite unimportant occurrences of a lean hematite ore. In a matrix of epidote, chlorite and small amounts of euhedral apatite grains, lie angular fragments of hematite usually some millimetres in size. Occasionally there are bigger fragments of an epidote rock. The iron mineralization is in some localities surrounded by epidote-quartz-rich or albite-extreme alteration rocks. The ore is younger than the late Archean Lina granite. Still younger than the ore is a generation of quartz veins which contain vugs filled with quartz. The ore and the associated metasomatic rocks are probably of late-metasomatic origin and formed in connection with faults. The ore and the alteration rocks seem to be spatially related to meta-sediments which mostly are of quartzitic composition. Due to the tectonization in connection with the faulting the meta-sediments were a favorable site for the deposition of the ore-forming solutions.

The opinion for the late-formation of the ore is supported by geochemical investigations of the trace elements in the hematite. The content of these is very low, the iron-forming solutions being depleted in trace elements.

In the proximity of Kihlanki village, about 80 km NNE of Narcken, there are found in the moraine a great amount of glacial boulders of the same type of mineralization. According to work by Fromm (1965) and Hoppe (1967), there is in the Korpilombolo and Pajala areas a young ice-movement from SW-SSW. The direction of the movement of the glaciation in Norrbotten is mainly from the NW. The boulders found at Kihlanki seem to confirm the evidence of a young ice-movement from the SSW. This direction has thus to be taken into account when tracing the source of glacial boulders in the Korpilombolo-Pajala-Kihlanki region.

Introduction

In the vicinity of the small village of Narken, situated about 150 km SE of Kiruna and 150 km N of Luleå in Norrbotten county, Northern Sweden (Fig. 1), there occur several small occurrences of a lean hematite ore. Due to the poor quality of the ore and the very restricted extension, the occurrences have no economic importance. The ore type differs, however, both in mineralogical respect and common appearance from the other iron ore types known in Northern Sweden and is therefore the subject for a description in the present paper. The relatively young age of the mineralization – it being younger than the Lina granite of Late Archean age, makes the ore type especially interesting. Further, glacial boulders of this peculiar ore type have been found in the Kihlanki area, about 80 km NNE of Narken. This is in accord with work by Fromm (1965) and Hoppe (1967), who showed that during the latest glaciation there existed a young ice-movement from the south in Korpilombolo-Pajala area.

The iron oxide mineralization at Narken is encountered at five different places in the nearhood of the village (Fig. 2). The two "biggest" occurrences, namely at Vattuvaara, 3 km SE of the village, and at Kartovaara, 4 km NNE of the village, were discovered in 1946 in connection with the regional geological mapping of the Norrbotten County that was performed by the Geological Survey of Sweden under the leadership of Professor O. Ödman. No immediate attention was given to these findings, but in 1950 the Survey made a magnetic (Tiberg scale) measurement over the area around the occurrence at Vattuvaara. An area of 1.8×2.5 km was covered. The measurement lines had a spacing of 80 m and the measurement points of 20 m. Only very weak magnetic anomalies were discovered. The iron mineralization was not indicated which is natural as the outcrops are totally hematitic with no magnetite.

In 1967 in connection with a campaign which encouraged private people to search for minerals of economic interest in the Norrbotten County and which was sponsored by the Norrland foundation, two samples of hematite ore were sent in from the Narken area. One of the samples was from the occurrence at Kartovaara. The other sample was from a local boulder found in the moraine in Narken village itself. In 1969 two more samples were sent from the Narken area in connection with the same campaign. These emanated from the occurrence at Vattuvaara. One of the senders had also found a lot of local boulders of a similar hematite mineralization along the Kalix river east of the occurrence at Vattuvaara.

As a consequence of the samples sent in, the present author paid short visits to the different places from where the samples were taken. In order to find out if the different occurrences had some economic interest and to study the mode of formation of this rather odd type of iron ore, the author, with the aid of two students, Hans Larsson and Tapio Lehto, made a rapid mapping of the geology

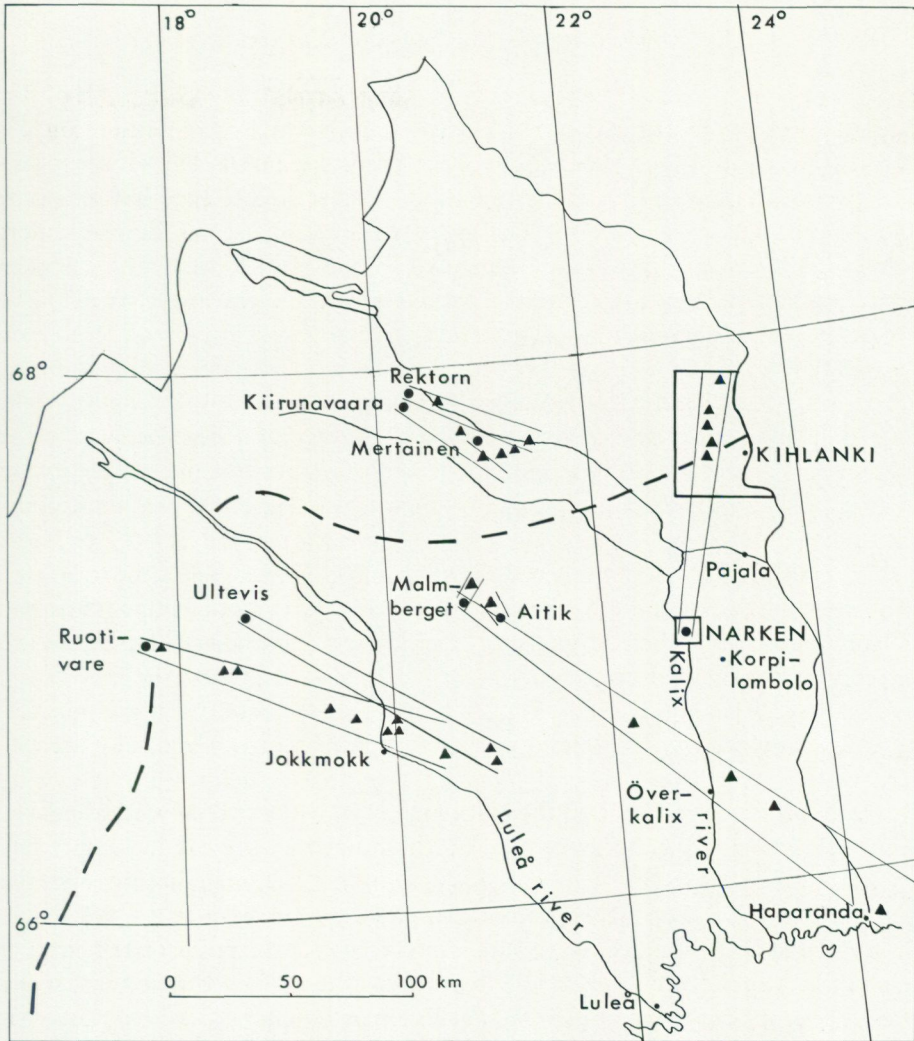


Fig. 1. Position of the Narken and Kihlanki areas in Northern Sweden. Further, there is shown the boulder train from the Narken ore and some other ore deposits. The main ice divide after G. Lundqvist (1961) is shown by a broken line.

of the Narken area in 1970. The outlines of the different geological rock units on the map (Fig. 2) are to a large extent based on an aero-magnetic map in the scale 1:50 000. The geological map must be considered as a sketch map. The main purpose of the investigation was to study the iron mineralization in the area and not the regional geology. A knowledge of the latter is, however, necessary to understand the way the ore formed.

The iron mineralisation in the Narcken area

GENERAL GEOLOGICAL SETTING

According to the geological map of Norrbotten County by Ödman (1957) the Narcken area is mostly covered by the Lina granite which is the youngest Archean rock. Radiometric age determinations of this granite type has given an age of 1540 m.y. (Welin 1970). The age determinations show, however, that some samples among this granite type give an age of 1820 m.y. These higher values possibly belong to granites connected with the older group of Archean intrusive rocks, namely the "Haparanda granite series" (Ödman 1957) or "granodiorite group" (Frietsch 1971). It is at the moment not possible to make a division into an "older" or "younger" Lina granite based on geological field data. The appearance and the composition of the two granites of different age is similar. As there are no radiometric age determinations of the granite in the Narcken area, it will be designated as a "common" Lina granite being the youngest Archean intrusive.

The map of Ödman shows that there occurs a N-S trending intrusion of gabbro in the Lina granite north and east of the Narcken village. South of the village there is E-W belt of gneisses of unknown age and nature. These are affected by the migmatization connected with the Lina granite.

The present geological map (Fig. 2) shows that the main features outlined by Ödman on the whole are holding, but that in detail there naturally are differences.

The dominating rock within the Narcken area is, without doubt, a red microcline-rich Lina granite, younger than all the other rocks. Next in importance of the plutonic rocks is a gabbro which occurs as irregular "islands" in the granite. These are presumably remnants of a larger intrusive massif which has been "eaten up" by the Lina granite. Further there are parts of the granite which have a relatively high magnetic level on the aero-magnetic map. They probably represent areas of gabbro that has been assimilated in the granite. It is likely that the gabbro in the Narcken area is a continuation of the large gabbro massif at Tärendö (NW of Narcken, cf. the Tärendö map sheet SE, by Padget 1970) but that the gabbro at Narcken has been strongly affected by the granite.

The third deep-seated rock in the Narcken area is an amphibole-bearing syenite, which most possibly is a real intrusive, even if inhomogeneties suggesting an origin by hybridization are rather common. These features are probably due to the assimilation of basic, volcanic rocks by the syenite.

The gabbro and the syenite are cut by a few, quite narrow dikes of basic composition.

The only supracrustal rocks that are found in the area are grey, fine-grained meta-sediments which mostly are of quartzitic composition. The sediments cover several smaller areas. Whether they are remnants of an originally co-

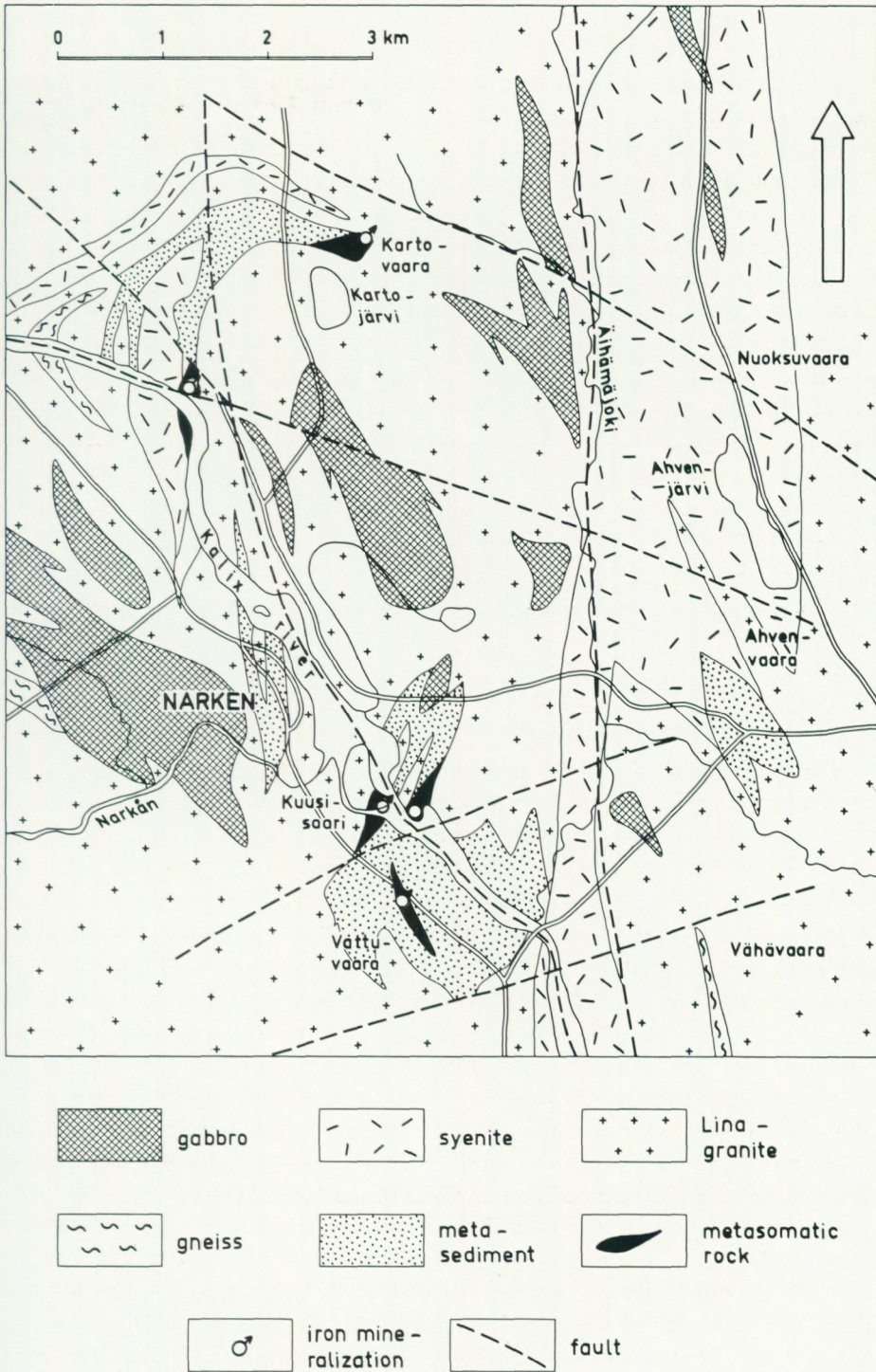


Fig. 2. Sketch-map showing the rock types in the Narken area.

herent area, now destroyed by the Lina granite, or were deposited in separate basins cannot be stated. The quartz-feldspar-gneisses which are occurring in relatively restricted amounts in the Narken area, are at least in some cases metamorphic derivatives of the sediments.

The iron mineralization of the area is related in space to the meta-sediments. Together with the mineralization, which probably resulted by late-metasomatic activity, there has occurred an epidotization and albitization. The last mentioned process has only affected the meta-sediments. The epidotization is younger than the Lina granite. Younger than the epidotization is a generation of quartz veins which typically have some centimetres long druses filled with quartz crystals.

The late-metasomatic processes are related to a tectonization younger than the Lina granite. The tectonic processes must, however, have continued during and after the metasomatic processes and the epidote-iron oxide mineralization was broken up resulting in a breccia with fragments of these minerals.

The age relationship between the different magmatic rocks and processes in the Narken area is shown in Table 1.

Table 1. Schematic succession for the different magmatic rocks and processes in the Narken area

quartz veins
metasomatic processes with the formation of epidote, chlorite, quartz and apatite
tectonization
metasomatic processes with the formation of iron oxides, epidote and albite-extreme rocks
tectonization
Lina granite
basic dikes
syenite
(oldest) gabbro

The meta-sediments are older than the Lina granite and the metasomatic alteration processes. The relationship with the other plutonic rocks is not known. As they are the only supracrustal rocks in the Narken area and form scattered occurrences surrounded by plutonic rocks, the meta-sediments cannot be stratigraphically compared with similar units in rock sequences in other parts of Norrbotten.

As the igneous rocks dominate in the Narken area it is not possible to make any interpretation of the primary structural features. The scattered occurrences of the meta-sediments do not give any hint of the tectonic style. Even the aeromagnetic maps which usually assist tectonic interpretation do not give any help in this case. The only structural elements that can be discerned are those of the later deformation connected with faults. They are drawn on the geological map by means of the aero-magnetic map and the topographic lines observed. One of the main fault lines strikes NW-SE along the Kalix river. N-S

trending lines occur along Äihämäjoki and from Narken village northwards. In the northern part of the mapped area there are also lines striking WNW-ESE and in the southern part lines trending ENE-WSW.

The schistosity of the rocks in the Narken area is mostly N-S with some deviation towards the east or west. Further, schistositities locally strike E-W. In all cases the dip of schistosity is vertical.

META-SEDIMENTS

Several separate, relatively small occurrences of meta-sediments are found in the Narken area. Most of them are situated along the Kalix river. Further, there is one occurrence south of Ahvenvaara to the east of Narken on the road to Korpilombolo. The interrelationship between these occurrences is not known. All are surrounded by the Lina granite. They might have belonged to the same sedimentation area which later was split by the granite. The areo-magnetic map does not tell anything about the extension of the meta-sediments. They are mostly non-magnetic and do not differ magnetically from the surrounding granite. In some cases the sediments are covered by weak magnetic anomalies.

The meta-sediments are fine-grained, weakly schistose rocks with a grey, or in some cases brown-grey or green-grey colour. Rather common is an indistinctive banding which is made up by 2-3 mm wide alternating layers of light material (quartz-feldspar) and dark material (epidote-chlorite). Occasionally there occur in the darker bands small aggregates of pyrite. The direction of the banding is generally rather variable within each occurrence. In the sediments surrounding Vattuvaara the strike is mostly NW-NNW and the dip vertical or steeply towards SW-SSW. However, in the western and northern part of this area the banding strikes E-W. In the sediments south of Ahvenvaara the strike varies between NW and N. In the sediments north of the Narken village the direction is NNE-NE.

The meta-sediments are mostly affected by the Lina granite. The granite sends in several centimetre wide veins which usually follow the schistosity or banding in the meta-sediments, but may be cross-cutting. On the peninsula east of Kuusisaari, where one of the iron mineralizations in the Narken area is situated, the meta-sediments lie as 3-4 m large, more or less angular remnants in the granite. The border between both rocks is sharp. The meta-sediments are intensively smallfolded with very varying fold axes, of which, however, those plunging steeply towards the east and south are dominant. The meta-sediments are here further cut by a late generation of quartz veins, which are up to 0.5 meter wide and have a variable direction. In these occur vugs filled with well-developed quartz-crystals up to 3 cm in size. Southeast of Narken, on the west bank of the Kalix river, the Lina granite also cuts the meta-sediments and contains up to decimetre large, angular fragments of these.

The meta-sediments are built up of quartz, epidote and chlorite forming an equigranular aggregate. The microscope shows that the texture is only slightly affected by pressure. A weak parallel texture is sometimes seen. The grain-size is mostly between 0.05 and 0.1 mm, the extremes being 0.03 and 0.3 mm. The quartz forms anhedral grains with a wavy extinction. They sometimes have an outer rim rather rich in sericite. Around the quartz lies a "network" of pale-green chlorite, mostly with anomalous interference colours, and brownish, turbid epidote. In some samples quartz dominates, chlorite and epidote being subordinate. The epidote which forms 0.05 mm big anhedral grains in the chlorite, has sometimes a dark-brown kernel (presumably orthite). At Vattuvaara the meta-sediments contain red-brown biotite and no chlorite.

Plagioclase-bearing meta-sediments are found at several places. East of the iron mineralization at Vattuvaara the meta-sediments contain quartz and subordinate amounts of brown biotite and albite. The latter is partly sericitized. East of Kuusisaari the meta-sediments also contain minor amounts of plagioclase. The dark minerals are here chlorite and biotite. Plagioclase-bearing sediments are further found at the outlet of the small Äihämäjoki stream in the Kalix river (Fig. 3) and at the outcrops east of Äihämäjoki. They contain quartz, albite and biotite, but differ from the other meta-sediments as they contain



Fig. 3. Meta-sediment. Quartz and small amounts of albite and biotite. Äihämäjoki outlet in the Kalix river. Thin section. Nic. +, x 35.

subordinate amounts of a grass-green hornblende. The albite, which is partly perthitic, is here strongly sericitized. In minor amounts microcline is also present. It is of interest to note that in all the plagioclase-bearing sediments epidote is missing or occurring only in small amounts.

In all types of the meta-sediments investigated apatite, orthite, iron oxides and leucoxene are found as accessory minerals.

There is no doubt about the sedimentary origin of these rocks. In the darker varieties, especially those which are amphibole-bearing, there is probably pyroclastic material mixed with the clastic material, implying that these rocks originated as tuffites.

GABBRO

The gabbro is a medium-grained, non-schistose rock which in most cases is cut by veins of the Lina granite. In the granite veins there are angular fragments of the gabbro. In part the granite is amphibole-bearing, possibly due to the assimilation of gabbro material in the granite. On the whole hybridization products between gabbro and granite rather common. The gabbro, in the contact against the granite, is sometimes schistose.

Occasionally the gabbro is affected by later, secondary alterations. Thus the gabbro south of Kartojärvi is somewhat epidote-bearing and cut by centimetre-wide epidote veins of variable directions.

SYENITE

The syenite is a grey-brown to white-grey, medium-grained, occasionally weakly schistose rock which is made up of a red-brown or sometimes grey-white feldspar, forming up to 2 centimetre long grains, and dark minerals amongst which a green amphibole dominates. Less common is chlorite. There are sometimes rather great variations in the content of dark minerals and their grain-size. The inhomogenities in composition are similar to those in hybridic rocks. It is, however, most plausible that the syenite is a real intrusive rock and that inhomogenities are due to assimilated, basic rocks in the syenite (see below).

Samples from the area west of Vähävaara show under the microscope that the rock is dominated by 7–8 mm long, broad laths of a turbid, sericite-altered albite-oligoclase which contains a little epidote. The plagioclase is surrounded by a green hornblende, a pale green chlorite and quartz with wavy extinction. The last mentioned mineral occurs in about 7–8 mm long aggregates. The hornblende is largely altered to chlorite. In both minerals occur subhedral titanite, iron oxides and some epidote. A fresh microcline in rather large grains is sometimes found together with the quartz. Subhedral apatite grains occur as an accessory mineral in the quartz and microcline. The rock is cut by small veins of epidote which partly is red-brown (orthitic).



Fig. 4. Amphibole-bearing syenite (light) with angular fragments of a feldspar-porphyritic greenstone. Scale: knife in the upper part, about 20 cm long. West of Vähävaara.

The syenite is cut by up to 30 cm wide veins of the Lina granite and its pegmatite and is thus older than the granite. In many places the syenite is cut by epidote veins and is locally strongly epidotized. This occurs, for example in the syenite SE of the bridge over the river Kalix where a red, rather coarse, hybridic syenite is very rich in epidote. In the syenite west of Vähävaara there are parts which consist of a medium-grained epidote with up to 5 mm great aggregates of biotite.

The intrusive nature of the syenite is seen in the area west of Vähävaara. In the southernmost outcrops the syenite contains angular fragments of a dark feldspar-porphyritic greenstone (Fig. 4). At this locality and in the outcrops 1 km south of the bridge over the river Kalix, there also occur almost totally

resorbed, nebulitic remnants of fine-grained basic rocks. In the Nuoksuvaara area there occur more or less rounded fragments of a dark, fine-grained greenstone and a weakly schistose amphibolite which sometimes contains amphibole phenocrysts.

South of the bridge over the river Kalix in the syenite there are small quartz veins trending E-W. These are faulted and cut by epidote-filled fissures. The syenite is here also cut by basic dikes and by a 0.5 m wide dike of green-white, medium-grained quartz-rich intrusive, possibly related to Lina granite.

BASIC DIKES

Narrow basic dikes are found in the syenite and gabbro at Mestoslinka (6 km NW of the Narcken village, outside the map on Fig. 2) and also in the syenite south of the bridge over the river Kalix. These occurrences are too small to be shown on the map.

At Mestoslinka a 30 cm wide dike occurs in the syenite trending N60°E and dipping almost vertically. Further, the gabbro at the same place is cut by small basic dikes. The gabbro, which here is porphyritic with up to 0.5 mm long feldspar phenocrysts, forms angular fragments about 15–20 cm in size. South of the bridge over the river Kalix, west of Vähävaara, there occur in the syenite several basic dikes (Fig. 5). These are 1–2 m wide, trend N85°E and dip ver-



Fig. 5. Basic dike (at the hammer) in syenite. West of Vähävaara.

tically or 85° towards the south. The contact against the syenite is sharp. A part of the basic material fills small embayments and fissures in the syenite.

In all localities the basic dikes are made up by a dark, fine-grained, weakly schistose rock, which in places contains up to some millimetre big spots of hornblende which are orientated along the schistosity. Occasionally the basite is cut by small epidote-schlieren. In one of the dikes south of the bridge over the river Kalix the rock is cut by some decimetres wide quartz veins. The quartz is bordered against the basic dike by a some centimetres thick zone of epidote.

The microscope shows that the mineralogical composition of the dikes is the same in all localities. The main minerals are a grass-green hornblende and a turbid, weakly brownish oligoclase-andesine which is strongly sericitized. In subordinate amounts there occurs fresh microcline together with the plagioclase. All the minerals mentioned make up a equigranular aggregate with a grain size of about 0.2–0.3 mm. Some grains of both hornblende and plagioclase attain 2–3 mm. Sphene, apatite, epidote and opaque minerals are found as accessories.

LINA GRANITE

As has been stated before, the Lina granite covers the main part of the Narcken area. It is a red, mostly fine- to medium-grained, sometimes weakly schistose rock which is poor in dark minerals. In some places, as at Vähävaara and NW of the village of Narcken, the granite is rather fine-grained and somewhat schistose, having an almost quartzitic appearance. On the other hand there are varieties of the granite with a grain-size over 5 cm. In these pegmatitic varieties quartz is dominating and feldspar subordinate or absent.

The Lina granite is the youngest rock of the area. It intersects the meta-sediments, gabbro, syenite and gneiss. These rocks except for the gneiss also occur as angular to subangular fragments in the granite. The granite is, however, partly affected by a later tectonization and alteration. A rather common feature is that the granite is epidotized. The epidote appears evenly distributed in the rock or as 2–5 mm wide veins. This is *inter alia* the case with the granite outcrops along the river Kalix. An epidotized granite is thus observed north and east of Narcken village, east and south of Kuusisaari and in the southern part of Vattuvaara. Further, the granite in the western part of Vattuvaara and south of Kuusisaari is cut by narrow veins of quartz in which the mineral forms 2–3 cm long, euhedral grains. These veins, which are orientated at random, sometimes contain small amounts of red feldspar.

In some places the granite has been affected by a late tectonization. At Vähävaara the granite is partly sheared in a N–S direction. The granite south of Narcken, at Narkån (west of Kuusisaari), is strongly crushed in a direction striking $N50^\circ W$ in the north-western part of the outcrops. The crush zone, which has a width of about 100 m, is the central part rich in epidote: in a mat-

rix of epidote and quartz here occur up to centimetre-big, irregular grains of a red feldspar.

The microscope shows that the Lina granite is built up of about equal amounts of quartz, microcline and albite in a hypidiomorphic texture. The feldspars, which sometimes are weakly turbid, form up to 5 mm long, anhedral crystals. The quartz which has a wavy extinction, occurs mostly as a matrix between these. In both, occur small inclusions of the other feldspar. The albite is occasionally sericite-altered and zoned. A green chlorite and opaque minerals occur as accessories.

A thin section of a fine-grained "quartzitic" granite from the western part of Vattuvaara shows that the rock is dominated by 0.2–0.5 mm big, anhedral quartz grains with wavy extinction. Epidote is found in subordinate amounts as irregular aggregates partly growing over the borders of the quartz grains. Microcline occurs in small amounts.

GNEISSES

In the Narcken area there are some small occurrences of gneisses. In part these are most probably metamorphic derivatives of the meta-sediments. This is certainly the case with the gneisses found roughly 3 km W of Narcken. They are grey, fine-grained, banded rocks with alternating quartz-feldspar and mica layers. The gneiss is here cut by 1–2 m wide granite dikes which follow the foliation. The microscope shows that the gneiss is built up by a fine-grained aggregate (0.1–0.2 mm) with a weak parallel texture. The main minerals are quartz and a somewhat sericitized albite. Both minerals occur as anhedral grains with rather even boundaries. In subordinate amount there are laths of a red-brown biotite, often forming separate layers. In these are found up to some millimetre-big, skeleton-like grains of andalusite.

Within the Lina granite at Vähävaara, which here is rather fine-grained, there is a NNW–SSE trending zone of a gneiss. It is made up of a grey, fine- to medium-grained schistose matrix of biotite and quartz which contains some centimetre-big, white-brown, irregular feldspar crystals.

Gneisses are covering a rather big area at Saikosjärvi, 7 km SW of Narcken village (outside the map-area on Fig. 2). There occur quartz-feldspar-biotite-gneisses which though mostly rather coarse, are partly fine-grained. In places the gneisses contain a green, most probably chrome-bearing mica.

THE IRON MINERALIZATION AND ASSOCIATED ALTERATION ROCKS

Now follows here a description of the different hematite mineralizations in the Narcken area together with the epidote-quartz-rich rocks and albite-rich rocks that accompany them. None of the mineralizations has any economic value as the occurrences are too small and lean. The largest mineralization lies

at Vattuvaara, SE of Narcken village. The occurrence at Kartovaara, NNE of the village, is smaller, and still smaller are the mineralizations around Kuusi-saari in the river Kalix. In the occurrence SW of Kartojärvi there is found an epidote-quartz alteration with only quite small amounts of hematite. North of Narcken village, on a small island in the river Kalix, there is also an occurrence where only epidote-quartz-altered rocks are encountered.

Vattuvaara

The iron mineralization at Vattuvaara is situated about 3 km SE of Narcken village and about 50 m SW of the main road to the south to Överkalix. Here a hematite-epidote breccia is outcropping over a distance of about 50 m. The outcrops are orientated in a NW-SE direction. The width of the zone is at least 5-10 m. In the immediate vicinity to the south there are some small outcrops of the meta-sediments.

Two types of breccia can be distinguished which grade into each other without any sharp border. One type is hematite-rich with fragments of epidote and hematite in a matrix of hematite, epidote and chlorite. The other type contains quartzitic fragments in an epidote-rich matrix.

In the hematite-rich breccia the macroscopically visible fragments are almost solely made up by fine-grained epidote. These fragments are subangular and up to some decimetres in size (Fig. 6). The matrix between these is made up by a fine- to medium-grained, non-schistose aggregate of hematite, epidote and chlorite. The hematite forms 0.05-2 mm, occasionally 10 mm big, angular or sub-angular fragments (Fig. 7). The hematite contains in most cases small, irregular remnants of magnetite which usually are in the middle of the hematite grains. The magnetite is partly altered to hematite along the octahedral planes and there is no doubt about the later origin of the hematite. In the hematite small grains of pyrite occur quite occasionally.

The matrix between the epidote and the hematite fragments has a grain-size of about 0.02 m and is made up of anhedral epidote and pale-green chlorite, the latter mostly with anomalous interference colours. Partly there are bigger laths of chlorite up to some millimetre in size. In minor amounts are found euhedral crystals of apatite which are about 0.5 mm long and occasionally have a kernel of epidote. As an accessory mineral occurs orthite also well crystallized or in some cases metamict. The presence of orthite is here, like in the other occurrences of the iron mineralization in the Narcken area, responsible for the weak radioactive radiation that is observed over the outcrops. In the epidote-chlorite matrix there occur irregular or somewhat elongated fillings up to 1 mm in size (Fig. 8). At the border there are subhedral grains of epidote and chlorite. The central part of the fillings consist of anhedral grains of quartz.

The matrix of the epidote-rich breccia is rather similar to the above de-



Fig. 6. Epidote-fragments (light) in a matrix of hematite and some epidote. Vattuvaara.

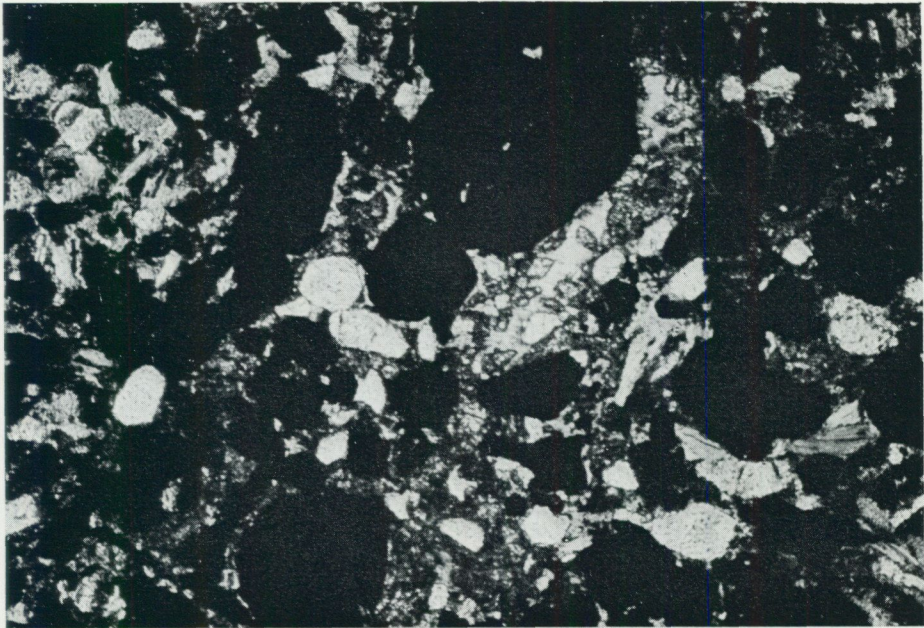


Fig. 7. Iron mineralization. Fragments of hematite (black) in a matrix of epidote and chlorite. White, often prismatic grains are apatite. Vattuvaara. Thin section, Ord. light, x 35.

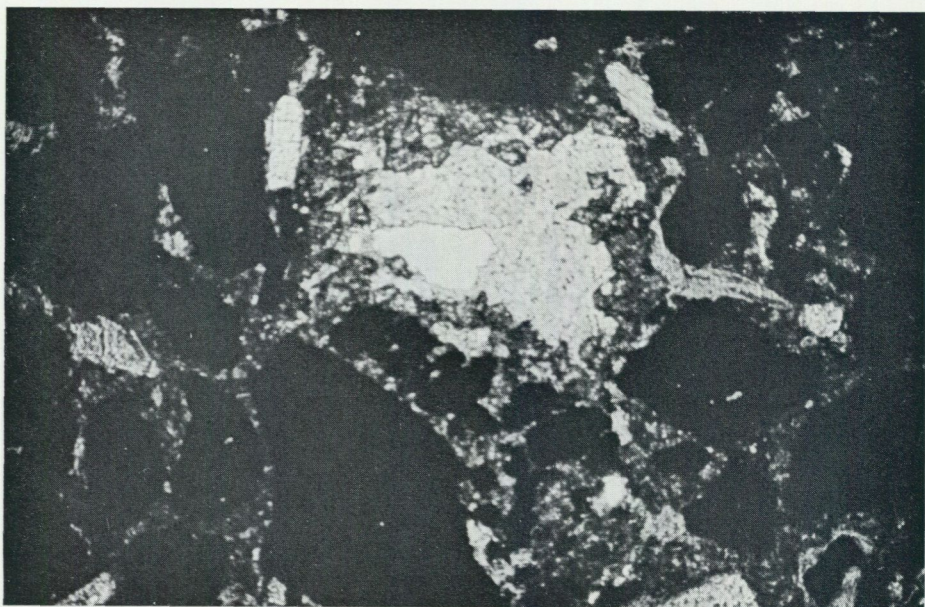


Fig. 8. Iron mineralization. Fragments of hematite (black) in a matrix of epidote and chlorite (in part larger, lath-formed grains). The vug is filled with quartz (white, in the center), chlorite (grey-white) and epidote (grey, at the border). Vattuvaara. Thin section. Ord. light, x 35.

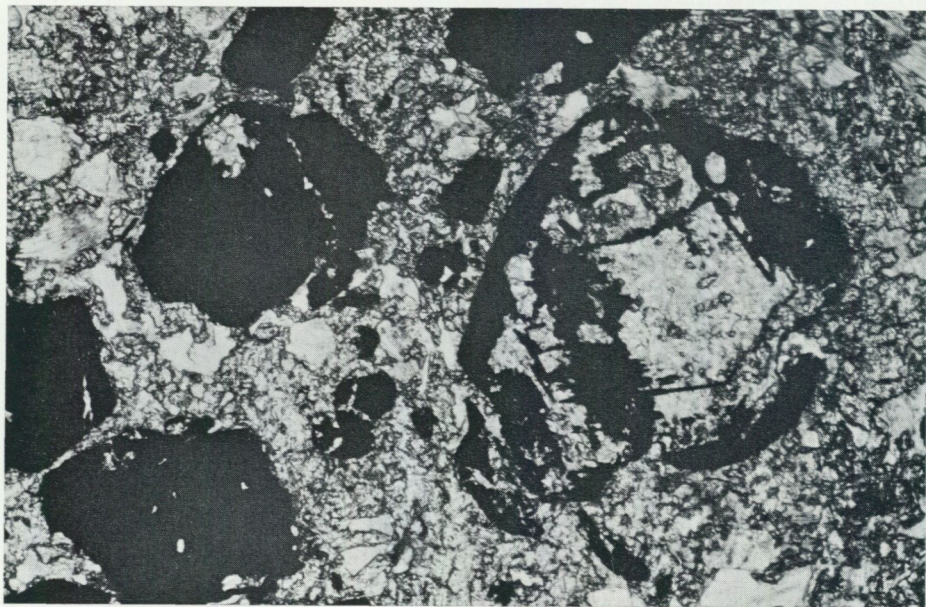


Fig. 9. Iron mineralization. Hematite (black) in a matrix of epidote and chlorite (grey-white, lath-formed grains). In the hematite grains chlorite and some epidote. Vattuvaara. Thin section. Ord. light, x 35.



Fig. 10. Angular fragments of a quartzite (light) in a matrix of epidote. Vattuvaara.

scribed, except that epidote here dominates. Further, a great part of the chlorite occurs as 1 mm long laths which form 2–3 mm wide zones veining the rock or up to 4 mm big aggregates. Quartz partly occurs in subordinate amounts as 0.1 mm big anhedral grains with simple intergrowths and a wavy extinction. The hematite fragments are here developed as skeleton crystals in which the open space is filled with epidote and chlorite (Fig. 9).

The epidote-dominated breccia contains up to 5 cm big, subangular fragments of a light green-grey, dense, non-schistose quartzite (Fig. 10), which is similar macroscopically to some varieties among the meta-sediments. The fragments are crushed and veined by 1 mm wide quartz-filled fissures. The quartzite consists of 0.1 mm big, anhedral quartz grains with simple intergrowth surfaces, and subordinate amounts of anhedral epidote and laths of a

pale-green chlorite. The epidote, which is partly forming monomineralic zones, has sometimes a kernel of a metamict orthite. In accessory amounts there is found iron oxides. These fragments are without doubt related to the meta-sediments.

The meta-sediments to the south of the iron mineralization are brown-grey, fine-grained and weakly schistose. The main minerals are quartz, epidote and a red-brown chlorite. The sediments are cut by 1–2 cm wide quartz veins in which the quartz forms up to 1 cm long, euhedral crystals. These veins are sometimes brecciating the sediments and small angular fragments of these are found in the veins. The quartz around the fragments is rather fine-grained compared to the coarser quartz of the vein as a whole. Quite locally are found in the quartz veins fragments of a brown-red, fine-grained feldspar rock, which is presumably a metasomatic alteration product of the meta-sediments. This feldspar rock is very similar to the albitic leucodiabases which are found in other parts in the Norrbotten county. These rocks are by some authors (e. g. Ödman 1957) considered to have a late-magmatic origin connected with a basic volcanism and by other authors (e. g. Padget 1959, Frietsch 1966) to have a metasomatic origin, being formed in connection with fault lines.

To the east of the breccia zone, along the western bank of the river Kalix, there occur over a distance of about 500 m a great number of local boulders of a hematitic breccia similar to that described. If the source of the boulders is the Vattuvaara occurrence it means that the direction of the ice movement has been almost straight from the west. As will be shown later there is possibly a young ice-movement from the SSW or S in the Narken area. If the boulders were transported by this movement it would mean that the source was to the south of Vattuvaara, the boulders emanating from an occurrence which does not outcrop. The evidence for transport towards the north is supported by the fact that a local boulder of the hematite breccia was found in the moraine in the southern part of Narken village. The boulder, which is fairly angular and about 3 dm long was found at a depth of about one metre when excavating for the basement of a house. Further, there are a great many breccia boulders found SW of Kartojärvi, immediately to the east of the iron mineralization on the northern embankment of the river Kalix.

Kartovaara

On the northern side of low hill Kartovaara, 4 km NNE of Narken village, there occurs a hematite ore of rather restricted extension. Detailed mapping shows that there are two separate mineralizations of which the largest has a size of about 5×10 m. The other mineralization, which lies about 5 m to the east, has an area of about 5 m². There is no distinctive strike of the ore. It seems

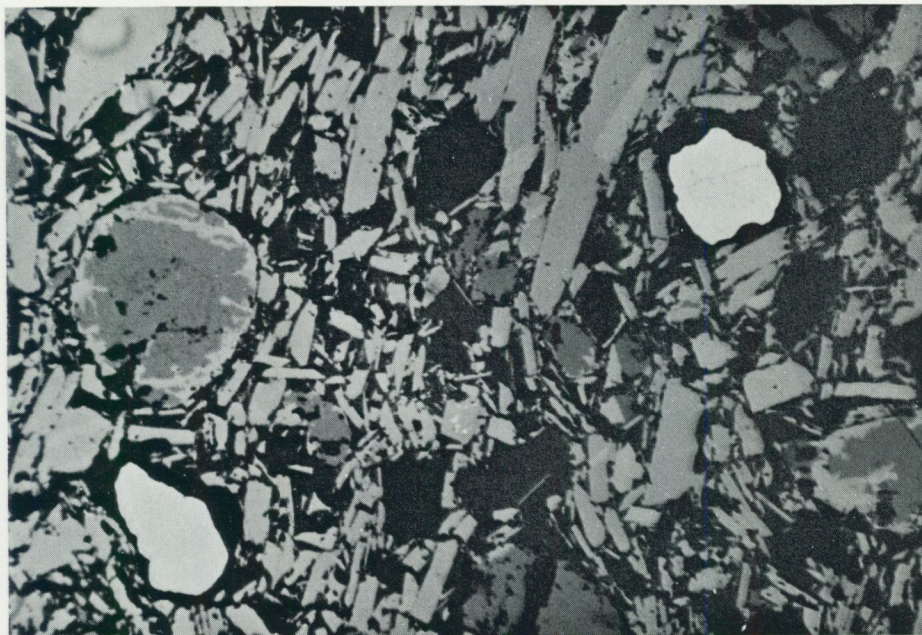


Fig. 11. Iron mineralization. Hematite (light-grey, laths and needle-like grains), small amounts of magnetite (grey, irregular, partly rather round grains which at the border are hematite-altered) and apatite (black, rectangular or hexagonal grains). White grains are chalcopyrite. The dark matrix surrounding all minerals is epidote. Kartovaara. Polished section. Ord. light, x 73.

merely to form irregular bodies with sharp borders against the host rocks which are metasomatically altered and brecciated. These altered rocks are bordered to the south by the Lina granite.

The mineralization at Kartovaara is rather similar to the hematite-rich breccia at Vattuvaara. It has a fine-grained, non-schistose, hematite-epidote matrix in which lie up to 2 mm, occasionally 10 mm big, angular fragments of hematite. Locally the breccia is somewhat magnetic which means that the iron oxides in the matrix and the fragments in part consist of magnetite. In the matrix occur small amounts of 1–2 mm big, subhedral grains of pyrite. In this breccia there are no larger fragments and epidote-rich parts as at Vattuvaara.

The microscope shows that the mineralizations are dominated by 0.1–0.2 mm long, laths or needle-shaped grains of iron oxides (Fig. 11). In small amounts there are up to 3–4 mm rectangular grains. The laths or needles are mostly orientated at random but sometimes in a semi-parallel way. Hematite dominates, magnetite occurring only in smaller amounts. The magnetite is mostly altered to hematite along the grain borders. Many of the bigger, rectangular grains are made up of magnetite and they are usually crushed and cataclastic. Between the iron oxides there are small anhedral grains of turbid

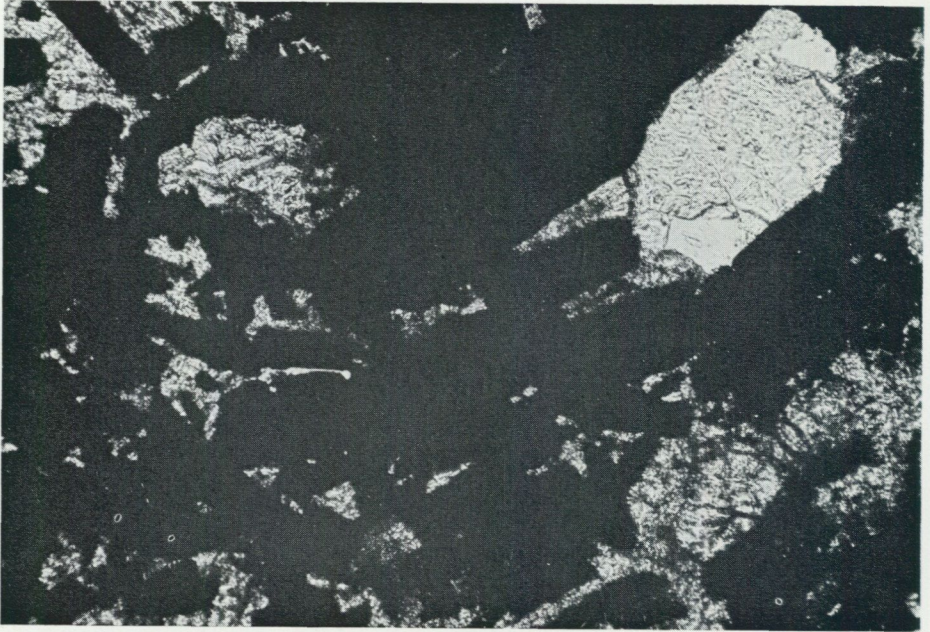


Fig. 12. Iron mineralization. Hematite (black) surrounded by epidote (grey) and apatite (grey-white, in the upper, right part). Kartovaara. Thin section. Ord. light, x 190.

epidote and small laths of brown biotite (Fig. 12). In small amounts occur 0.1 mm long euhedral or somewhat corroded grains of apatite. Further there are some corroded and cataclastic grains of pyrite and exceptionally of chalcopyrite. Both sulphides are veined by fine cracks which in part are goethite-filled. The bigger pyrite grains cause the needles of the iron oxides to "flow" around the pyrite. Rather usual are up to some millimetres big, rounded or sometimes elongated vugs filled with quartz and minor amounts of epidote forming sub- to euhedral grains.

The iron-rich breccia at Kartovaara is on all sides surrounded by albite-rich alteration rocks. These have a rather varying mineralogical composition due to different contents of epidote, amphibole and chlorite. There seems to be no definite borders between the different rock types as they mostly grade into each other.

The most common type is a red or brown, fine-grained, non-schistose, syenitic feldspar rock, often relatively rich in epidote. The epidote is evenly distributed or occurs as veinlets, mostly with diffuse borders against the rock. The texture is hypidiomorphic in most cases. The main mineral is a rather turbid and epidote-altered albite forming subhedral, often broad laths. They are usually less than 1 mm in size but in some cases up to 5 mm. Subordinate is a yellowish epidote which lies around the feldspar laths and partly corrodes



Fig. 13. Albite-extreme, syenitic rock. Albite (laths), tremolite-actinolite (in the interstices between the albite) and some quartz (small white grains). Kartovaara. Thin section. Nic. +, x 35.

these. In connection with the epidote there is some orthite. Accessory minerals are quartz, green amphibole and green chlorite. In some samples quartz is a main mineral, and occurs together with 1 cm big laths of microcline.

South-west of the iron mineralization, on the western slope of Kartovaara hill, there is a rather irregular distribution between the above described syenitic rock and albite rocks, which are relatively rich in dark minerals. They vary much in composition and often have a hybridic appearance. Most common are brown-grey, medium-grained, non-schistose rocks built up by red feldspar lying in a matrix dominated by amphibole (Fig. 13). The texture is intersertal. The microscope shows 0.5–3 mm long, broad, subhedral laths of a red-brown, rather fresh or sometimes turbid albite which is relatively rich in small aggregates of epidote and chlorite. The albite is surrounded by a green tremolite-actinolite which is partly altered to a brown-green chlorite containing leucoxene. As a later mineral around the albite and amphibole there occurs small amounts of quartz and microcline. The rock is often cut by mm-wide veins with quartz and epidote.

Some of the rocks found on the western slope of Kartovaara are dark-grey or grey greenish, fine-grained and have a greenstone-like appearance. However,

under the microscope these are very similar to the last described rocks, the only difference being a somewhat smaller grain size. They consist of turbid albite laths, intersertally arranged in a matrix of pale-green tremolite and small amounts of epidote and pale-green chlorite. These rocks are sometimes cut by the first described red, syenite rock and occur in veins of this as angular fragments.

On the north-western slope of Kartovaara there is a rather peculiar rock which consists of a fine-grained epidote-matrix with up to 2 cm big, angular grains, almost fragment-like, of a brownish, turbid microcline rich in small grains of quartz and epidote. The microcline grains are crushed and broken. The epidote-matrix is veined and "sucked" by quartz.

To the south and north-west of the iron mineralization the red, syenitic rock is cut by an irregular net-work of quartz veins about 1-2 cm wide. The syenite lies as angular fragments between the veins giving the rock a breccia-like appearance. The quartz in the veins is brown-white and forms up to 5 mm big, rather well-crystallized grains. As a rule the quartz is followed by epidote and the syenitic rock near the quartz veins is rather epidote-rich.

It is quite obvious that the different albite-epidote-amphibole rocks described above are not intrusives, but the product of hybridization or metasomatic alteration. The common feature for all the rocks at Kartovaara is a richness in albite. The author is therefore most inclined to consider the different types of "syenite" to be related to the leucodiabases, being formed by metasomatic alterations. Albite-extreme rocks, together with an iron mineralization similar to that at Kartovaara, have been found at Vattuvaara (p. 20) and at Kuusisaari (p. 25).

Kuusisaari

The island of Kuusisaari, east of the Narkån outlet in the river Kalix, in the northern part is built up by the Lina granite. In the northernmost outcrops (on the eastern side of the island) the granite contains remnants of the meta-sediments, which shows that these rocks are occurring in the vicinity. South of the granite there occurs a fine-grained, epidote rock with 2-3 mm big, angular fragments of hematite. The epidote rock is cut by veins of brown-white quartz which contains up to 3 cm big druses with idiomorphic quartz crystals. The epidote rock is further cut by 4 cm wide veins of a fine-grained hematite. These are surrounded by 1-2 cm wide, random orientated quartz veins which partly are somewhat epidote-bearing. The epidote rock is here "sucked" with finely divided quartz.

On the southern point of Kuusisaari there are found alteration rocks of different kind. Some twenty metres north of the point there is a pale-brown, medium-grained, non-schistose feldspar rock which contains up to 1.5 cm long, narrow, needlelike aggregates of biotite arranged at random or sometimes in a texture similar to an intersertal one. The rock is mainly built up of



Fig. 14. Albite-extreme, syenitic rock. Albite (laths) with some biotite (dark or grey, irregular grains) and magnetite (small black grains). Kuusisaari. Thin section. Nic. +, x 35.

2–5 mm long, rather broad laths of albite which is somewhat turbid and epidote-biotite-altered. The albite is surrounded by anhedral grains of quartz with a wavy extinction, and a red-brown biotite in rather long laths. In connection with the biotite there is some leucoxene and iron oxides. The rock is cut by narrow epidote veins.

On the southern point of the island there is a brown-violet, fine-grained feldspar rock which is cut by quartz veins with druses filled with euhedral quartz grains. The rock almost totally consists of about 0.5 mm long laths of a turbid albite arranged in an intersertal texture (Fig. 14). The albite is rich in anhedral grains of yellow epidote, red-brown biotite and hematite. These minerals also form separate aggregates on the side of the albite laths. In small amounts, the rock contains quartz, mostly between the albite, and leucoxene, usually lying as rim around the hematite.

On the western side of Kuusisaari, almost immediately west of the above described feldspar rock, there occurs a zone, some metres wide, of a hematite mineralization quite similar to that at Vattuvaara and Kartovaara. In a matrix rich in hematite and epidote lie up to 1 cm big angular fragments of hematite ore, a fine-grained epidote rock and a dense quartzite. The host rock of the breccia is an epidote-quartz-rich rock which contains narrow, irregular veins



Fig. 15. Small veins of hematite (dark) in a epidote-quartz-rich alteration rock. Kuusisaari.

of hematite (Fig. 15). At the end of the veins the hematite is replaced by quartz. Further, this epidote-quartz-rich rock is cut by centimetre wide quartz veins with druses filled by idiomorphic quartz. The quartz veins are bordered against the epidote-quartz-rich rock by a zone, some millimetres thick, of hematite.

East of Kuusisaari

East of Kuusisaari, on the eastern bank of the river Kalix, there occur meta-sediments surrounded by the Lina granite. The meta-sediments which are banded and small folded (cf p. 9) are cut and intruded by the granite and form several metres big, angular or somewhat rounded fragments in the granite. The meta-sediments are further brecciated by up to 10 cm wide, rather straight quartz veins forming a net-work some metres wide. In the quartz lie small angular fragments of the meta-sediments (Fig. 16). The quartz-veins contain druses with well crystallized, 2–3 cm long quartz grains. Occasionally there is some hematite in the veins. A thin section of the quartz veins shows that 0.5–1 mm big, anhedral quartz grains with a wavy extinction dominate. The grain surfaces are rather irregular. The quartz is partly powdered with a fine dust of sericite. In small amounts there occur epidote and a pale-green chlorite.

Within the area covered by the meta-sediments a hematite-breccia similar to

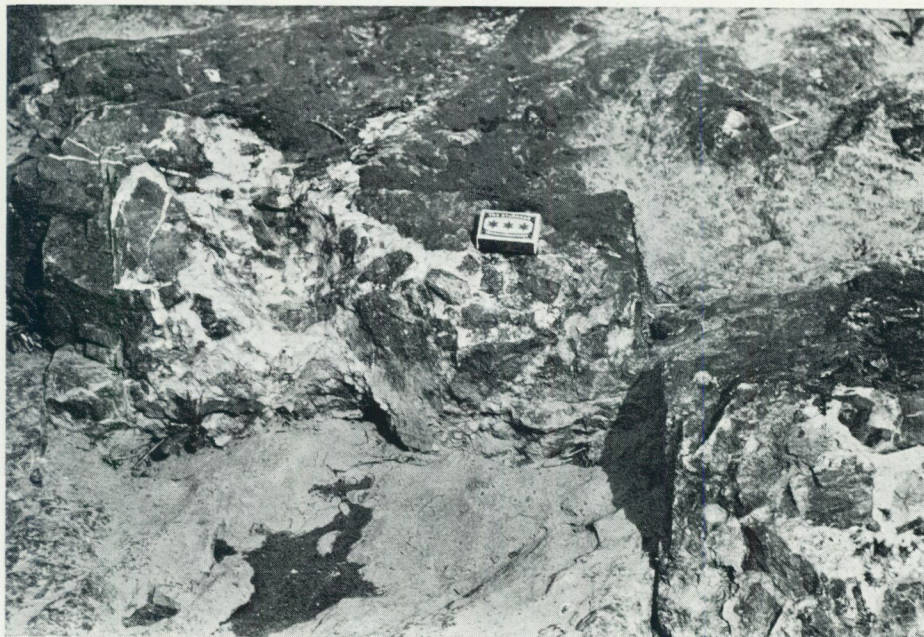


Fig. 16. Meta-sediments brecciated by quartz veins. East of Kuusisaari.

that on Kartovaara and Vattuvaara is encountered. The meta-sediments near the breccia are somewhat epidotized. The breccia, which covers an area of about 25×30 m, has a fine-grained matrix which is weakly magnetic implying the presence of magnetite. In small amounts there occur 1–2 mm big grains of pyrite. The matrix is built up mainly of hematite (and magnetite) fragments and a rather high content of quartz. The content of epidote and chlorite is here rather low compared to the other breccias described. In small amounts occur some millimetre long apatite crystals. The coarser fragments are mainly made up of hematite. They are angular and up to 1 decimetre in size. Less common are angular fragments of the meta-sediments and different types of alteration rocks. The fragments of the meta-sediment are sometimes up to 3–4 decimetres in size. Among the fragments of the alteration rock are found red-brown feldspar rocks like the “syenite” at Kartovaara. Further there are fragments of red-brown, dense, almost glassy, quartzite-like rocks and green-white, fine-grained quartzite-like rocks.

The hematite mineralization is veined by alteration rocks which in most cases are red-brown, fine-grained and built up mainly of feldspar and amphibole. Further the iron mineralization is cut by quartz veins similar to those in the meta-sediments. The quartz veins, which have quartz-filled druses, contain small angular fragments of the hematite mineralization and of the meta-sediments.

South-west of Kartojärvi

South-west of Kartojärvi, on the northern bank of the river Kalix there is an outcrop of a green, fine-grained, non-schistose epidote rock which contains small, angular to subangular fragments of hematite with some pyrite. The epidote rock is intersected by 2–5 mm wide quartz veins. The host rock of this epidote rock is not known. About 100 m to the WNW there are outcrops of the syenite.

North of Narken village

North of the village of Narken there are some small islands in the river Kalix. The rocks found here are rather varying. Most common is the syenite. Further there occurs a gabbro and the Lina granite. The syenite cuts the gabbro, but is in turn cut by the granite. In the syenite are found breccias with quartz and epidote. Sometimes the syenite is totally epidotized.

THE ORIGIN OF THE IRON MINERALIZATION AND ASSOCIATED METASOMATIC, ALTERATION ROCKS

The iron mineralization that occur at different localities in the vicinity of Narken village are most possibly of late origin formed by the action of metasomatic solutions in tectonic zones. There seems to be a connection between the iron mineralization and the meta-sediments which is most certainly a spatial relationship. A syngenetic, sedimentary origin for the iron mineralization is excluded. It is more likely that the meta-sediments were favourable tectonic elements, leaving space for the iron mineralization to form. The fact that mineralization is not found in the other rocks of the area is possibly due to the difference in competence between the sediments and the plutonic rocks.

The age of the iron mineralization must be relatively young. The iron mineralization is connected with an epidotization, which is a conspicuous feature in many of the rocks in the Narken area. This process has also influenced the Lina granite and the iron mineralization must therefore be younger than the granite.

The formation of the iron mineralization has taken place in crush zones in the meta-sediments. The tectonization of the sediments facilitated movement of the ore-bearing solutions. These brought in iron oxides and epidote. The meta-sediments were altered at the same time, giving rise to the albite-extreme, syenite-like and hybridic rocks. Of special interest in this connection is the crush zone that occurs in the Lina granite at Narkån, south of Narken (cf. p. 14). The central part of this crush zone contains epidote with irregular feldspar grains, a combination that among others is found in the proximity of the iron mineralization at Kartovaara. Further, the quartz veins which cut the iron mi-

neralization, and presumably are the latest phase in the metasomatic activity, also intersect the granite.

The formation of the iron mineralization can be described schematically in the following way. The Narken area was affected by faulting of rather young age, occurring after the formation of the Lina granite which is younger than the supracrustal rocks and the other plutonic rocks of the area. The resulting faults have different directions. One of the main tectonic lines follows the river Kalix and trends in a NW-SE direction. In the vicinity of this main line, and especially where this is intersected by the other fault lines with a more E-W direction, the circumstances were favourable for metasomatic solutions to operate. At the junctions between the different lines the tectonic effects were the greatest. In the meta-sediments there originated a system of open fractures. This made it possible for the iron mineralization to form. The surrounding meta-sediments were partly altered by the metasomatic activity and the albite-extreme, syenite-like rocks were formed. The first stage of the mineralization was the introduction of iron oxides (hematite and magnetite) together with epidote and small amounts of pyrite. These minerals filled the fracture system or crystallized in veins in the meta-sediments. At a somewhat later stage the fracture fillings and veins were tectonically affected, the tectonization continued throughout the whole metasomatic activity. The first mineralization was broken up and the result was the present breccia with fragments of iron oxides and epidote. The iron oxides formed small fragments whose size usually does not exceed some millimetres. Only in small amounts are there fragments up to some decimetre in size of a massive iron ore. The epidote mostly formed larger fragments, also some decimetre in size. Locally the meta-sediments and the metasomatic alteration rocks occur as fragments. This breaking up of the first formed mineralizations was followed by the introduction of a new generation of epidote together with chlorite and minor amounts of apatite and quartz. The formation of albite-extreme rocks out of the sediments must have occurred in part later than this phase as the iron mineralization east of Kuusi-saari is veined by the albite-extreme rocks. The latest phase in the whole metasomatic activity was the formation of the quartz veins with the quartz filled vugs. A small amount of iron oxides was brought in in connection with the formation of quartz.

It is evident that magnetite at least in part has been the primary iron oxide in the mineralization but later altered to hematite by oxidation. This alteration took place only in those parts of the iron mineralization where pyrite is missing. It is a conspicuous feature that the magnetite-bearing parts of the breccia always contain small amounts of pyrite, which is not the case with the "pure" hematitic parts. As has been pointed out by the present author (Frietsch 1966, 1970) the oxidation of magnetite to hematite is prevented by the presence of reducing agents which can be e. g. sulphides and graphite. The partial pressure

of sulphur in the Narken mineralization has been locally high enough to keep the oxygen pressure relatively low so that not all the magnetite was oxidized. Whether the oxidation of the magnetite occurred in connection with the formation of the iron mineralization or with later, supergene processes is not known.

The iron mineralization in the Narken area resembles in some respects the fragment-bearing ore at the Gruvberget iron ore deposit in the Svappavaara area (Frietsch 1966). This type of ore which only takes up a minor part of the ore body in the hanging wall contains fragments of hematite ore and sericite schist. The matrix is made up by hematite, chlorite, quartz and calcite. The hematite in the matrix consists mainly of 0.05–0.3 mm big, angular grains and which mostly are single crystals. The fragment-bearing hematite ore has a tectonic origin and is related to a crush zone that follows the hanging wall of the ore body. The hematite in the fragments and in the matrix are crush products of the hematite ore making up the main part of the ore body. The other minerals in the matrix are considered to be metasomatic. That the tectonization and the formation of the fragment-bearing ore is relatively young is shown by the presence of fragments of microcline derived from the pegmatites of the Lina granite.

There are thus some similarities in the mode of formation and the relative age between the iron mineralization in the Narken area and the fragment-bearing hematite at Gruvberget. The main hematite ore at Gruvberget from which the fragment-bearing ore emanated is, however, of magmatic origin like the other iron ores of the Kiruna type.

No possible source for the ore forming solutions in the Narken area can be given. There are no indications of such a late ore-forming activity elsewhere in Norrbotten.

GEOCHEMICAL FEATURES OF THE IRON MINERALIZATION

The chemical composition of the iron mineralization at Vattuvaara, Kartovaara and Kuusisaari is shown in Table 2. The main variations between the analyses are due to the varying content of epidote, chlorite and quartz. The higher content of magnesium and aluminium in the sample from Vattuvaara is related to a higher content of chlorite. The higher silica content in the sample from Kuusisaari is due partly to a rather high quartz content partly to the presence of quartzite-fragments. The $\text{Fe}_2\text{O}_3/\text{FeO}$ -ratio in the analyses shows that the mineralization at Kartovaara contains some magnetite and that the mineralization at Vattuvaara and Kuusisaari consists of an almost pure hematite. Furthermore the hematite-magnetite ore from Kartovaara has the highest sulphur content which is in accordance with the statement made earlier (p. 29) that sulphur restrains the oxidation of magnetite to hematite. In the Kuusisaari mineraliza-

Table 2. Chemical composition of the iron mineralization in the Narken area. Weight %.

	Vattuvaara sample No. 090-1840	Kartovaara sample No. 090-1841	Kuusisaari sample No. 090-1842
SiO ₂	12.0	19.9	25.6
TiO ₂	0.09	0.13	0.09
Al ₂ O ₃	8.0	7.0	3.4
Fe ₂ O ₃	64.9	55.3	60.1
FeO	2.5	5.2	0.6
MnO	0.08	0.03	0.03
CaO	6.1	6.7	5.1
MgO	2.7	0.8	0.9
Na ₂ O	0.3	0.6	0.8
K ₂ O	0.2	0.6	0.6
H ₂ O	2.3	1.6	0.8
H ₂ O	0.3	0.4	0.2
P ₂ O ₅	1.3	0.81	0.41
CO ₂	0.02	0.05	1.37
S	0.02	0.66	0.02
BaO	0.01	<0.01	<0.01
	100.8	99.79	100.0
Corr. O-S		-0.32	
		99.5	

tion there is some calcite which gives the relatively high carbonate content in the analysis.

One of the conspicuous features of the iron mineralization in the Narken area is the common presence of euhedral grains of apatite. The content of phosphorus in the analyses is consequently rather high. The apatite in the samples from Vattuvaara and Kartovaara was separated by heavy liquids and the concentrate analyzed mainly for fluorine and chlorine. The partial chemical analyses are shown in Table 3. In both samples there is a preponderance of fluorine over chlorine. The F/Cl-quotient is greater than 17. A similar value is found for the apatite in most of the iron ores of the Kiruna type in Norrbotten (Frietsch, in preparation). In some deposits of this ore type the apatite is, however, intermediate in the fluorine-chlorine content. A similar F-Cl-intermediate apatite is further found in several skarn iron ores in Norrbotten. There seems thus to be a difference in the composition of the apatite in the iron ores of the Kiruna type and the iron mineralization at Narken, both of "magmatic" origin, and the apatite in the skarn iron ores, which most likely are of sedimentary origin (Frietsch 1971).

Table 3. Partial chemical analyses of apatite from the iron mineralization in the Narcken area. Weight %.

	Vattuvaara sample No. 1820	Kartovaara sample No. 1823
F	3.4	3.5
Cl	<0.2	<0.2
Na	0.03	0.06
Mg	0.08	0.01
Al	0.2	0.07
Si	0.08	0.9
Ti	0.05	0.05
V	<0.002	<0.002
Cr	<0.001	<0.001
Mn	<0.01	<0.02
Fe	0.3	0.25
Co	0.003	0.003
Cu	0.006	0.002
Sr	0.02	0.04
Mo	<0.001	<0.001
Ce	tr.	tr.
Nd	tr.	tr.
Pb	<0.001	<0.001
F/Cl	>17	>17.5

A late-magmatic, metasomatic origin for the iron mineralization in the Narcken area is favoured by the geochemical composition of the iron oxides. Hematite from the mineralization at Vattuvaara, Kartovaara and Kuusisaari was separated by heavy liquids and the trace elements were determined spectroscopically at the laboratory of the Geological Survey of Sweden. The procedure of the investigation is identical to that used for the iron oxides in the other iron ore types in Norrbotten (cf. Frietsch 1970). The chemical analyses show that the hematite in the Narcken area on the whole is depleted in trace elements (Table 4). As has been shown by Frietsch (1970), this is characteristic for the iron oxides in some late-formed, metasomatic iron ores. This concerns especially the hematite in the iron ores of the Hauki type in Norrbotten which are considered to have been formed during a late stage in the same magmatic activity that gave rise to the apatite iron ores of the Kiruna type. Due to the late stage in the magmatic process the ore forming solutions giving the Hauki ores were relatively "empty" in trace elements. For comparison, the trace element contents of the hematite in the Hauki ores is given in Table 4. The similarity with the hematite from the Narcken area is obvious.

A rough estimate whether a rock or mineral is "rich" or "poor" in trace elements can be obtained by calculating the "accumulation-coefficient" (Frietsch 1970, p. 107). This coefficient is obtained by dividing the sum of the clarkes of concentration of the different elements by the number of the elements. If only the ferrides (viz Cr, Ti, Ni, Co, V and Mn) which are of most interest in this

Table 4. The content of some elements in hematite in the iron mineralizations in the Narcken area.

Sample No.	Mineral	Weight % of			p.p.m. of									
		SiO ₂	Al ₂ O ₃	CaO	Mg	Mn	Ti	Ni	Co	Cr	V	Cu	Zn	Pb
		Vattuvaara												
1819	Hematite	1.5	0.67	0.5	1700	< 80	240	30	40	<10	160	170	<10	20
1820	Hematite	1.8	0.78	0.7	2700	< 80	240	20	30	<10	140	140	<10	20
		Kartovaara												
1823	Hematite	1.5	0.77	1.1	<60	< 80	360	10	<10	<10	40	20	<10	<10
		Kuusisaari												
1842	Hematite	1.0	0.16	0.3	180	< 80	180	<10	10	<10	100	15	<10	<10
		Average Narcken area												
	Hematite	1.5	0.60	0.4	1100	< 80	260	10	20	<10	110	85	<10	10
		Iron ore of Hauki type, Northern Sweden (Frietsch 1970)												
	Hematite		>0.7	<0.5	<3000	<200	700	<20	<20	<20	80	60		

connection, are considered, the average for all Narken hematites gives an "accumulation-coefficient" of only 0.3. This low value indicates a strong deficiency of these elements and is similar to that obtained (0.4) for the hematite in the ores of the Hauki type. These values are both low compared with the coefficients for the iron oxides in magmatic formations which vary between 2 and 6, implying that the iron oxides in these formations have been enriched in the ferrides in comparison with the composition of the upper lithosphere.

Thus the geochemical features of the iron oxides in the Narken area favour the opinion of their late-magmatic, metasomatic origin.

The iron ore boulders in the Kihlanki area

GENERAL GEOLOGICAL SETTING

A similar iron mineralization as in the Narken area has been found as boulders in the glacial drift in the vicinity of the Kihlanki village at the Swedish-Finnish border (Fig. 17). The boulders were discovered by Mr Karl Grönberg living in Pissiniemi, NE of Kihlanki. In connection with the campaign, mentioned earlier, to encourage private persons to search for minerals of economic interest in the Norrbotten County, Mr Grönberg has thoroughly investigated the area around Kihlanki. When the present author, during the summer 1970, made a short visit to the area, 80 boulders more or less belonging to the same type of iron mineralization had been found. Most of the boulders are concentrated to the area west and north-west of Kihlanki village. They lie in a rather narrow sector about 20 km long and extending roughly NNE-SSW. Further to the north, at Puristakero, there are found some more boulders. The boulder-bearing zone has thus a length of roughly 30 km.

The geology of the bedrock in the area is rather simple. In the main, three types of rock are encountered: gabbro, gneiss and granite. The gabbros form semi-rounded occurrences which in part are eaten up by the granite. Near the Finnish border there are some rather irregular massifs. The gabbros cover only a minor area. Next in importance are the gneisses which mostly are of acid composition and poor in dark minerals, they are mainly quartz-feldspar rocks. The origin of these gneisses is not known. In some cases, as in the area south-east of Lumivaara, there are gneisses which are quartzite-like and possibly have a sedimentary origin. In the northern part of the Kihlanki area there occur basic gneisses which presumably are metamorphosed greenstones or lime-silicate rocks. The gneissic structure is in the main striking N-S. The granite that covers the main part of the Kihlanki area is a red, medium-grained microcline-quartz rock, referred by Ödman (1957) to the Lina granite. It cuts the gabbro and the gneisses. In the latter, the granite is mostly following the structure of the gneissification.

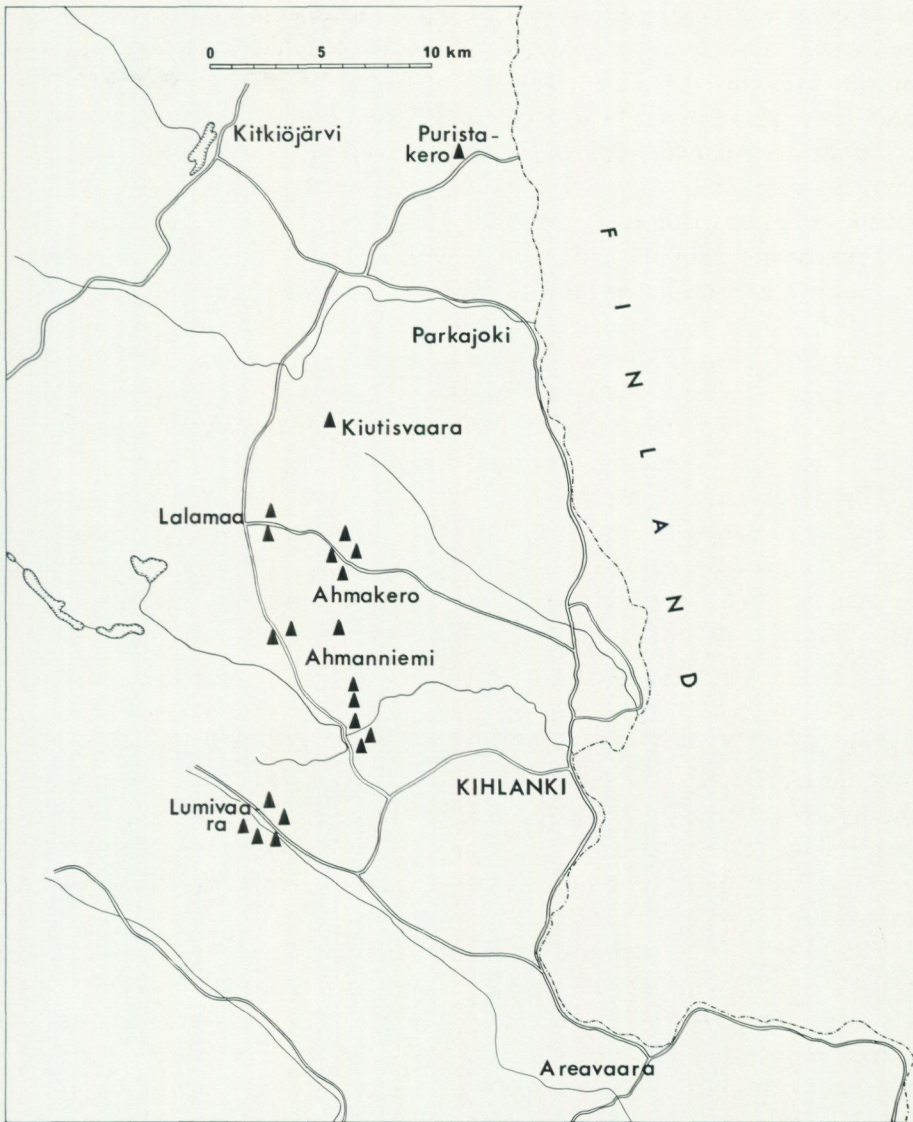


Fig. 17. Sketch map showing the position of the iron ore boulders W and NW of Kihlanki. The borders of the map, which are shown on Fig. 1, are equivalent to the map sheet 29 M Huuki.

South of this granite-gneiss area there occur supracrustal rocks which from the area west of Areavaara extend to the south-west over the village of Kaunisvaara for a distance of about 30 km. This rock series, with a width of several kilometres, is built up by greenstones, marls, graphite-bearing schists, dolo-

mites and quartzites. Near Kaunisvaara village there occur, connected with the dolomites, rather big occurrences of magnetite ore which is rich in lime-magnesium-silicates.

In none of the above mentioned rocks has an iron mineralization been encountered like that occurring in the glacial boulders around Kihlanki.

DESCRIPTION OF THE IRON ORE BOULDERS

The iron ore boulders in the Kihlanki area are sub-angular to rather well rounded and reach in size about 0.5 m³. Dominating minerals are as in the iron mineralization in the Narken area iron oxides and epidote. The high content of these minerals gives the boulders a dark colour which makes them easily recognizable from the lighter boulders of the Lina granite and the gneisses which dominate the moraine within the Kihlanki area.

The most common type of iron ore boulders is a breccia with a fine-grained matrix of hematite, epidote and chlorite. Angular and irregular fragments of hematite and small amounts of a dense, epidote rock, up to 5 mm, or sometimes 10 mm, in size, occur in the matrix. The latter is built up of 0.2–1 mm big, angular fragments of hematite and a subhedral, yellowish epidote (Fig. 18). Sub-

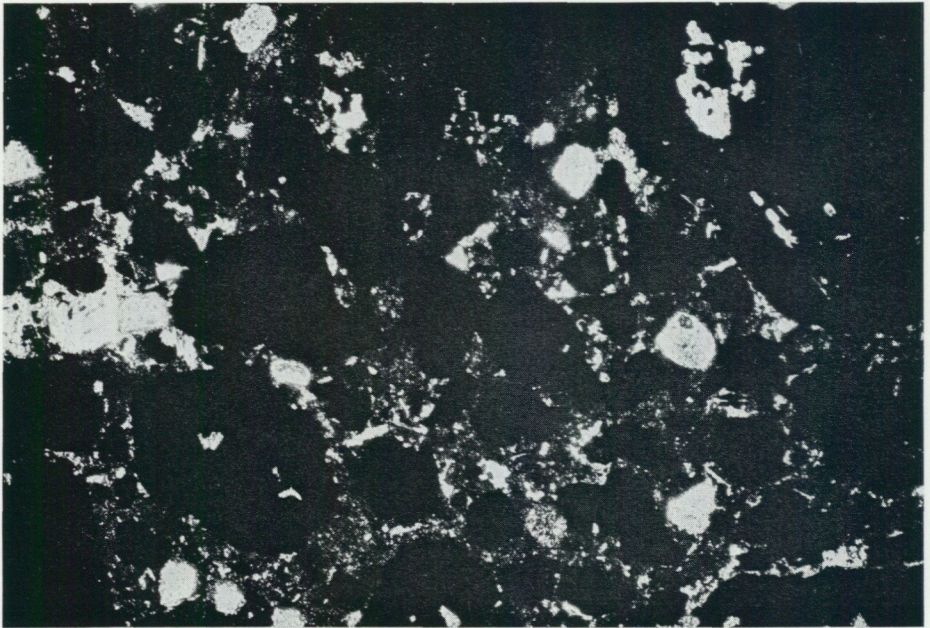


Fig. 18. Iron mineralization. Fragments of hematite (black) in a matrix of epidote and some chlorite. White, often prismatic grains are apatite. In the hematite small fillings of chlorite. Glacial boulder, Hirsikotanvaara. Thin section. Ord. light, x 35.

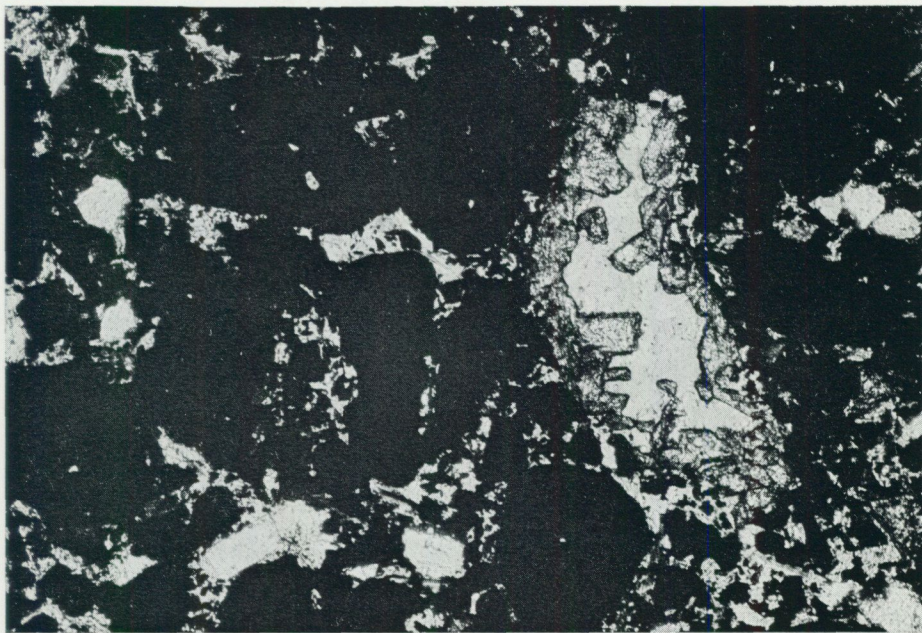


Fig. 19. Iron mineralization. Fragments of hematite (black) in a matrix of epidote and some chlorite. Bigger white grains are apatite. The vug is filled with epidote (grey, at the border) and chlorite (grey-white, in the center). Glacial boulder, Hirsikotanvaara. Thin section. Ord. light, x 35.

ordinate to these there is a fine-grained, pale-green chlorite with anomalous interference colours. The epidote is sometimes zoned, having a dark brown kernel of orthite (?). The chlorite occurs occasionally enclosed in small vugs in the hematite fragments. Further the matrix contains up to some millimetre big, elongated or more or less rounded vugs filled with chlorite (in the center) and epidote (at the border) (Fig. 19). In the vugs the epidote forms euhedral crystals growing into the chlorite. In minor amounts there occurs in the epidote-chlorite matrix 0.2–0.3 mm long, sub- to euhedral apatite grains. As accessory minerals occur muscovite and a brown-green biotite.

The hematite fragments are angular and strongly crushed. Sometimes, they form needle-like crystals like in the Narken area. The hematite always contains small irregular remnants of magnetite usually lying in the middle of the grains. Occasionally the magnetite contains hematite laths following the octahedral planes. This shows that hematite is formed from magnetite by oxidation.

In some boulders at Lumivaara and Ahmakero the iron oxide is mainly magnetite which is partly altered to hematite along the borders of the grains or along the octahedral planes. In these magnetite-dominated types there occur small amounts of up to some millimetre big grains of pyrite, or in quite small amounts, of chalcopyrite. The sulphides form up to 2 mm big, subangular

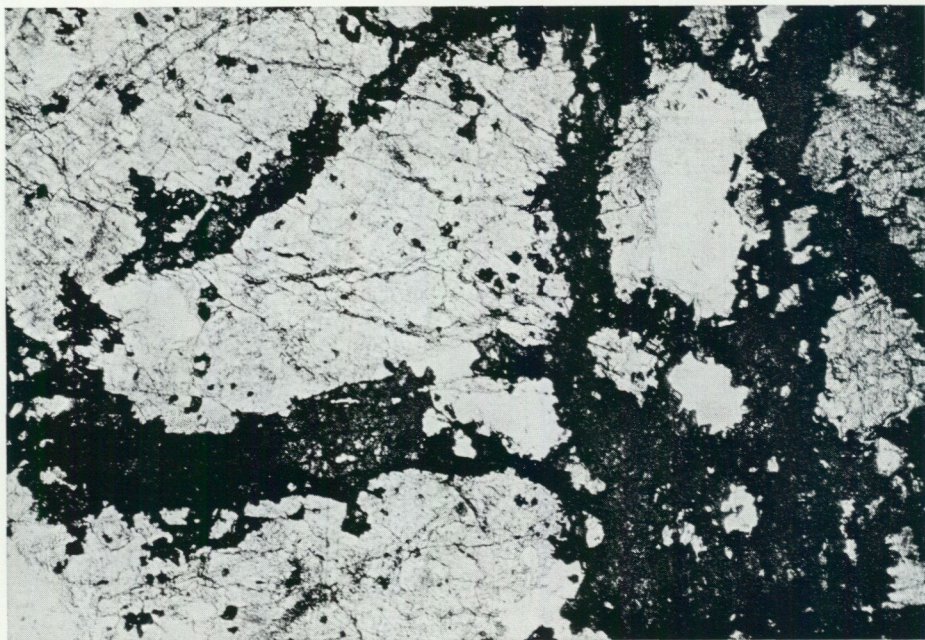


Fig. 20. Veins of epidote (black to dark grey) in microcline (grey, in the left part of picture) and some quartz (white, smaller grains). Glacial boulder, Lalamaa. Thin section. Ord. light, x 35.

grains which often are intersected by numerous small cracks along which alteration to goethite (?) occurs. Some of the pyrite grains contain small vugs filled with chlorite. The pyrite grains are probably fragments as they occur very much in the same way as the magnetite fragments.

In some cases the iron mineralization is cut by narrow, irregular epidote veins.

Some of the breccia boulders from Ahamanniemi, Lumivaara and Ahmakero differ from those described above by containing small amounts of quartz in the matrix. The quartz forms anhedral, irregular grains and lies mostly around the iron oxide fragments, but partly also as small separate aggregates. The quartz is usually crushed and has a wavy extinction. Sometimes there are seen narrow zones in the breccia poor in iron oxides and built up of epidote, chlorite and quartz.

At Hirsikotanvaara there are also iron ore boulders which are rather rich in some centimetre wide quartz-filled veins. The quartz, which forms rather well-crystallized grains, contains irregular aggregates of epidote, chlorite, hematite (as needle-like crystals) and small amounts of euhedral apatite. The quartz has brecciated the epidote-chlorite-hematite matrix which often lies as remnants in the quartz.

South of Lalamaa there are a few boulders which are made up by a brown-red, medium-grained granite consisting of quartz and feldspar. The granite is cut by small veins of epidote and occurs, in part as up to 2 cm big, irregular fragments in the epidote. In the epidote there are sometimes quartz and red feldspar in some centimetre big crystals or aggregates. A thin section of a granite fragment shows anhedral grains of quartz and a brownish, somewhat turbid microcline. Both minerals are veined by a yellowish epidote (Fig. 20) which contains small amounts of iron oxide needles and euhedral apatite grains. In these boulders, as in the Narken area, there is an epidotization which is younger than the Lina granite.

In a boulder south of Ahmanniemi there is an epidote-hematite-magnetite breccia which contains up to 1 centimetre big, angular to subangular fragments of a white, dense quartzitic rock. This is built up of quartz in 0.02–0.5 mm big grains with irregular grain surfaces.

THE SOURCE OF THE IRON ORE BOULDERS

The description above shows that the iron mineralization in the glacial boulders in the Kihlanki area is quite similar to that occurring in the vicinity of Narken. This concerns both the mineralogical composition and the textural features. In both cases the iron mineralization forms a breccia with coarser fragments of hematite and to some extent of epidote in a matrix of hematite, epidote, chlorite and in some cases quartz. The hematite in the matrix forms small angular, sometimes needle-like fragments. The occurrence of euhedral apatite grains and small vugs filled with epidote, chlorite (and quartz) in the epidote-chlorite matrix underline the similarity between the mineralization at both localities. Small grains (fragments?) of crushed pyrite which are veined by goethite-filled cracks occur occasionally and in these sulphide-bearing parts the iron oxide fragments are to a large extent magnetite instead of hematite. The content of magnetite seems to be higher in the boulders at Kihlanki than in the occurrences at Narken. As in the Narken mineralization the magnetite is to some extent altered to hematite. In both localities the iron mineralization is younger than a quartz-microcline rich (Lina) granite but older than veins of quartz which cut and brecciate the mineralization.

On the basis of the above mentioned similarities the present author is of the opinion that the glacial ore boulders at Kihlanki form a real boulder train and that the source of the boulders is the iron mineralization in the Narken area.

It has to be pointed out that the iron mineralization at Narken and in the boulders at Kihlanki is a very rare type. It is not known in any other locality in Norrbotten. Naturally it is quite possible that there could exist other, still unknown, occurrences of this ore type which have delivered the Kihlanki boulders, but this would be a remarkable coincidence. The final proof for the hypo-

thesis that the Narken mineralizations are the source for the ore boulders at Kihlanki can, however, be delivered when there are encountered more boulders of the same ore type in the region between these localities. No investigations have been made in this respect. Further, the Kihlanki area has to be searched for glacial boulders of the albite-extreme alteration rocks. If such are found together with the ore boulders there could be no doubt as to the source area.

The Narken mineralizations, as a source for the Kihlanki boulders, requires a transport of 80 kilometres and a direction of the ice-movement from the SSW. The last mentioned is opposed to the fact that most of the long transported glacial boulders in Norrbotten have moved from NW or WNW. However, in the area between Narken and Kihlanki somewhat different glaciation features have prevailed. There are indications of a young ice-stream from the S-SSW. Therefore the ice-movement during the latest glaciation in this part of northern Sweden will be discussed in some detail.

The direction of the ice-stream during the latest glaciation is imperfectly known in the area around Kihlanki. According to G. Lundqvist (1961) the main ice-divide goes over the area just north of the Kihlanki village with an ENE-WSW direction (Fig. 1). The site of the ice-divide is here based on glacial striae rather far from the Kihlanki area. No glacial striae are found on the outcrops within the area. The nearest glacial striae, according to Lundqvist, are found 35 km W of Kihlanki and the ice-movement has here been to the NNE, implying that the ice-divide is south of this observation point. Other striae are found about 50 km S of Kihlanki and thus south of the supposed ice-divide. These striae are all showing an ice stream from WNW-NW.

Fromm (1965) found, in the area around Korpilombolo (about 15 km SE of Narken, cf. Fig. 1), glacial striae of different ages and directions. There are older striae from the NW and WNW. These directions are common for the whole central and southern part of Norrbotten. The younger striae are from the SW and SSW. Further there are younger striae from WSW and SW in the area south-east of Pajala village. About 2 km NW of Pajala there is a double till. Fromm showed that the two tills differ from each other by containing different boulder material and by having the longitudinal axes of the boulders differently orientated. The lower and older moraine has been deposited by an ice-stream from the NW and the younger moraine by an ice-stream from the SW. This change in the ice-movement is in accordance with the change in direction based on the striae.

The common pattern, according to Fromm, concerning the relationship between the different generations of striae is, that the direction of transport rotate in an anti-clock wise, the youngest striae caused by an ice movement from the SW-SSW. Along the coast in the Råneå-Luleå-Piteå region there is a rotation back again, the youngest ice movement coming from the north-west. It follows that for a period the ice divide must have had a much more southerly

position than believed earlier and that this period occurred in a rather late stage of the glaciation.

The discovery by Fromm of a young ice-movement from the south in the Korpilombolo-Pajala region was confirmed by Hoppe (1967). He found two more localities near Korpilombolo where the striae show a final ice-movement from the SSW-S. Hoppe pointed out that the final ice-movement from the SW and S has been observed only within restricted areas at Pajala and Korpilombolo, whereas in the main part of the area around these localities the last ice-movement was from the NW. The change to the movement from the SW took place at a late stage.

The orientation of the drumlins in the Korpilombolo-Pajala region are of the greatest interest for the interpretation of the source of the iron ore boulders at Kihlanki. Hoppe (*ibid.*) shows that the drumlins in the area west of the Kalix river are orientated in a NW-SE direction. They are formed by an ice-movement from the NW. In the Korpilombolo-Pajala region the drumlins are orientated in a SSW-NNE direction. According to Hoppe, on the basis of the direction of the glacial striae it is most plausible to believe that the drumlins in this region are formed by an ice-movement from the SW-S.

Hoppe (*ibid.*, p. 207) concludes for the Korpilombolo-Pajala region that "in the central part the general ice movement from the NW was replaced in the very last stage by movement from SW, SSW or S. There is, however, no evidence that this movement was just than a local one" and "this last ice movement did not represent a continuous flow from the area SW of Korpilombolo all the way to the neighbourhood of Pajala; it rather occurred gradually as the ice receded".

The young ice-movement from the SSW-S postulated by Fromm and Hoppe thus gives a satisfactory explanation to the transport of the iron ore boulders from Narken to Kihlanki. If the direction of the drumlins system between Narken and Pajala on Hoppe's map (*ibid.*, Fig. 2) is extended further to the NNE it will hit the Kihlanki area. The long distance of transportation, however, is remarkable and implies that the ice-flow must have been of greater endurance than supposed by Hoppe.

The evidence discussed above requires that in the Korpilombolo-Pajala-Kihlanki region there was a young ice-movement from the SSW-S which resulted in transport of ore boulders over rather long distances. The direction of transportation of these boulders is different from recorded for the other far transported ore boulders in Norrbotten. In all other cases the boulders were transported by the older ice-movement from the NW or WNW. As the problem of origin of the long transported ore boulders is not only of academic interest but also of great value as a guide in prospecting, the different cases of long transported ore boulders in Norrbotten will be described briefly below. The boulders trains for these examples are shown in Fig. 1.

Geijer (1917b) found glacial boulders from the Hauki hematite ores and the so-called Rektor porphyry, both from the area immediately NE of Kiirunavaara, at Äijärova which lies between Svappavaara and Vittangi. Boulders of the syenite porphyry from the foot-wall at Kiirunavaara also occur here. The direction of transport is from $N70^{\circ}W$ and the distance 55 km. Geijer also described a boulder of the latter rock at Svappavaara which requires a transport from $N65^{\circ}W$ over a distance of 43 km. At Mertainen there are boulders of the quartz-bearing porphyry and syenite porphyry (with magnetite veins) from Kiirunavaara. The transport is from $N70^{\circ}W$ and the distance 29 km. At Svappavaara there are boulders from the "ore breccia" at Mertainen which means a transport from $N75^{\circ}W$ and a distance of 11 km.

All the above mentioned glacial boulders from the Kiruna area and the Mertainen deposit are thus confined to the same ice-transport from $N65-75^{\circ}W$. Striae observations and a double till at the Leveäniemi iron mine, near Svappavaara, show that the direction represents an older movement of the ice. Ek (1971) showed, on the basis of the distribution of the different rock types in the till at Leveäniemi, that the lower till has been deposited by an older glacial transport from the N, NW or W and the upper till by a younger glacial transport from the SW. J. Lundqvist (1971) describes, from the same area, older striae from north-west and younger striae from south-west.

Ödman (1947) showed that the manganese ore boulders found in the vicinity of Murjek (east of Jokkmokk) emanated from a source at Ultevis (north-west of Jokkmokk). The transport is from $N70^{\circ}W$ and the distance about 115–125 km.

The present author has observed glacial boulders from the Malmberget iron ore at Mäntyvaara, Pojmisträsk and Kiilijärvi. The direction of the transport is from $N65^{\circ}W$ and the greatest distance of transportation (Kiilijärvi) is 155 km. East of the town of Haparanda, on the Finnish side of the border (in the immediate vicinity of the Finnish town Tornio) some iron ore boulders occur. The present author has unfortunately never seen any of these, but descriptions and analyses (which inter alia show a relatively high content of phosphorus) indicate that they possibly emanate from an ore of the Kiruna type. If Malmberget has been the source of these boulders the transportation is from $N65^{\circ}W$ and the distance 215 km.

The magnetite-ilmenite ore at Ruotivare has given a very narrow and well defined boulder train going over Tjåmotis to the area north and east of Jokkmokk. Boulders are found north of Kvikkjokk, at Tjåmotisjaure, Björkudden, Klubbudden, Ålojaure, Juggijaur and Kuouka. The transport is from $N80^{\circ}W$ and the distance to Kuouka is 135 km.

In the south-western part of Norrbotten there is also an ore boulder train at Storbodsund, about 175 km W of Luleå (not shown on the map in Fig. 1). Grip (1953) stated that the nickel-bearing gabbro at Storbodsund has given a

boulder train of a length of about 55 km. The transport is from N50°W. About 75 km WNW of Storbodsund lies the lead ore deposit Laisvall. According to Grip galena-bearing boulders have been found 7 km to the SSW-SW of the ore. The spread of the boulders is rather great over this distance.

There are consequently five, more or less well defined and rather extensive ore boulder trains in Central and South Norrbotten where the direction of transport has been from the NW-WNW. Usually this direction of transport, which is due to an older ice-flow, is assumed when looking for the source of glacial boulders in these parts of Norrbotten. Astonishingly enough there are no indications of long transported boulders which follow the younger ice-movement from the WSW. In the northern part of Norrbotten and along the Norwegian border, i. e. north and west of the main ice divide, other directions (from SE, S or SW) are prevailing. In the mountains along the Norwegian border there are also local deviations caused by topography.

The evidence of a long transport of glacial boulders from the SSW in the Korpilombolo-Kihlanki region contrasts with the usual long transport of glacial boulders from the NW-WNW for the greatest part of Norrbotten and is therefore of particular interest. This direction from the SSW has at least to be taken into account when considering matters of ore prospecting and quaternary deposits in the area between Korpilombolo and Kihlanki. There are indications that such a deviating direction for the transport of boulders even exists outside this region. Glacial boulders from the Malmberget iron ore have, for example, been found at Sarvesjaure which is about 10 km to the NNE of the deposit. Further, boulders of the ore and the host rock from the Aitik copper deposit (ESE of Malmberget) have been found about 10 km NNW of the occurrence (oral communication by K. A. Sandahl). These findings are in accordance with the investigations by Geijer (1917a, 1948) of the glacial features in the Nautanen area, north-east of Malmberget. He found that at a relative late stage of the glaciation there occurred in this area a movement of the ice towards the N and NNW. The movement was influenced by the topography of the area. Geijer based his opinion mainly on the direction of the moraine ridges which he considered as terminal moraines.

The ice-movement from the south in the Malmberget region, however, is most probably only a relatively local phenomenon related to the vicinity of the main ice-divide and of restricted importance compared with the southerly transport in the Korpilombolo-Pajala-Kihlanki area.

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