SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 708 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 68 NR 15

RUDYARD FRIETSCH

THE EKSTRÖMSBERG IRON ORE DEPOSIT, NORTHERN SWEDEN

STOCKHOLM 1974

SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 708 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 68 NR 15

RUDYARD FRIETSCH

THE EKSTRÖMSBERG IRON ORE DEPOSIT, NORTHERN SWEDEN

STOCKHOLM 1974

ISBN 91-7158-068-9

Kartan är ur sekretessynpunkt godkänd för spridning i statens lantmäteriverk 1974-10-03.

CONTENTS

ABSTRACT

The Ekströmsberg deposit is built up of magnetite, martite and hematite forming several long narrow ore bodies in a quartz-bearing porphyry, with minor intercalations of a syenite-porphyry. The quartz-bearing porphyry has been subject to metasomatic alteration with the new-formation of sericite and quartz. Locally there are narrow layers of ore which have been almost totally silicified. The sericite-quartz-alteration is due to a late, low-thermal activity within the same magmatic process which produced the ore. Associated with this metasomatism is the transformation of magnetite to martite and hematite. The ore, which is apatite-bearing with the apatite mainly occurring as thin layers, is similar to most of the other late-magmatic iron ore deposits of the Kiruna type in Northern Sweden. The Ekströmsberg ore differs, however, from these deposits as it does not have an ore-breccia forming an irregular net-work in the host rock. Instead there occurs a rather extensive system of parallel veinlets of ore.

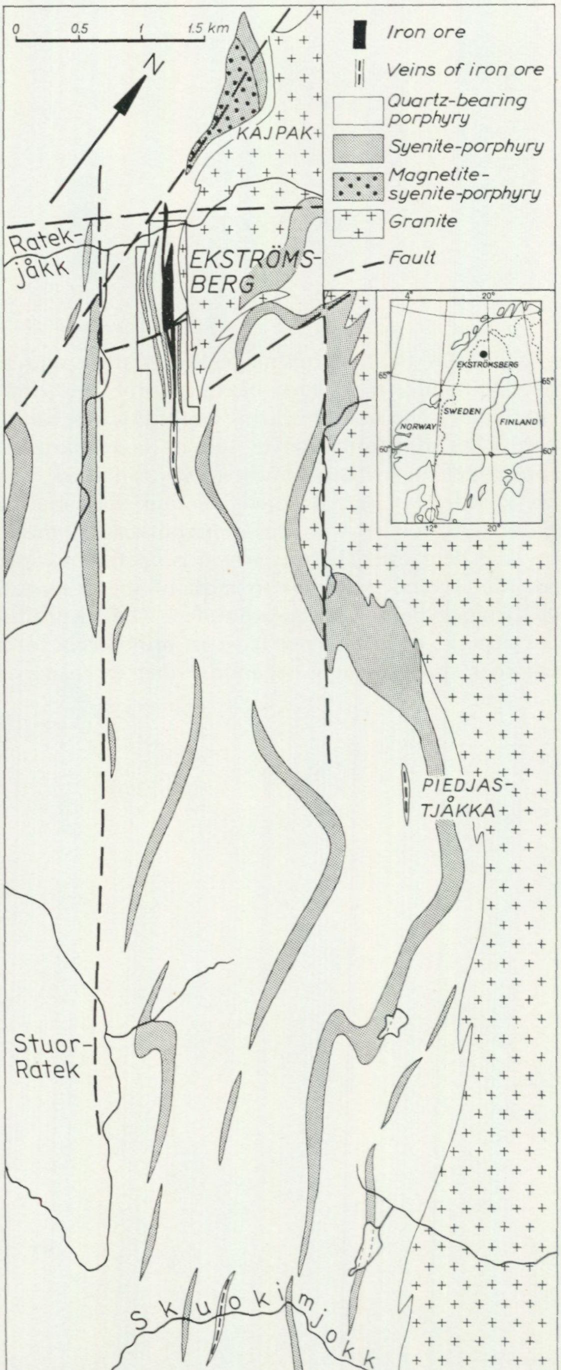


Fig. 1. *Sketch map showing the geology around the Ekströmsberg deposit and some other iron ores to the south. Mainly after Offerberg (1967).*

INTRODUCTION

The Ekströmsberg iron ore deposit is situated 30 km WSW of Kiruna in Northern Sweden. The area is almost unhabited, and the nearest means of transport is the main road between Kiruna and Nikkaluokta, about 5 km to the north. The nearest point on the railway between Gällivare and Kiruna is the Kalixfors station about 30 km E of the deposit.

The ore-bearing area extends NW—SE and has a length of about 2 km. The north-western end lies near the river Ratekjåkk (Fig. 1), which flows from Lake Onna Ratekajs to Lake Laukkujärvi in the Kalix river valley. The ore-bearing area is situated on the north-western slope of the mountain Piedjastjåkko (Fig. 2). The north-western part lies 585 m above sea level and the south-eastern part

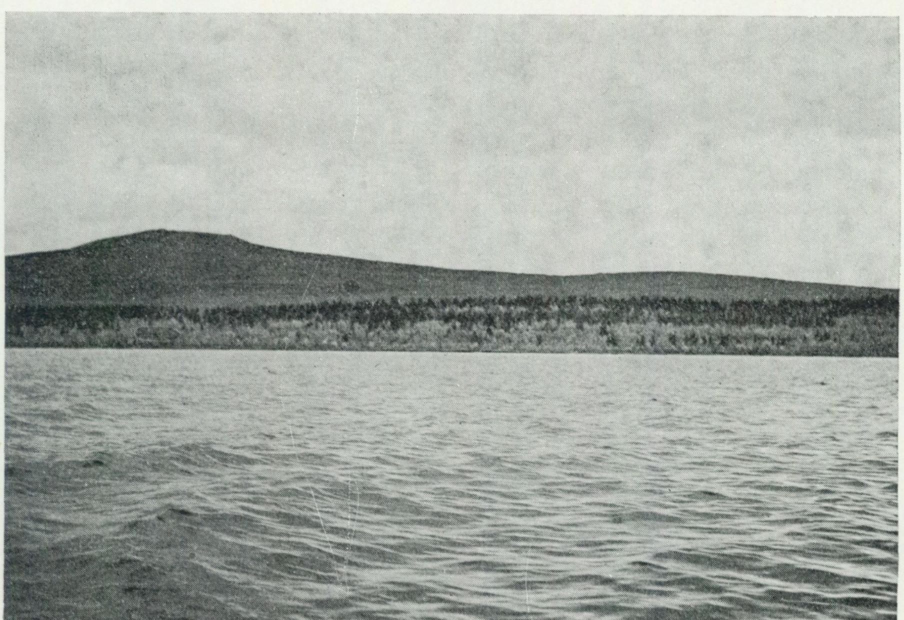


Fig. 2. *Piedjastjåkka seen from Lake Laukkujärvi. The Ekströmsberg ore lies immediately to the left of the low hill at the right of the picture.*

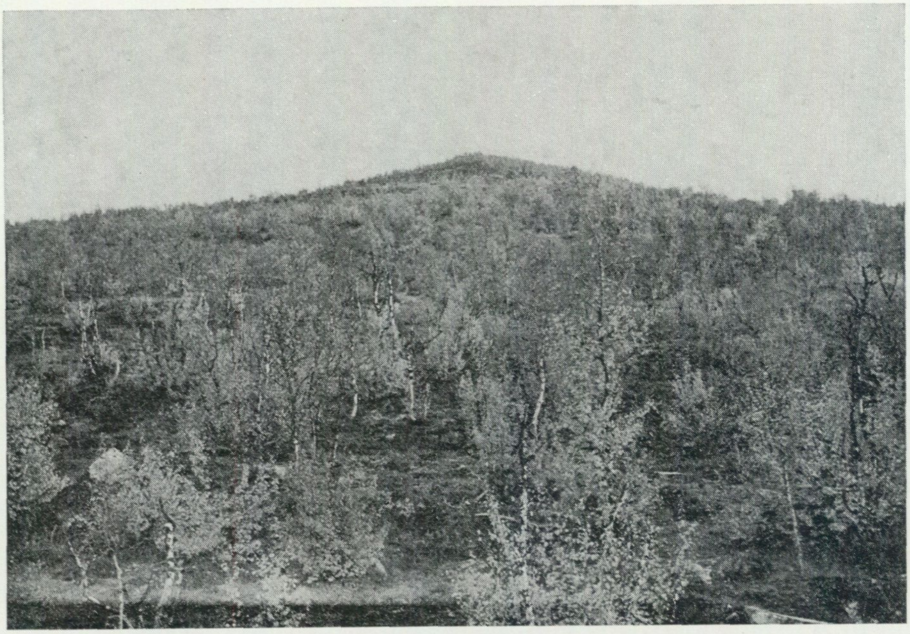


Fig. 3. *Piedjas-Välkomma (at 500 S) seen from NW. On the escarpment the iron ore is outcropping.*

about 100 m higher. The lower part is covered by a sparse vegetation of dwarfed birch, while in the higher parts there occurs only a low vegetation of brushwood.

The greater part of the ore deposit has a drift cover. The greatest thicknesses of moraine (about 20 m), are found locally over the south-western part of the deposit (at 700 S/110 W[1]), and over the part of the ore which lies NW of Ratekjåkk (between 9 and 14 m). In the central part of the ore-bearing area, at 300—600 S/0—200 W, the cover is thin or absent and there are outcrops of the ore and the host rocks over a relatively large area. In the western part of this area there are good outcrops in a long narrow NW—SE ravine. Against Piedjas-Välkomma at 500 S/0—50 W, which is a separate small hill making up a promontory to Piedjastjåkka (Fig. 3), the cover increases again. On the top of Piedjas-Välkomma the cover is about 2—3 m but the ore outcrops in places (Fig. 4). From this point the ore forms a more or less clearly visible ridge for some hundred metres to the SE. In the south-eastern part of the ore field the thickness of the cover increases again, amounting roughly to 8—10 m.

The Ekströmsberg ore was first mentioned in print by Roman (1818). The name of the deposit refers to the manufacturer Ekström from Kengis, near the Pajala

[1] Refers to a co-ordinate system staked out in the area (Plate 1).

Fig. 4. *Outcrops of magnetite ore at Piedjas-Välkomma.*

village on the Finnish border. He had visited the deposit some years before 1818 and had obtained a somewhat exaggerated idea about the size of the ore. He considered the ore to surpass those of Kiirunavaara and Luossavaara. Thereafter the Ekströmsberg ore must have fallen into oblivion. Gumaelius (1877) mentions the deposit as doubtful, as a geological commision, which visited the area in 1875, had not been able to find the ore. The ore was rediscovered in 1895 by the Lapp Nila Ribbja. Since 1907 the Ekströmsberg ore has been owned by the Crown.

The ore has been investigated geologically several times (Svenonius 1900, Bäckström 1904, Stutzer 1907, Lundbohm & Petersson 1910, Geijer 1912, Berglund 1924 and Frietsch 1954). The first systematic investigations of the ore were made at the turn of the century. From 1897—1900 geological and magnetic mapping (with the Tiberg scale) was done, and one diamond drill-hole was put down. During 1950—1954 investigations were made by the Geological Survey of Sweden. These comprised geological mapping, some complementary magnetic measurements and 12 diamond drillholes. During 1961—62 the Survey made detailed magnetometric and gravimetric measurements, and from 1965—1969 35 cores were drilled and the geological map was revised.

The present paper is a somewhat abridged report delivered by Frietsch (1974 b) to the ore prospecting section of the Geological Survey.

GEOLOGICAL SETTING

Several apatite-bearing magnetite-hematite ore bodies occur in the iron ore deposit at Ekströmsberg. The host rock is a quartz-bearing porphyry in which intercalations of a syenite-porphyry are common. According to radiometric determinations the age of similar acid porphyries, at Kaska Tjåurek SW of Ekströmsberg and at Kiirunavaara, is somewhat more than 1600 m.y. (Welin et al. 1971). The acid volcanic rock are underlain by basic volcanic rocks, metasediments and conglomerates, which make up the oldest supracrustal rocks on the Kiruna map sheet (Offerberg 1967). Quartzites and conglomerates, which only cover restricted areas, are younger than the acid volcanic rocks.

The Ekströmsberg deposit occurs in the same stratigraphic position as some other apatite iron ores in the area south of the deposit. All these ores are more or less symmetrically arranged around the NW—SE trending anticline at Kaska Tjåurek and Onna Tjåurek where the acid volcanic rocks are accompanied by rather important amounts of intermediate to basic volcanic rocks. The magnetite deposits Tjåorika and Renhagen occur to the SW of this anticline, and the Harrejaure magnetite-hematite deposit lies on the southern boundary of the anticline. Further to the north of the Harrejaure deposit, and thus NE of the Tjåurek anticline the quite small iron ores Skuokimjokk and Piedjastjåkka are found (Fig. 1). At both localities a quartz-bearing porphyry contains veins, up to some metres wide, of a fine-grained, siliceous and apatite-free hematite ore which partly replaces the host rock (Svenonius 1900, Frietsch 1967, 1970). These ores are metasomatic and represent a late, low-thermal phase within the same magmatic activity which produced the apatite-bearing iron ores of the area. Further to the NW from Piedjastjåkka the Ekströmsberg ore occurs. Some kilometres to the north, at Kajpak (formerly called Njakak), there is a magnetite-syenite-porphyry. This rock occurs in the same stratigraphic position as the ores mentioned earlier, but is of another type and cannot be compared with these.

The dominating rock within the Ekströmsberg area is a quartz-bearing porphyry (Plate 1) which locally is sericite-altered. Towards the north-east the porphyry is bounded by a perthite granite. In the porphyry occur intercalations of a syenite-porphyry which are parallel with the direction of the ore bodies. The syenite-porphyry is partly rich in magnetite and passes into a magnetite-syenite-porphyry.

Fig. 5. *Lineation in magnetite ore plunging 10—20 degrees to the SE. 980 S/20 E.*

In the Ekströmsberg deposit there occur a great number of more or less parallel ore bodies which are surrounded by narrow veinlets of ore with the same direction as the ore bodies. The largest ore body consists of magnetite and lies in the north-eastern part of the deposit. SW of this body there is a relatively large body of hematite. Between these two main ore bodies there are smaller ones of magnetite and martite. SW of the main hematite ore body there are smaller bodies of hematite and martite. In the hematite bodies furthest to the SW, and partly also in the magnetite and hematite ore bodies, there are locally, narrow intercalations of quartzites rich in iron oxides.

The strike of the ore bodies and intercalations of the syenite-porphyry is N 30—35°W. In the south-eastern part there is a slight deviation to the west and in the north-western part a slight deviation to the north. The dip is vertical or 85 degrees to the south-west. The schistosity of the area follows the above mentioned direction. It is most pronounced in the quartz-bearing porphyry in the proximity of the main hematite ore body. The quartz-bearing porphyry contains here only very rare phenocrysts and has partly a "mylonitic" appearance.

In the ore and the quartz-bearing porphyry there are lineations which have a plunge of 10—30 degrees to the south-east (Fig. 5). Svenonius (1900) observed in an ore body in the northern part of the deposit a small fold where the axis plunges 25—30 degrees to the SSE. In the hematite at 520 S/103 W there

Fig. 6. *Jointing in hematite ore which dips 55—60 degrees to the NNW. 520 S/103 W.*

occur joints which dip 55—60 degrees to the NNW (Fig. 6). They are possibly ac-surfaces indicating a fold-axis which plunges 30—35 degrees to the SSE.

The plunge of the ore bodies is not known, but it could probably follow the direction of the above mentioned structures which means plunge at rather modest angles to the SSE. The magnetic map of the ore-bearing area shows that the magnetic anomalies at the north-western end of the deposit cease rather abruptly, while the anomalies at the south-eastern end have a rather large extension to the south-east beyond the area which is considered to be of economic interest and which has been investigated by drilling. This extension might be due to small veins of iron oxides in the quartz-bearing porphyry, but might also be the result of the ore bodies plunging in this direction. Further, the negative anomalies which are found on both sides of the ore bodies at the north-western end of the deposit, and the lack of such anomalies at the south-eastern end possibly indicate that the lower magnetic pole is more deeply lying at the south-eastern end than at the north-western end.

The Ekströmsberg area is cut by several faults which trend N—S, NW—SE or NE—SW (Fig. 1). These are deduced from the aero-magnetic map and magnetic measurements on the ground, which are extended far beyond the ore-bearing area. The most important of the tectonic lines trends from Lake Stuor-Ratek in a north-westerly direction to Lake Paittasjärvi in the Kalix river valley. In the middle of the Ekströmsberg deposit, between the profiles 700 S and 800 S, there is a fault system which strikes NE—SW (Plate 1) and with all probality dips steeply to the SE. This fault system has been deduced from the drilling. There is a rapid decrease of the ore with depth. Thus the total width of all ore bodies at the surface is about 100 m, while at a depth of about 60 m below the surface, it is only 50 m (Plate 2). Probably a block, which is limited on both sides by the NE—SW faults, has been displaced out from the ore and has also been lowered compared to the surroundings. In the continuation from profile 800 S to the south-east, the width of the ore is relatively small. The mode of occurrence of the ore is here the same as to the north-west, i.e. with magnetite to the north-east and hematite to the south-west. The drillings in profiles 900 S and 1000 S show that the width of the ore decreases with depth (Plate 2). It is therefore plausible that the part of the ore which lies south-east of the crossing fault system makes up a deeper part of the ore zone which has been uplifted, the present erosion surface thus showing the roots of the ore zone. The drillings, however, reach only a relatively small depth, some hundred metres below the surface, and do not indicate whether the ore really pinches out or not at this depth. Geophysical calculations show that the whole length of the ore zone has the same depth, varying mainly between 300 and 500 m, and that there are no differences in dept of the ore between the north-western and the south-eastern part.

DESCRIPTION OF THE ROCKS

QUARTZ-BEARING PORPHYRY

In restricted areas, such as north-east of the main magnetite ore body between the profiles 500 S and 700 S, at 425—500 S/60 W, at 1300—1500 S/100—200 E and north of Ratekjåkk, the quartz-bearing porphyry is almost non-schistose and well preserved. It has a grey-red, dense matrix which contains anhedral or subhedral feldspar phenocrysts up to 1 cm long. These are built up of microcline with minor amounts of albite in perthitic intergrowth. The phenocrysts are mostly somewhat crushed (Fig. 7) and veined by secondary quartz and sericite. The matrix, with a grain size of about 0.02 mm, consists of quartz and microcline, often in a micropoikilitic texture. Magnetite and hematite are usual subordinate minerals and occur as small grains which often cluster to form aggregates. Zircon and sphene occur as accessory minerals. Due to a pigmentation of iron oxides the matrix is faintly red-coloured. A patchy texture is relatively common; quartz, and to a lesser extent feldspar, form aggregates up to 0.3 mm in size with a smaller amount of iron oxides than the surrounding matrix. In these patches occur semi-parallel laths of feldspar 0.1 mm long. Long and narrow, irregular aggregates with secondary quartz are also rather common. Other secondary minerals, mostly occurring in connection with the quartz aggregates, are muscovite, allanite, tourmaline, and fluorite. The porphyry is also cut by small veins containing calcite and fluorite. In the drill-holes it has been observed that in the quartz-bearing porphyry 5—6 m wide zones occur where some angular fragments of the porphyry, several centimetres in size, lie in a matrix of chlorite with small amounts of biotite, fluorite, calcite and chalcopyrite. These breccias are most probably of tectonic origin.

In most parts of the ore deposit the quartz-bearing porphyry is strongly schistose. Here the colour is mostly grey or greengrey. Feldspar phenocrysts are rare or absent and have a size less than 1 mm. In places the porphyry has a mylonitic appearance. The mineral assemblage is almost the same as that described above, the only difference is that biotite and chlorite appear as newformed minerals in zones parallel with the schistosity. These minerals partly form a network with 3—4 mm wide veins, which cut the porphyry irregularly. In places, such as at 570 S/120 W, the porphyry shows a well developed banded texture, which is a primary, fluidal texture, but was probably later emphasised by tectonic pressure. Here quartz, feldspar and magnetite, with a grain size of

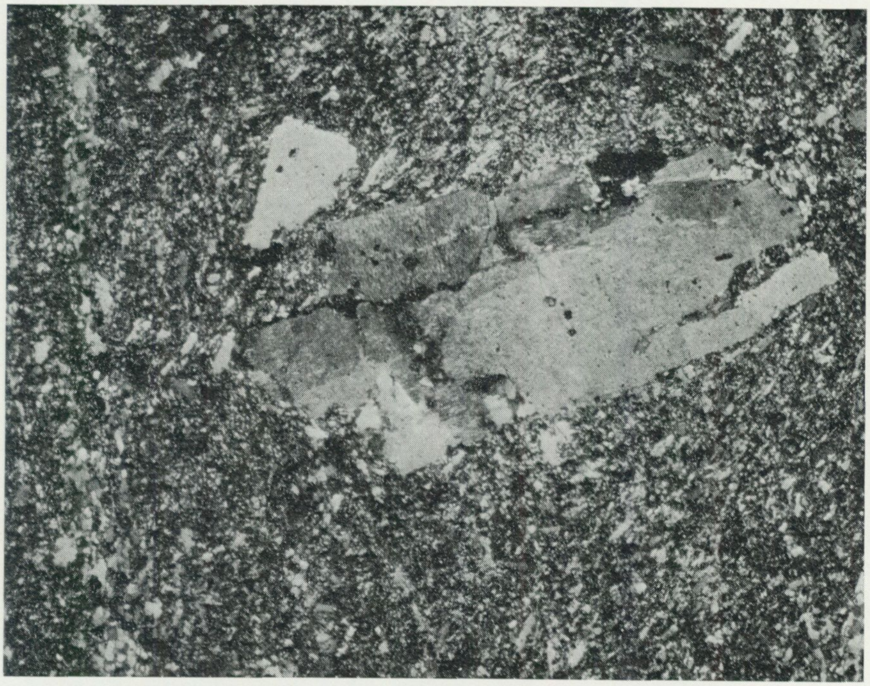


Fig. 7. *Quartz-bearing porphyry. In a matrix of quartz and feldspar occur phenocrysts of perthite. Larger black grains = iron oxides. 195 S/105 W. Thin section. Nic. +, x 33.*

about 0.01 mm, form 0.04—0.08 mm wide bands (Fig. 8). Feldspar phenocrysts are missing. Parallel with the banding occur secondary zones with muscovite and quartz. The latter mineral partly forms grains, up to 0.4 mm long, extended in the direction of the banding.

Two chemical analyses of the quartz-bearing porphyry are shown in Table 1. The composition is rhyolitic. Only few components occur in large amounts: silica, alumina, and alkalis. The latter show great variations in internal relationship. A strong predominance for potassium occurs (analysis No. 2, Table 1), but sodium-rich types are also present (analysis No. 1, Table 1). A thin section of the sodium dominated porphyry shows that it is similar to the porphyry in other parts. However, the phenocrysts are striped and probably built up of albite as the index of refraction is close to that of the bedding matrix. Potassium dominated forms have also been encountered at Piedjastjåkka (analysis No. 3, Table 1), about 4 km S of the Ekströmsberg deposit, and similar rocks have been reported by Offerberg (1967) from Skuokimjåkk, south of Piedjastjåkka. The analysis (No. 66) shows a quartz-bearing porphyry rich in silica (76.6 per cent SiO_2) and with a strong predominance for potassium (8.6 per cent K_2O and 1.4 per cent Na_2O). Concerning the relationship between the alkalis, the composition of the quartz-bearing porphyry thus varies within wide limits in the Ekströmsberg deposit and in the area to the south. In other respects the quartz-bearing porphyry from Ekströmsberg is rather similar to that in the Kiruna area. Analysis No. 4, Table 1, which is the average of four analyses of

TABLE 1. Chemical analyses of quartz-bearing porphyry (values in weight per cent)

Analysis No.	1	2	3	4
Sample No.	050-5823			
SiO_2	76.3	69.70	69.65	69.4
TiO_2	0.54	0.46	0.44	0.38
Al_2O_3	11.8	14.20	14.68	13.92
Fe_2O_3	2.0	2.69	3.01	3.33
FeO	1.3	0.65	1.01	1.52
MnO	0.04	0.11	0.04	0.04
CaO	0.7	0.07	1.02	0.89
MgO	0.50	0.11	0.32	0.64
Na_2O	6.4	2.22	0.22	5.59
K_2O	<0.1	9.28	9.25	3.08
$H_2O>105°C$	0.2	0.54	0.74	0.63
$H_2O<105°C$	0.2			
P_2O_5	0.06	0.06		0.06
CO_2	0.29			
P	0.03			
S	<0.02			0.03
BaO	0.01	0.03		
	100.37	100.09	100.38	100.54
Niggli-values				
si	440	360	357	325
qz	195	93	132	87
al	40.1	43.2	44.4	38.4
fm	19.4	14.6	18.6	22.4
c	4.34	0.44	5.60	4.47
alk	36.1	41.7	31.4	34.5
ti	2.34	1.78	1.69	1.34
p	0.14	0.13		0.11
h	3.84	9.30	12.7	9.86
k	0.01	0.73	0.96	0.26
mg	0.22	0.05	0.13	0.20

	Analyst:
1. Ekströmsberg, 200 S/105 W	K. Johansson
2. Ekströmsberg, 300 m SE Piedjas-Välkomma	G. Assarsson. Analysis No. 32 in Geijer (1931).
3. Piedjastjåkka	H. Santesson. Analysis No. 5 in Svenonius (1900).
4. Average of 4 analyses from Geijer (1910): Nos. XIII-XIV from Kiirunavaara and Nos. XV-XVI from Luossavaara.	

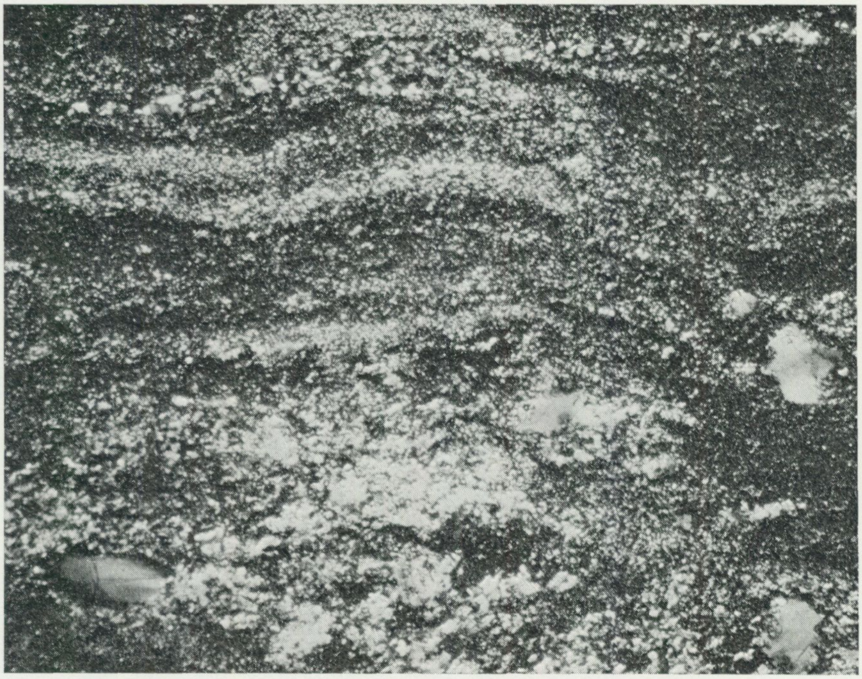


Fig. 8. *Quartz-bearing porphyry. In the fluidal banded matrix quartz grains and sericite-rich zones (mostly in the lower part of the picture). 570 S/120 W. Thin section. Nic. +, x 33.*

the quartz-bearing porphyry from Kiirunavaara and Luossavaara, is shown as a comparison. Apart from the alkali distribution the porphyries in both areas are rather similar.

Normally the porphyries, which form the host rocks of the apatite-bearing iron ores in Northern Sweden, are alkali intermediate with a slight dominance for the sodium component. The potassium dominated variety in the Ekströmsberg area is thus an exception. Interesting analyses are given by Snyder (1968) of the acid volcanic rocks (rhyolites) in which the apatite-bearing iron ores of Missouri, USA, occur. The host rock of these ores, which in most respects are similar to the iron ores of the Kiruna type in Northern Sweden, are made up of two groups of volcanic rocks, an older and a younger. Both contain 76.3 per cent SiO_2. The volcanic rocks of the older group are clearly potassium dominated (8.52 per cent K_2O and 0.13 per cent Na_2O) while the volcanic rocks in the younger group are alkali intermediate (4.50 per cent K_2O and 3.53 per cent Na_2O).

Differences in the normative composition are shown in the ternary diagrams of Figs. 9—11. The great spread in the relationship between Na and K in the porphyries of Ekströmsberg is clearly depicted by the composition of the normative feldspar which varies between almost pure albite and pure orthoclase.

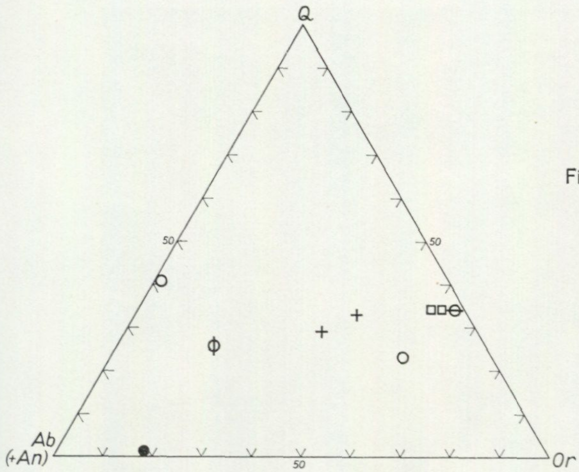


Fig. 9. The normative composition of the rocks in the Ekströmsberg area. Q, Ab, An and Or denote the normative minerals quartz, albite, anorthite and orthoclase calculated according to the CIPW-system and recalculated to 100 per cent.

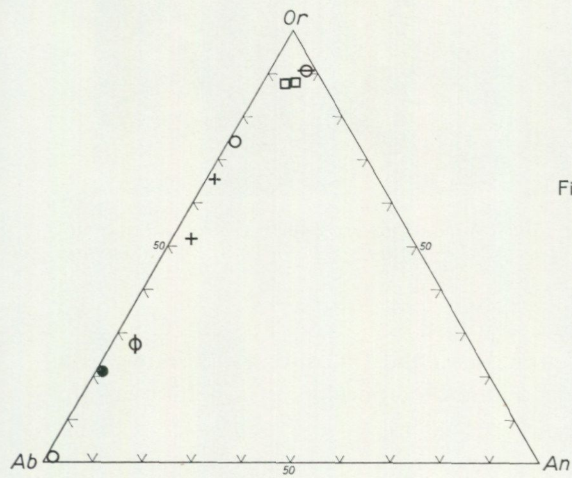


Fig. 10. The normative composition of the rocks in the Ekströmsberg area. Or, Ab and An denote the normative minerals orthoclase, albite and anorthite calculated according to the CIPW-system and recalculated to 100 per cent.

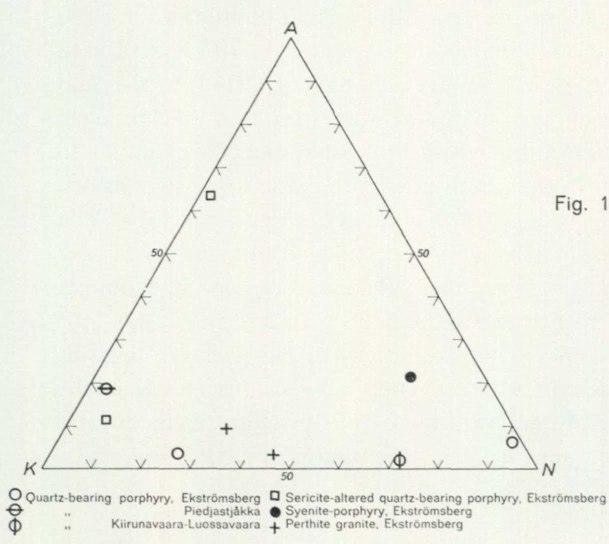


Fig. 11. A:K:N-diagram for the rocks in the Ekströmsberg area. $A = Al_2O_3 - (CaO + Na_2O + K_2O)$, $K = K_2O$ and $N = Na_2O$. CaO is reduced according to $CaO = (3\ P_2O_5 + CO_2)$. The components are recalculated to 100 per cent.

SERICITE-ALTERED QUARTZ-BEARING PORPHYRY

Sericite-altered zones occur rather commonly in the quartz-bearing porphyry. They have mostly a comparatively small width, but a great length in the direction of strike. The extension with depth is also large. NE of the main magnetite ore body, between profiles 400 and 900 S, there occur sericite-altered parts in the porphyry which probably are more or less continuous. The width of the alteration is mostly 10—20 m. West of the main hematite ore body, mainly N of profile 800 S, there are sericite-altered zones which, however, have only a small width, mostly 4—5 m. The sericite-alteration of the quartz-bearing porphyry is extended in the same direction as the general strike of the rocks and ores in the Ekströmsberg area, i.e. NW—SE. Dip also follows the general trend; it is vertical or steep towards the SW.

The sericite-alteration, which involves the new formation of mainly sericite and quartz, is most intense in the quartz-bearing porphyry. In the syenite-porphyry and the hematite ore it is known on a microscopic scale. The sericite-alteration has rather irregularly affected the quartz-bearing porphyry and seems to be a successive process. The sericite-altered porphyry is, by increasing schistosity and increasing content of sericite, altered to a grey-white or green-white sericite-

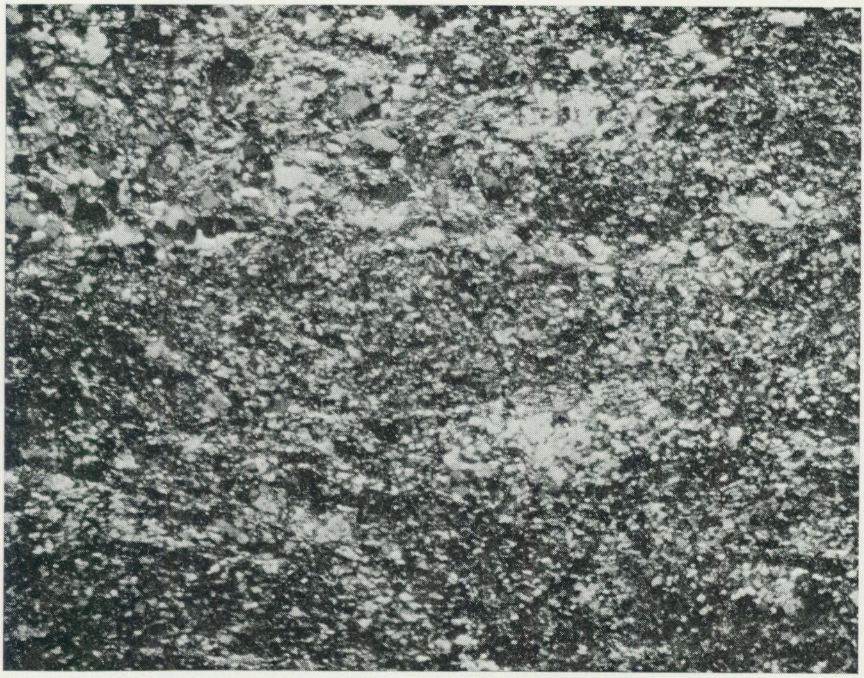


Fig. 12. *Sericite-altered quartz-bearing porphyry. The quartz-feldspar-rich matrix is veined by zones rich in sericite and partly also quartz (mainly in the upper part of the picture). Drill-hole 66803, 104 m. Thin section. Nic. +. x 33.*

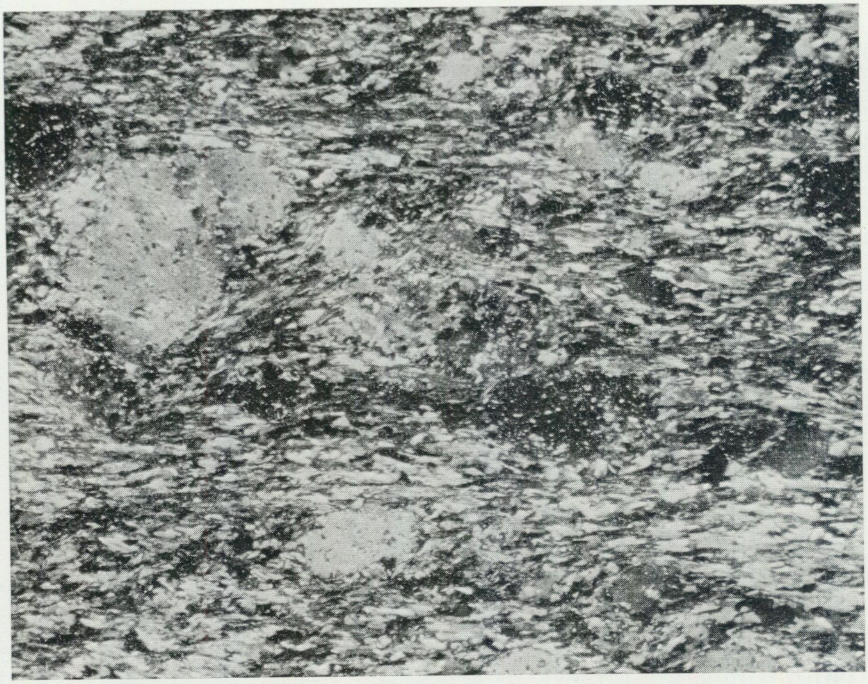


Fig. 13. *Sericite-altered quartz-bearing porphyry. Quartz porphyroblasts in a sericite-quartz-rich matrix. Drill-hole 66804, 68 m. Thin section. Nic. +, x 33.*

schist. No sharp borders between unaltered and altered porphyry can be seen. In the sericite-altered porphyry, however, narrow veins of a red, strongly schistose, only somewhat sericite-altered porphyry sometimes occur. Here the border is rather sharp. The alteration of the porphyry is thought to be due to hydrothermal solutions which followed tectonic zones, i.e. strongly schistose parts, in the rock.

Feldspar phenocrysts are absent from the slightly altered quartz-bearing porphyry. The fine-grained quartz-feldspar matrix is veined by about 1 mm wide schlieren with sericite (Fig. 12) and minor amounts of blue-green tourmaline, zircon and pale-green chlorite. Also there are secondary veins filled with quartz and some albite, green chlorite, sphene and fluorite.

The more altered zones in the quartz-bearing porphyry are built up of a fine-grained, more or less parallel aggregate of quartz and sericite (Fig. 13). The quartz forms sometimes 0.3—1.5 mm long, irregular aggregates which are rich in inclusions of sericite. The rock is also veined by quartz together with some fluorite, green chlorite and subhedral grains of sphene. The fluorite often occurs in the central part of the quartz veins.

Chemical analyses of the sericite-altered quartz-bearing porphyry (Table 2) show that the rock is richer in potassium and silica (seen from the higher si- and qz-values) than the unaltered porphyry. Analysis No. 1 is a sericite-bearing porphyry, while analysis No. 2 is a sericite-shist. The higher contents of fluorine and barium in the altered rocks indicate that the process which affected the porphyry is a metasomatic, hydrothermal one. The ternary diagram in Fig. 11 shows that the altered porphyry is richer in potassium and aluminium than the unaltered porphyry.

TABLE 2. Chemical analyses of sericite-altered quartz-bearing porphyry (values in weight per cent)

Analysis No.	1	2
Sample No.	050-5824	050-5825
SiO_2	70.6	77.4
TiO_2	0.56	0.55
Al_2O_3	12.7	13.4
Fe_2O_3	3.4	1.4
FeO	0.9	0.5
MnO	0.01	0.01
CaO	0.5	0.9
MgO	0.20	0.27
Na_2O	0.6	0.1
K_2O	9.1	3.9
$H_2O>105°C$	0.4	1.8
$H_2O<105°C$	0.2	0.2
P_2O_5	0.06	0.03
CO_2	0.12	<0.01
F	0.06	0.67
S	0.07	<0.02
BaO	1.4	0.06
	100.88	101.19
Niggli-values		
si	380	580
qz	143	402
al	40.1	59.1
fm	19.5	14.1
c	5.83	7.39
alk	34.4	19.4
ti	2.26	3.09
p	0.13	0.09
h	7.18	45.0
k	0.90	0.96
mg	0.08	0.21

	Analyst:
1. Drill-hole 66810, 90.5 m	K. Johansson
2. Drill-hole 67803, 204.6 m	K. Johansson

Fig. 14. *Syenite-porphyry. Phenocrysts of oligoclase in a matrix of biotite and magnetite (black). Drill-hole 67803, 74 m. Thin section. Nic. +, x 33.*

SYENITE-PORPHYRY

In the quartz-bearing porphyry a great number of long narrow intercalations of syenite-porphyry occur parallel with the ore bodies. This is especially the case in the south-eastern part of the deposit where the syenite-porphyry almost dominates and partly encloses the ore. In some cases the syenite-porphyry is enclosed in the ore. Thus there are layers of syenite-porphyry in the main magnetite ore and the main hematite ore. The length of the syenite-porphyry intercalations exceeds, in most cases, several hundreds of metres. The width varies mostly between a couple and several tens of metres. The widest intercalation situated in the south-eastern part of the deposit, has a maximum width of 35 m. The border against the surrounding quartz-bearing porphyry and ore is sharp. The intercalations of the syenite-porphyry follow the general structure within the deposit, thus their dip is vertical or steep towards the SW or NE.

The syenite-porphyry is a grey or green-grey, dense and mostly schistose rock. Occasionally in non-schistose parts there are phenocrysts of light-grey feldspar up to 5 mm long. The porphyry usually contains small amounts of magnetite and is weakly magnetic. Often chlorite occurs as schlieren up to some millimetres

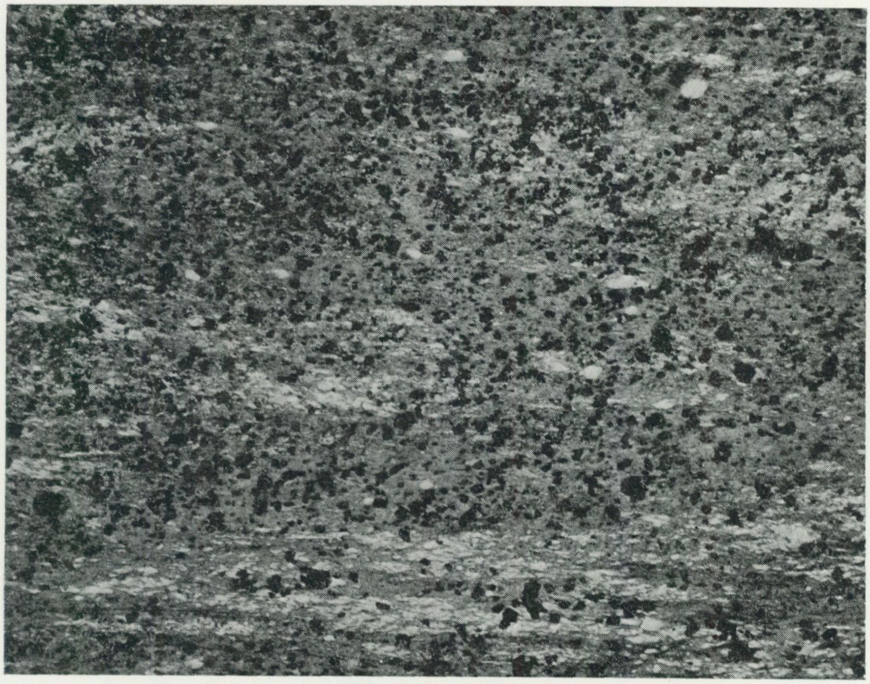


Fig. 15. *Syenite-porphyry, schistose. Parallel aggregate of biotite (grey), quartz (white) and magnetite (black). Drill-hole 66805, 23 m. Thin section. Ord. light, x 33.*

wide and parallel with the schistosity. The rock is cut by an irregular network of calcite containing rarely some chalcopyrite.

The microscope shows that the syenite-porphyry consists of 0.01—0.05 mm long, randomly orientated or sometimes semi-parallel laths of brown-green biotite. In this matrix lie laths of albite-oligoclase, up to 1 mm long, with about 10—15 per cent anorthite (Fig. 14). Albite twins are common and occasionally there occur twins after the Carlsbad law. In most cases the biotite and feldspar are equal in amounts, but in some samples there is a slight dominance of feldspar. Exceptionally, as at 590 S/40 W, the biotite is quite inferior and the porphyry is almost totally built up of intersertally arranged feldspar laths. Other minerals in the matrix are magnetite and sometimes green chlorite which replaces the biotite. Accessories are muscovite, calcite, zircon, yellow epidote, blue-green tourmaline, dark-brown allanite and apatite. All these minerals, except apatite, are probably secondary. The muscovite sometimes forms independent zones which cut the porphyry.

In the strongly schistose parts of the syenite-porphyry the feldspar phenocrysts are missing and the porphyry consists of a parallel aggregate of biotite with small grains of quartz with an undulating extinction (Fig. 15).

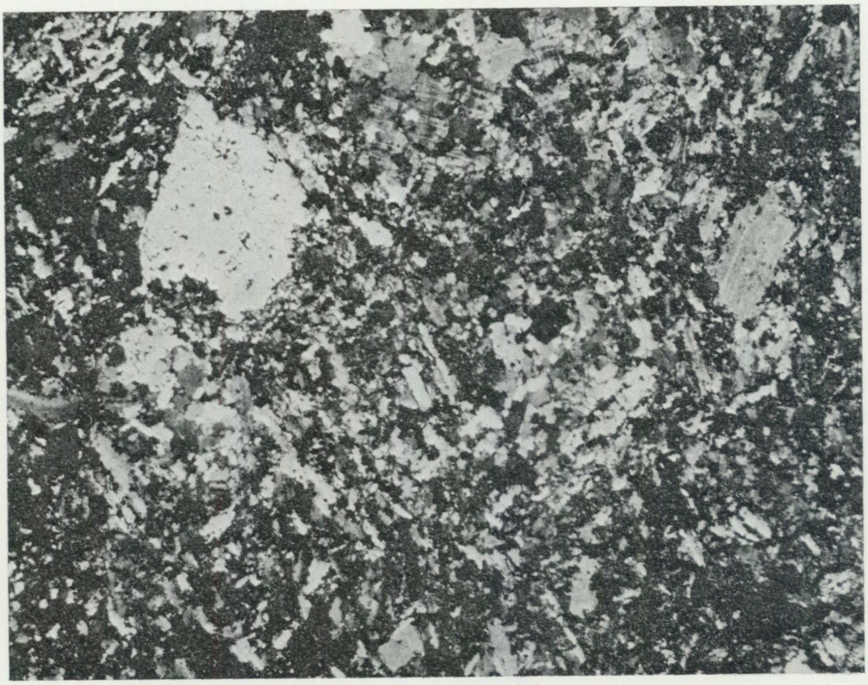


Fig. 16. *Magnetite-syenite-porphyry. Phenocrysts of albite-oligoclase in a matrix of albite-oligoclase and magnetite (black). Drill-hole 67803, 142 m. Thin section. Nic. +, x 33.*

By increase of the magnetite content the syenite-porphyry changes to a magnetite-syenite-porphyry, which differs from the former by darker colour and stronger magnetism. This magnetite-rich rock type is rather subordinate and seems to occur quite irregularly within the syenite-porphyry. The magnetite-syenite-porphyry is built up of 1 mm long laths of albite intersertally arranged in a matric of magnetite (Fig. 16) and small amounts of biotite and chlorite.

The syenite-porphyry, which in the profiles 700 S and 1200 S occurs immediately east of the main magnetite ore body, is partly fragment-bearing. In a grey-green, fine-grained and schistose matrix there occur pressed fragments, up to 5 cm long, of the syenite-porphyry or in minor amounts of the magnetite-syenite-porhyry. Also there are found rounded fragments, up to some millimetres in size, consisting of altered albite and microcline. The matrix is built up of biotite, chlorite and sericite and minor amounts of feldspar, quartz, zircon, sphene and magnetite. The fragment-bearing parts are most probably formed by tectonic brecciation of the syenite-porphyry. The albite-microcline fragments are possibly formed as hydrothermal products.

In Table 3 is shown an analysis of a syenite-porphyry relatively rich in magnetite. The analysis is similar to analyses of andesites and "dark syenite-porphyries" from the Kiruna map sheet (Offerberg 1967). The syenite-porphyry at Ekströmsberg is sodium dominated (5.9 per cent Na_2O and 2.1 per cent K_2O). The content of calcium is, on the other hand, low.

TABLE 3. Chemical composition of syenite-porphyry (values in weight per cent)

Sample No.	050-5826
SiO_2	46.5
TiO_2	2.1
Al_2O_3	16.8
Fe_2O_3	11.3
FeO	6.0
MnO	0.05
CaO	1.9
MgO	4.7
Na_2O	5.9
K_2O	2.1
$H_2O>105°C$	1.0
$H_2O<105°C$	0.2
P_2O_5	0.80
CO_2	0.03
F	0.48
S	0.02
BaO	0.04
	99.92
Niggli-values	
si	146
qz	—42.8
al	31.0
fm	40.5
c	6.42
alk	22.1
ti	4.94
p	1.06
h	10.44
k	0.18
mg	0.54

Drill-hole 67803, 74.5 m.
Analyst: K. Johansson.

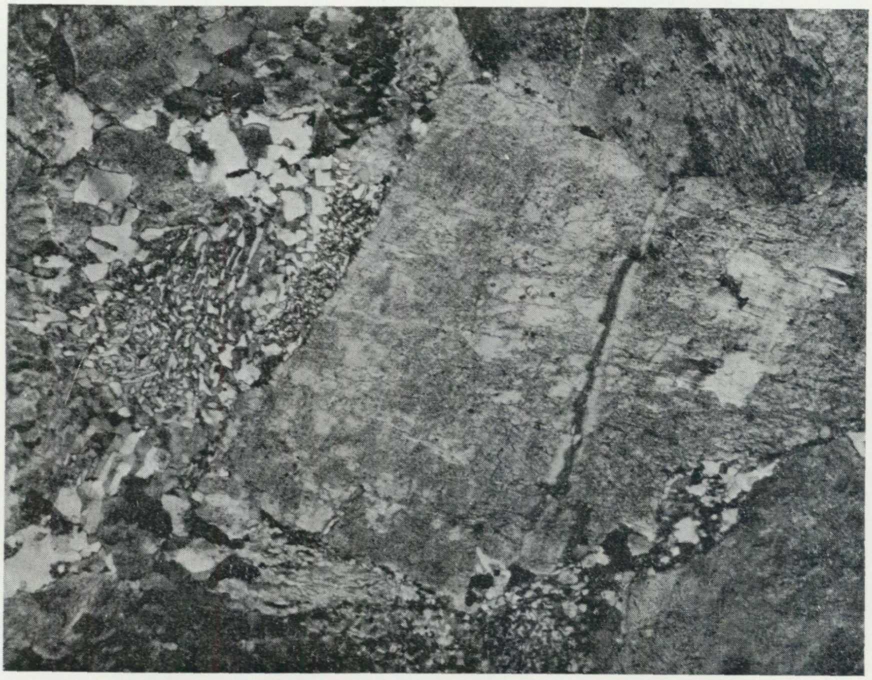


Fig. 17. *Perthite granite. Grains of perthite surrounded by quartz and perthite in a granophyric intergrowth. 80 N/220 E. Thin section. Nic. +, x 33.*

PERTHITE GRANITE

About 50 m E of the northern part of the main magnetite ore body there occurs a perthite granite which Geijer (1912) called granophyre. Within the ore field the perthite granite occurs from Ratekjåkk in the north to profile 700 S. To the south the granite is found at a greater distance from the ore-bearing area (Fig. 1). The strike and dip of the granite contact follows, in the main, the structure of the ore-bearing area. At profile 100 S the granite is in almost immediate contact with the ore zone, being separated from it by a relatively wide layer of skarn. Otherwise the granite is in contact with the quartz-bearing porphyry. These rocks pass successively into each other. Granite veins within the ore-bearing area are not known to occur.

The granite is a brown-red, or less commonly grey-red, fine-grained, non-schistose rock, which in a matrix of quartz and perthitic microcline, contains laths of a brown feldspar up to 1 cm long. The latter is a perthite with a relatively large amount of albite. In those parts where the granite is close to the quartz-bearing porphyry, the perthite grains are smaller, uneven and corroded. The matrix between the perthite grains is made up of quartz and perthite, mostly occurring in a granophyric intergrowth (Fig. 17). Partly the quartz forms 3—4 mm long, irregular, independent aggregates. Sphene, pale-green chlorite, calcite, muscovite and iron oxides occur as accessory minerals, often gathered in small aggregates or schlieren.

The chemical composition of the perthite granite is rather similar to that of the quartz-bearing porphyry (Table 4). The analyses show a pronounced dominance of potassium over sodium.

TABLE 4. Chemical analysis of perthite granite (values in weight per cent)

Analysis No.	1	2
Sample No.	P 1190	050-5822
SiO_2	71.6	70.3
TiO_2	0.39	0.69
Al_2O_3	12.8	13.6
Fe_2O_3	1.98	2.0
FeO	0.91	1.3
MnO	0.04	0.03
CaO	1.0	0.7
MgO	0.6	0.40
Na_2O	2.5	3.5
K_2O	6.7	5.8
$H_2O>105°C$	0.5	0.4
$H_2O<105°C$	0.26	0.2
P_2O_5	0.04	0.05
CO_2	0.58	<0.01
F	0.03	0.04
S	0.02	0.03
BaO	0.09	0.07
	100.01	99.11
Niggli-values		
si	386	368
qz	142	120
al	40.7	42.0
fm	17.2	16.8
c	5.97	4.07
alk	36.1	37.1
ti	1.58	2.71
p	0.09	0.11
h	9.00	6.98
k	0.63	0.52
mg	0.28	0.18

	Analyst:
1. 205 S/50 E	V. Grundulis
2. 80 N/220 E	K. Johansson

DESCRIPTION OF THE ORES

BRIEF OUTLINE

Within the ore-bearing area several long and relatively narrow ore bodies of magnetite, martite and hematite occur. The strike of these is roughly N 30°W. In the south-eastern part the strike is somewhat more to the west and in the north-western part somewhat more to the east. The dip is vertical or 85 degrees to the SW.

In the central part of the deposit the different ore bodies can be studied rather well in outcrops and prospecting trenches. However, in the north-western and south-eastern parts of the ore-bearing area, outcrops of the ore do not exist. The configuration of the ore bodies on the map (Plate 1) has therefore been drawn on the basis of drilling information and the magnetic measurements. The interpretation of the magnetic anomalies has a number of uncertainties, for example, the ore bodies are, to a relatively large extent, built up of hematite and martite, the latter with a varying degree of magnetization. The interpretation is also hampered by the fact that, within the ore-bearing area, rather strong negative anomalies occur over the magnetite ore. The magnetite here is most probably inversely magnetized.

The ore-bearing area has a length of about 1500 m. The total width of all the bodies is greatest in the north-western part and attains there a maximum 150—160 m. As already pointed out previously, there occurs to the south, between profiles 700 and 800 S, an important decrease in the width of the ore-bearing zone. This is due to a fault system, which crosses the ore bodies in a NE—SW direction. South-east of this fault system the width of the ore zone has decreased from a normal 100 m to 30—40 m. The ore bodies north of Ratekjåkk, which are separated from the main part of the ore-bearing zone, have a width reaching only about 20 m.

The geophysical calculations indicate that the ore bodies have a depth of about 300 to 500 m. The same tendency is found by the drillings. However, only in a few profiles the drillings have attained this depth. In the profiles 200 S and 300 S the ore zone almost pinches out at a depth of somewhat more than 300 m below the surface. In profile 400 S there is a similar decrease of the ore at a depth of 400 m, and in profile 500 S, a part of the ore (the main magnetite ore body) only goes down to a depth of 250 m. The very rapid decrease of the ore with depth, between profiles 750 S and 800 S, is related to the fault system which cuts and limits the ore at a depth of only 50—100 m below the surface.

The ore has an outcropping surface of 45 725 m², of which 27 890 m² are made up of magnetite, 9 610 m² of martite and 8 225 m² of hematite. The deposit contains 37.01 million tons of ore, of which 19.07 million tons are made up of magnetite with an average of 55.0 per cent iron, 7.85 million tons of martite with an average of 57.6 per cent iron and 10.09 million tons of hematite with an average of 56.1 per cent iron. All ore types contain on an average 1.3 per cent phosphorus.

MAGNETITE ORE

The most important ore body at Ekströmsberg consist of magnetite and occurs in the north-eastern part of the deposit. Within this magnetite body there are minor quantities of martite and hematite, especially in the SW part of the body. The south-eastern end also is made up of hematite. When all these parts are included, the length of the main magnetite ore body is 1300 m and the maximum width, between the profiles 400 S and 500 S, is about 50 m. South-east of profile 700 S the width of the ore body is only about 10 m, with the exception of the part at profile 1000 S where the width is near to 30 m.

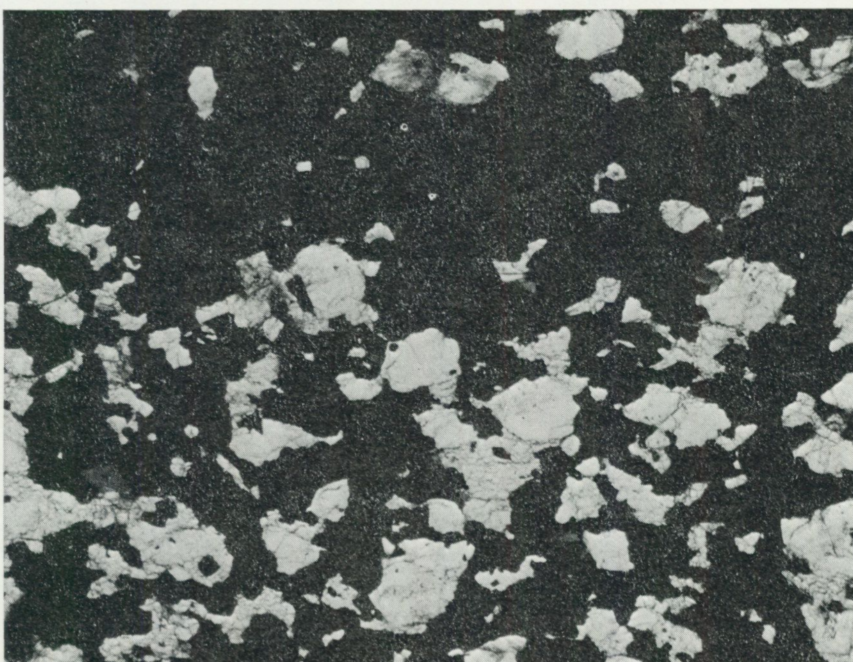


Fig.18. *Apatite-layered magnetite ore. Apatite (grey-white) lies in magnetite (black). 500 S/40 W. Thin section. Ord. light, x 33.*

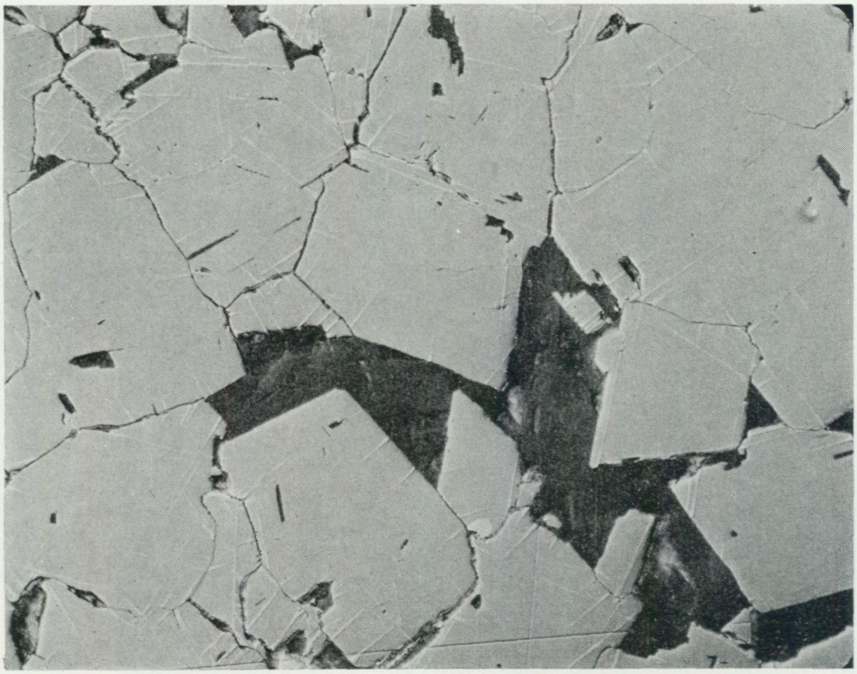


Fig. 19. *Magnetite ore. Magnetite (grey-white) and apatite (grey). Note small amounts of hematite (white) indicating slight martitization. 500 S/40 W. Polished section. Ord. light, x 425.*

Smaller bodies of magnetite, which to a relatively large extent are altered to martite, are found between profiles 200 S and 700 S immediately south-west of the main magnetite ore body. The width of these smaller ore bodies reaches about 10 m at a maximum. In the same part of the deposit occur narrow veins of magnetite in the quartz-bearing porphyry. This mineralization, which covers a relatively large area, has a content of iron which varies between 20 and 35 per cent, sometimes reaching almost 50 per cent. Magnetite ore is also found at the northern end of main hematite ore body. The hematite passes into magnetite north of profile 200 S and extending to profile 100 N. At profile 0 the magnetite reaches a maximum width of about 30 m. Immediately west of this magnetite ore occur veinlets of magnetite in the quartz-bearing porphyry.

The magnetite ore is grey-black, fine-grained and usually shows apatite-layering in which 0.1 — 1 mm wide apatite-rich layers occur between 2—4 mm wide magnetite-rich layers. The two types of layers do not have any sharp borders and pass into each other successively. Exceptionally, the apatite-rich layers are 1—2 cm wide. The layering is sometimes slightly folded, otherwise the strike is symmetrical with the extent of the ore bodies or veins. In some cases the apatite does not occur as distinct layers, but merely as irregular aggregates with only limited extent in the strike direction. The ore is cut by later veins filled with calcite, quartz and, rarely, small amounts of pyrite. These veins are some centimetres wide and partly very irregular.

The microscope shows that the apatite forms mostly 0.1—0.3 mm long, anhedral grains which occur in the above mentioned layering, or forms irregular aggregates, up to 1 mm in size, within the ore (Fig. 18). Other minerals in the ore are brown-green biotite, dirty-brown chlorite and quartz. There occur also secondary, irregular aggregates of albite, quartz and small amounts of allanite.

The magnetite forms mostly irregular grains, about 0.1 mm in size, with simple boundaries. There is often a slight martitization which generally follows the borders of the grains or the octahedral planes (Fig. 19).

MARTITE ORE

The martite ore, which has been formed from the magnetite ore by alteration (oxidation), is made up of a mixture of magnetite and hematite. In the earlier geological investigations of the Ekströmsberg deposit this kind of ore had not been observed. Magnetite and hematite were considered as two almost pure phases of ore, of which the magnetite however always contained some hematite.

The alteration of magnetite to martite has reached different stages in different parts of the deposit, and there are all gradations between almost pure magnetite and almost pure hematite. The alteration is a gradual process with no sharp borders between the different types. That martite is an intermediate stage between magnetite and hematite is shown by the fact that they are only exceptionally in direct contact with each other (as at profile 350 S and 700 S). In all other instances the two ore types are interlayered by martite.

The division into magnetite ore — martite ore — hematite ore on the map and the profiles is based on chemical analyses and macroscopic investigation. Ore that gives a red streak, indicating the presence of hematite, and has a varying degree of magnetism, was mapped as martite. The chemical analyses provide an adequate basis for estimating the amount of martite in the ore. By using the relationship between the content of total iron and the content of ferrous iron, the degree of martitization has been calculated using the following equations: the content of magnetite = 4.146 x per cent Fe^{2+}, the content of hematite = 1.43 x per cent Fe^{total} — 4.29 x per cent Fe^{2+} and the degree of martitization = 100 x content of hematite/(content of hematite + content of magnetite). An ore with a martitization degree less than 20 is considered as magnetite, between 20 an 80 as martite and more than 80 as hematite. This relationship is shown in Fig. 20.

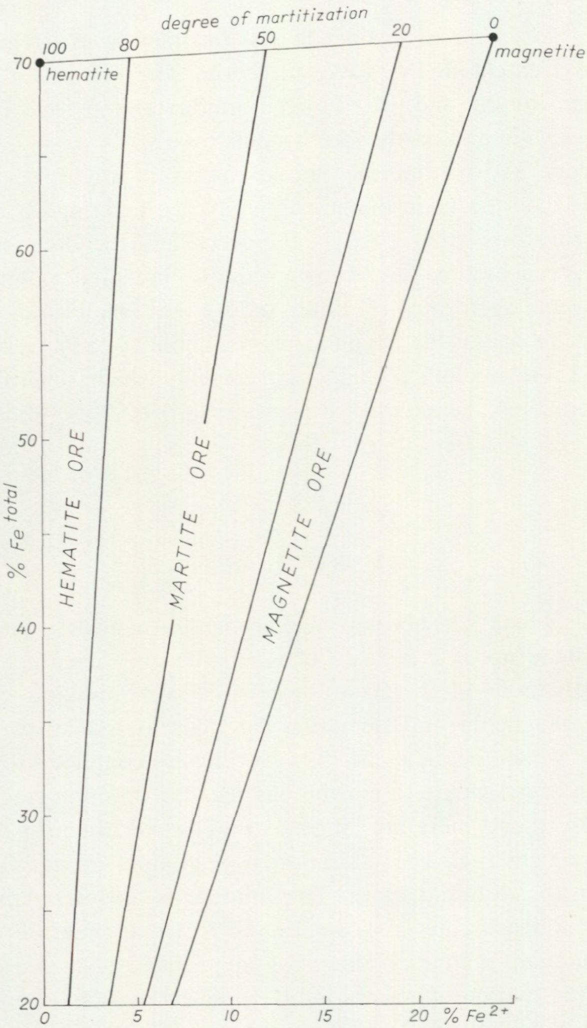


Fig. 20. *Relationship between ferrous iron and total iron in magnetite ore, martite ore and hematite ore.*

The amount of martite ore increases from NE to SW in the ore deposit, i.e. the further away from the perthite granite the more this type of ore occurs. Martite ore occurs mainly between the main magnetite ore body and the main hematite ore body. As previously pointed out, an important part of the main magnetite ore body is built up of martite. Martite ore also occurs west of the main hematite ore body. Other independent and important ore bodies of martite ore do not occur, the martite instead forms a part of either the magnetite or hematite ore bodies.

The martite ore is black-grey, fine-grained, non-schistose or weakly schistose. Sometimes the colour is bright red due a high content of hematite and goethite. The martite ore is apatite-bearing, the apatite occurring in 1—2 mm diffuse

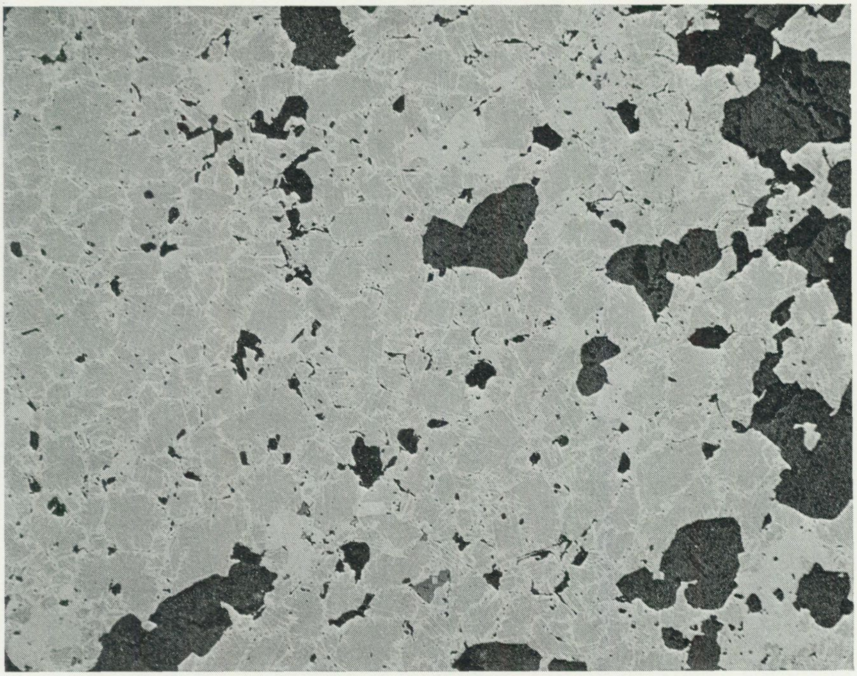


Fig. 21. *Martite ore. Magnetite (grey) surrounded by hematite (grey-white). Dark-grey = apatite. Black = cavities. Drill-hole 67802, 130 m. Polished section. Ord. light, x 82.*

layers quite similar to those in the magnetite and hematite ore. Schlieren and aggregates of calcite are relatively common and at least partly secondary. Often a secondary network of 1—2 mm wide, irregular veins with quartz are seen. Locally the martite ore contains some green amphibole, mostly as patches 1—2 cm in size.

The microscope shows that the apatite forms anhedral grains, 0.05 — 0.1 mm and sometimes 0.2 — 0.3 mm long, within the ore. Accessory amounts of allanite occur together with apatite. In the schlieren and aggregates of calcite there are small amounts of apatite. In clearly secondary calcite schlieren is found lepidocrocite and dirty-green chlorite. In the secondary quartz schlieren the quartz forms anhedral grains, 0.05 mm in size, with undulating extinction.

The martitization of the magnetite exhibits the following changes. In ore bodies with only a slight alteration the ore is built up of 0.1 — 0.5 mm long anhedral magnetite grains, with irregular but simple grain boundaries. The magnetite shows a rather prominent martitization following the octahedral surfaces. Around the magnetite grains there occurs a thin border of hematite which has partly recrystallized, forming larger areas between the magnetite (Fig. 21). In places the hematite forms anhedral mostly parallel grains, about 0.2 mm long.

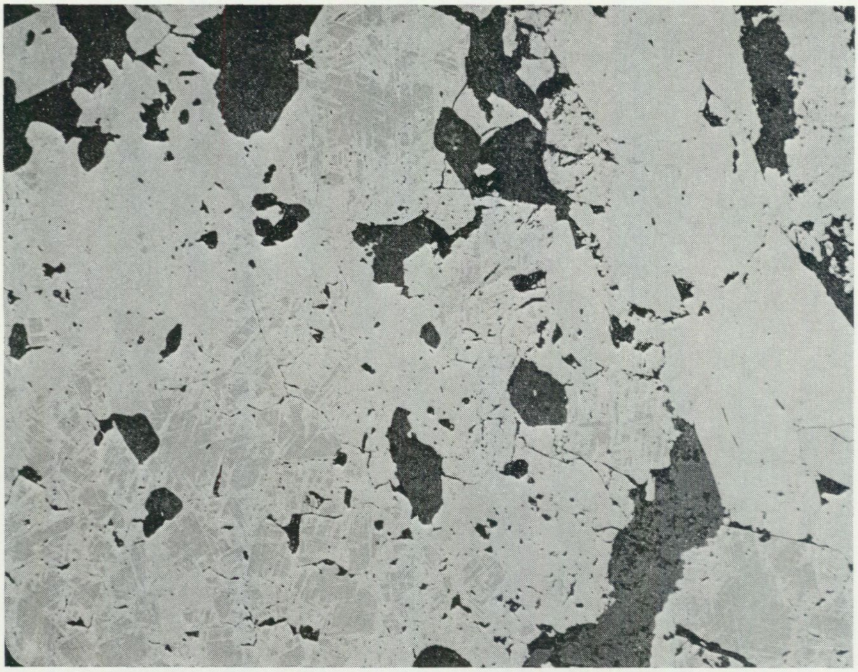


Fig. 22. *Martite ore. Hematite (grey-white) with remnants of magnetite (grey). Dark-grey =apatite. Black = cavities. Drill-hole 67803, 130 m. Polished section. Nic. +, x 168.*

There is no sharp border between magnetite and hematite, it merely appears that the magnetite has been "dissolved".

The following stage in the alteration is an ore with dominating amounts of hematite and small amounts of magnetite. The hematite occurs as 0.05 — 0.1 mm long, anhedral and irregular grains. Sometimes coarse varieties occur in which the hematite forms anhedral grains, 0.1 — 0.5 mm, exceptionally 1—3 mm in size, in semi-parallel schlieren or irregular aggregates. Together with the hematite there are small amounts of anhedral to subhedral grains of magnetite, 0.1 mm in size, which are martitized along octahedral planes or grain boundaries. To a lesser degree there are diffuse and irregular remnants of magnetite which often are in the middle of the hematite grains (Fig. 22). The final stage in the martitization is a "pure" hematite ore.

Locally there are also found some different types of martite ore. In these there is no indication that hematite has been formed from magnetite, as unaltered magnetite and hematite lie side by side (Fig. 23). In some varieties there are parallel layers, up to some millimetres wide, of both magnetite and hematite and small amounts of apatite (Fig. 24). All the minerals form anhedral grains, 0.05 — 0.1 mm long, which are elongated in the direction of the layering.

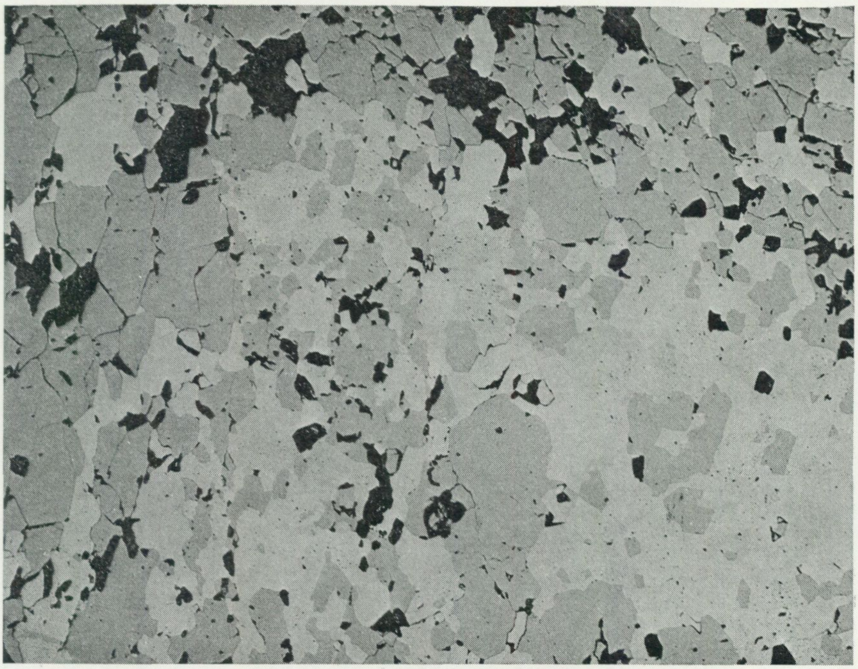


Fig. 23. *Martite ore. Hematite (grey-white) and magnetite (grey) dominate. Dark-grey = apatite. Black = cavities. Drill-hole 66805, 54 m. Polished section. Ord. light, x 82.*

Fig. 24. *Martite ore. Magnetite (grey) with subordinate amounts of hematite (grey-white) and apatite (dark-grey). Drill-hole 66806, 80 m. Polished section. Ord. light, x 42.*

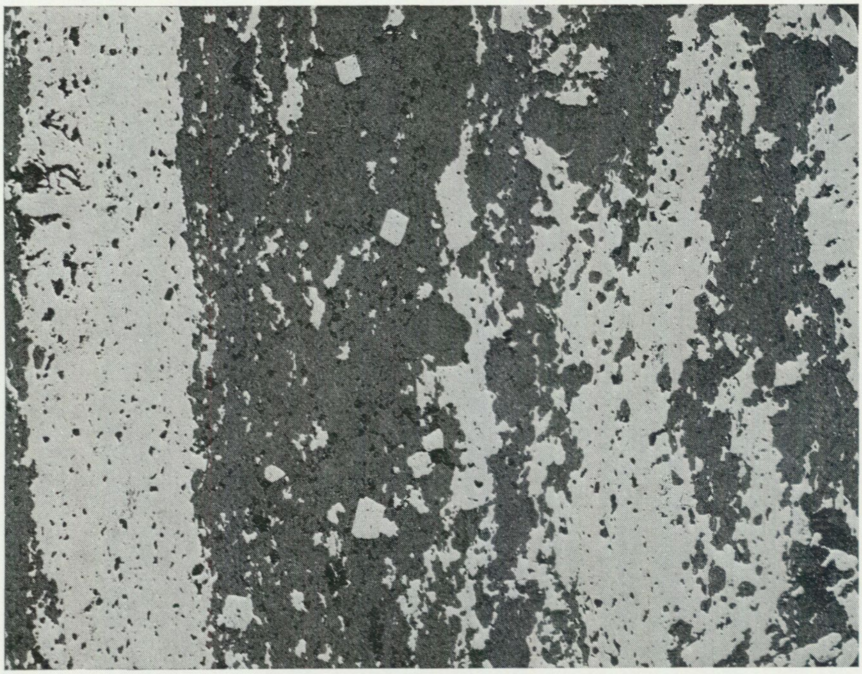


Fig. 25. *Hematite ore. Hematite (grey-white) and apatite (grey). In the apatite-layers idiomorphic pseudomorphs of hematite after magnetite. 408 S/129 W. Polished section. Ord. light, x 42.*

HEMATITE ORE

Hematite ore occurs in the SW part of the deposit. The most important hematite ore body has a length of about 1000 m, from profile 200 S to profile 1200 S. In the southernmost part it splits up into narrow schlieren in the quartz-bearing porphyry. The maximum width of this ore body reaches somewhat more than 15 m. Smaller hematite ore bodies occur W of the main hematite ore body, from profile 700 S to profile 100 N.

The hematite ore is blue-grey, fine-grained and mostly somewhat schistose. Occasionally the colour has changed into blue-violet by superficial oxidation. An apatite-layering similar to that in the magnetite ore and martite ore commonly occurs. The apatite-layers are usually 1—2 mm wide and diffuse against the hematite. They are sometimes somewhat slightly folded, further there occurs some displacement due to small faults. Calcite forms schlieren up to some centimetres wide, with little endurance along the strike, and there are also schlieren some millimetres wide with chlorite and sericite. These schlieren are most probably secondary. Irregular druses up to several centimetres long are rather com-

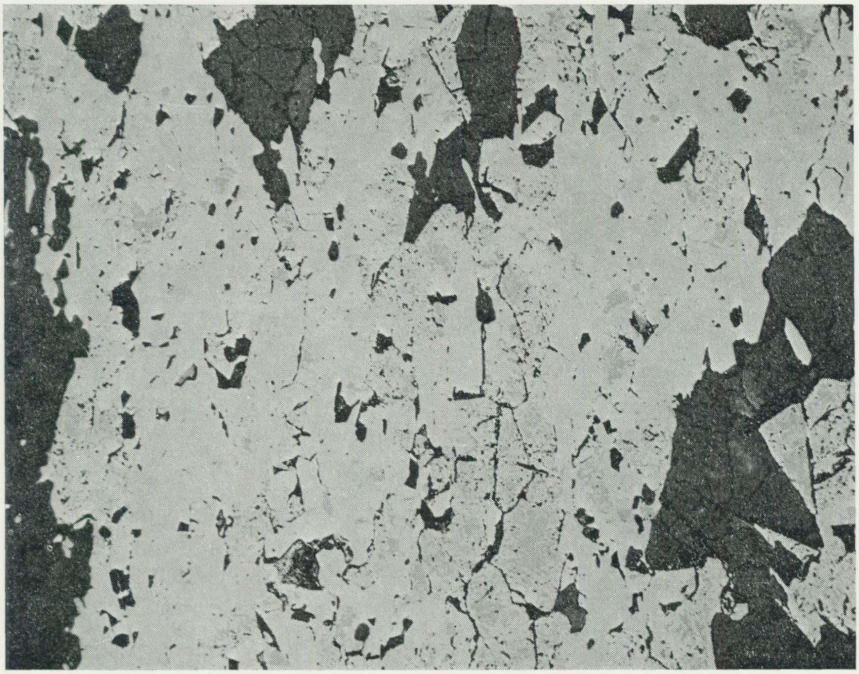


Fig. 26. *Hematite ore. Hematite (grey-white) with diffuse remnants of magnetite (grey). Dark-grey = apatite and to small extent quartz. Polished section. Ord. light, x 168.*

mon, and they are filled with euhedral crystals some millimetres in size of quartz, feldspar and chlorite. The hematite ore also contains schlieren up to several centimetres wide, of the quartz-bearing porphyry which often is totally sericite-altered.

The hematite ore is built up of 0.1 mm long anhedral grains which form parallel aggregate often elongated in the direction of schistosity (Fig. 25). Locally, as at 200 S and 506 S, there occurs a dense, non-schistose ore with a grain size of only 0.03 — 0.05 mm. Rarely, the hematite ore contains some magnetite, mostly as small, diffuse remnants in the hematite grains (Fig. 26). There also occurs a peculiar martite as 0.1 — 4 mm large porphyry-blastic grains which are crushed and have irregular boundaries. The martite consists of hematite with an octahedral texture (Fig. 27).

Few other minerals occur in the hematite ore in addition to hematite. The most common is apatite as 0.1 mm long, anhedral grains within the ore. In those parts where the ore is apatite-layered the grain size of the apatite is mostly only 0.02 mm, but there also occur some grains of apatite which are 0.3 mm long and orientated in the direction of the layering (Fig. 28). Other minerals observed in small amounts are pale-green biotite, muscovite, lepidocrocite and red-brown

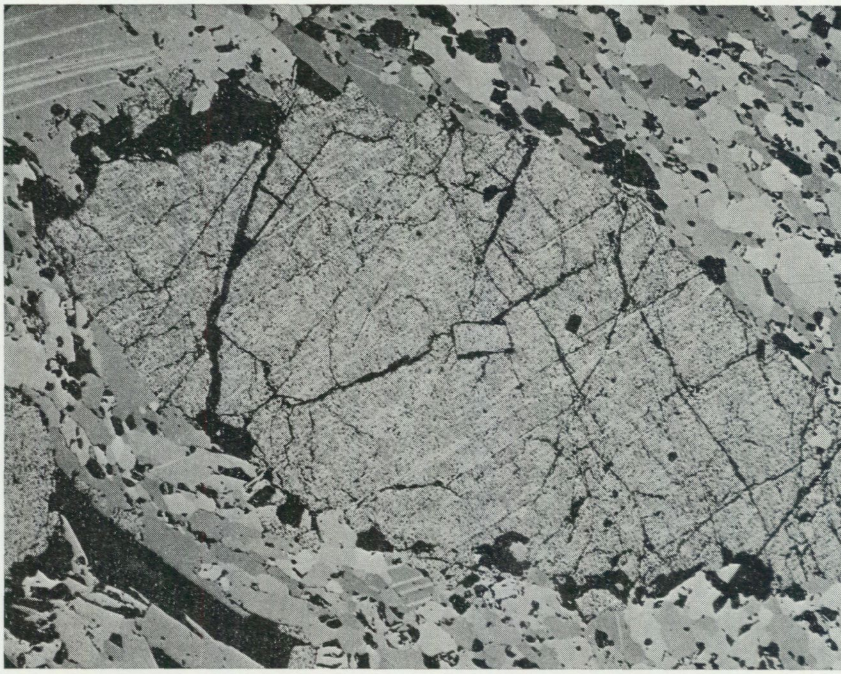


Fig. 27. *Hematite ore. Porphyroblast of martite with octahedral texture in a matrix of hematite (grey-white to grey). Black = cavities. Polished section. Nic. +, x 42.*

allanite. Parallel with the apatite-layering occur narrow schlieren of quartz and relatively large amounts of allanite.

ORE VEINLETS IN THE QUARTZ-BEARING PORPHYRY

In the quartz-bearing porphyry of Ekströmsberg there occur relatively abundant parallel veinlets of iron oxides (magnetite, martite and hematite). In the syenite-porphyry such veinlets have not been observed. An ore breccia with an irregular network of iron oxides brecciating the host rock, which is found in most other apatite iron ores in Norrbotten and well developed in the deposits of Mertainen, Tuolluvaara and Luossavaara among others, is thus missing in Ekströmsberg.

The ore veinlets mainly occur in the north-western part of the deposit. South-west of the main hematite ore body there occur abundant ore veins, mainly hematite but also magnetite and martite. The area north-west of the northern end of the main magnetite ore body is also relatively rich in veinlets of magnetite and martite.

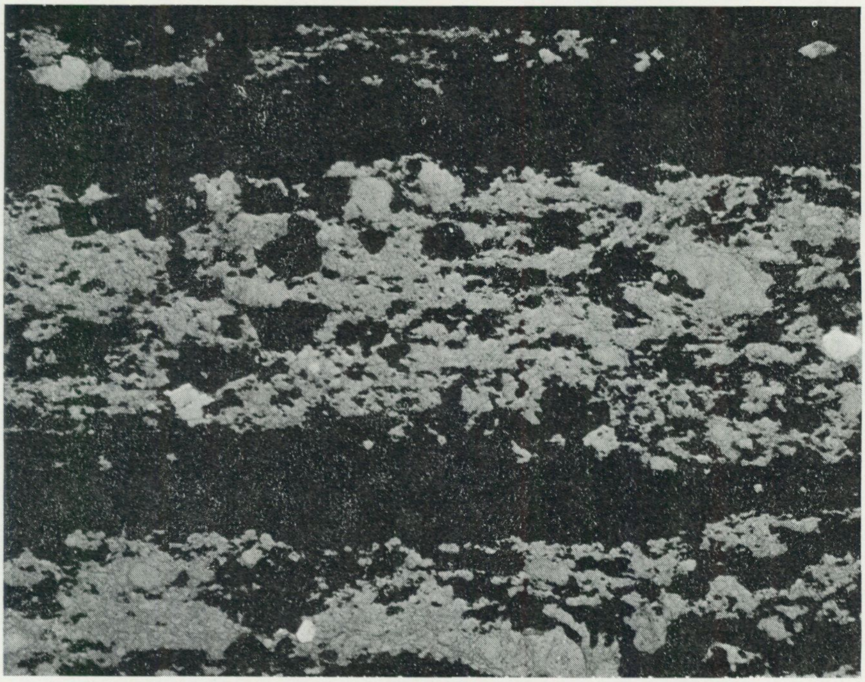


Fig. 28. *Hematite ore. Parallel layers of hematite (black) and apatite (dark-grey), in the latter some grains of muscovite (grey-white). 408 S/129 W. Thin section. Nic. +, x 33.*

The width of the ore veinlets varies from millimetres to metres. Sometimes banded ore is found with alternating layers some millimetres wide of ore and porphyry. Mostly the veinlets are rather irregular and show little endurance along strike (Fig. 29). The length of the veins in these cases are only a few times their width. The ore veinlets are affected by later tectonic movements. They are sometimes slightly folded or displaced by faulting, the maximum displacement reaching some centimetres.

The quartz-bearing porphyry in which the ore veinlets occur, is rather unaffected by the ore. The contact with ore is always sharp. The colour is red but the phenocrysts are generally missing. Often the porphyry is grey, depending on an increased content of chlorite and muscovite.

There seems to be no difference in the mode of appearance between the ore veinlets and the ore bodies. The strike and dip of both coincide. The mode of formation of the ore veinlets is not clear. If the veinlets originally formed a network similar to the ore breccias in the other apatite iron ores in Lapland, they must have obtained their present parallel structure through late tectonic activity. That the ore veinlets have an intrusive appearance is shown by the fact that they locally contain angular fragments of the porphyry up to some centimetres

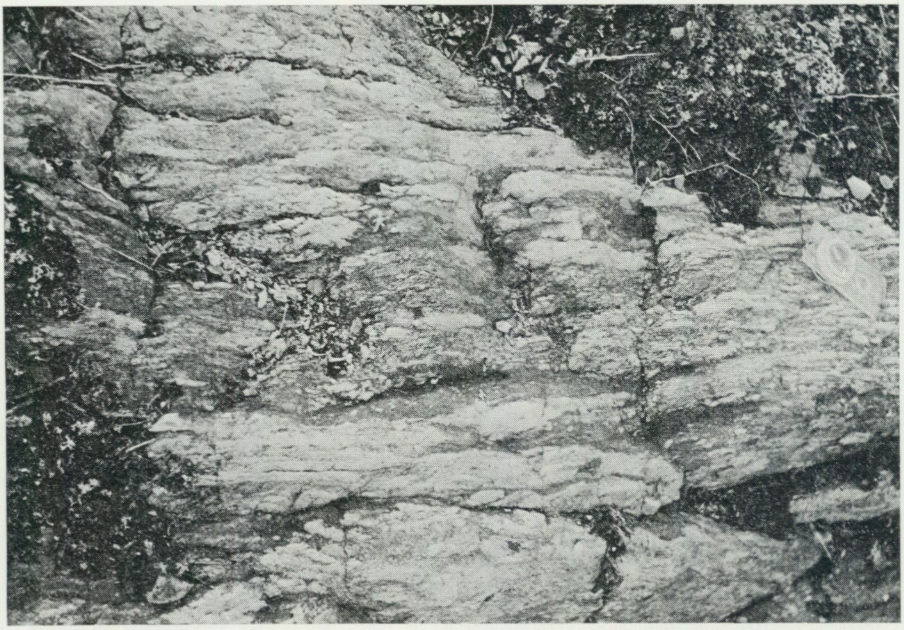


Fig. 29. *Schlieren of magnetite in a schistose quartz-bearing porphyry. 190 S/95 W.*

in size. Geijer, (1912) however, considers the ore veinlets as simultaneous with the quartz-bearing porphyry and not as distinctly younger veins or intrusions.

QUARTZITE

In the north-western part and to some extent in the south-western part of the Ekströmsberg deposit there occur narrow intercalations of iron oxide-layered quartzites. The width of these does not exceed 3—4 m. The length is not known, but can possibly, in some cases, be rather large. Most of the quartzites are found between the main hematite ore body and the syenite-porphyry to the south-west of this ore. The quartzites, which here are hematite-layered, occur immediately adjacent to the north-westernmost intercalation of syenite-porphyry. The quartzites seem to occur at more or less the same stratigraphic level. It is not possible to say if these intercalations are connected with each other, or are separate bodies. In the area between profiles 400 S — 500 S there are hematite-bearing quartzites on both sides of the main hematite ore body, in close proximity to it. Within the same area martite-layered quartzites occur in the north-western part

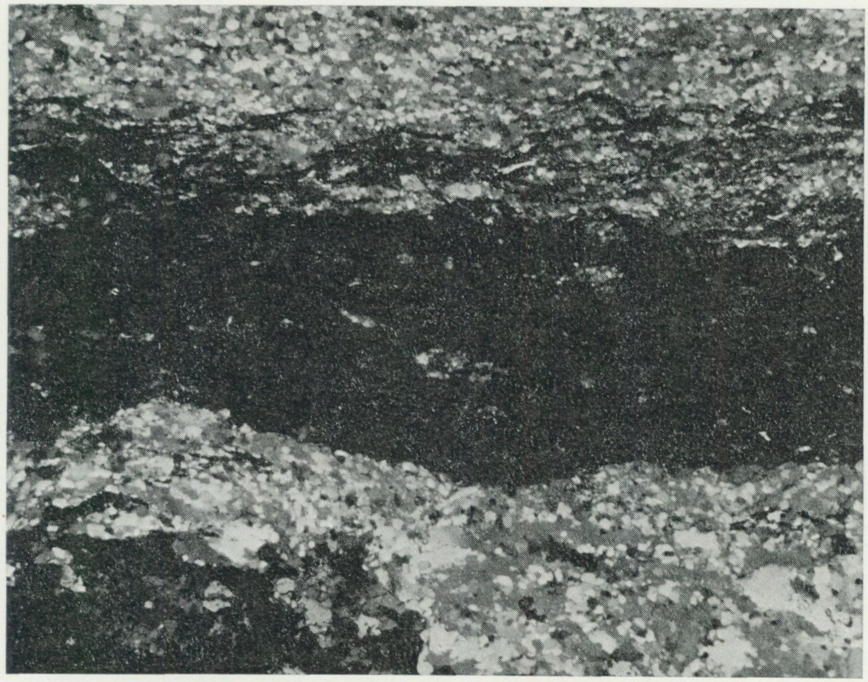


Fig. 30. *Hematite-layered quartzite. Hematite (black) surrounded by layers of quartz. In the hematite, allanite and small amounts of tourmaline occur. 506 S/126 W. Thin section. Nic. +, x 33.*

of a minor magnetite-martite ore body, which lies between the main magnetite ore body and the main hematite ore body. Magnetite-layered quartzites occur at profile 200 S in connection with a small magnetite ore body W of the main magnetite ore body, and in the magnetite ore body, at profile 900 S.

The content of iron oxides in the quartzites varies within rather wide limits and the rock can therefore be described as a quartz-bearing iron ore or an iron oxide-bearing quartzite. In the magnetite-bearing quartzites there is, however, a dominance of the iron oxides. The iron content of the quartzites is generally low, between 20 and 35 per cent.

The hematite-bearing quartzites, which are most common, are made up of fine-grained hematite which contain lenses of grey-white quartz 2—3 mm wide and some centimetres long. Exceptionally the width of the lenses reaches 1 cm. The quartz forms 0.02—0.03 mm anhedral grains with simple boundaries. The border between the quartz-layers and the hematite-layers is generally sharp. The hematite forms 0.02—0.05 mm irregular grains which sometimes are elongated parallel with the layering. In the hematite there occur, to a very small extent, remnants of magnetite which are altered to hematite after the octahedral planes. In the quartz-layers there occur accessory amounts of muscovite and allanite.

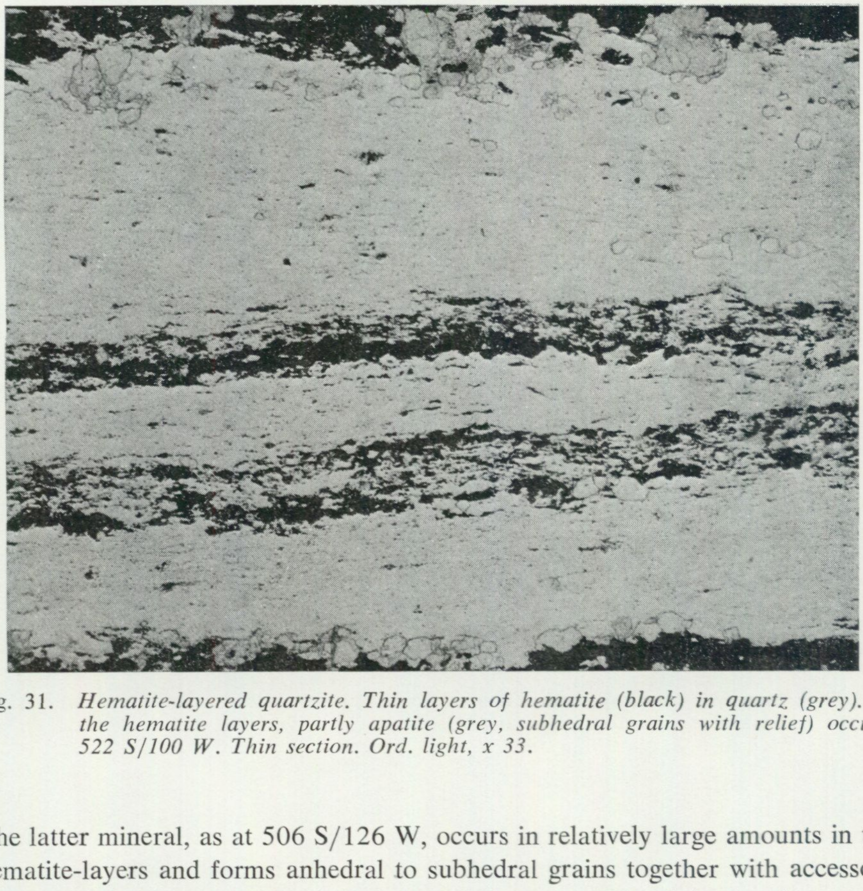


Fig. 31. *Hematite-layered quartzite. Thin layers of hematite (black) in quartz (grey). In the hematite layers, partly apatite (grey, subhedral grains with relief) occurs. 522 S/100 W. Thin section. Ord. light, x 33.*

The latter mineral, as at 506 S/126 W, occurs in relatively large amounts in the hematite-layers and forms anhedral to subhedral grains together with accessory amounts of zircon, fluorite, tourmaline and biotite (Fig. 30). Apatite occurs generally as an accessory mineral in the hematite layers, but forms sometimes separate layers, mainly in the hematite-layers, and to some extent in the quartz-layers (Fig. 31). Most of the quartz-layered quartzites contain about 0.2 per cent phosphorus.

Sometimes, as at 500 S/106 W, there are found quartz-bearing hematite ores which show a very indistinct layering. Quartz and hematite form irregular aggregates in which the hematite occurs as small irregular accumulations (Fig. 32). The hematite is accompanied by small amounts of apatite and allanite.

The martite-bearing quartzites show only a less pronounced layering. They are similar to the quartz-bearing hematite being built up of fine-grained aggregates of 0.03 mm anhedral quartz grains in which varying amounts of martite occur. In some samples the quartz dominates, in others the martite. Sometime the quartz has become coarser by recrystallization and forms grains up to 0.5 mm in size with undulating extinction. The martite occurs as minute, disseminated grains which partly cluster into schlieren or aggregates. In small or accessory

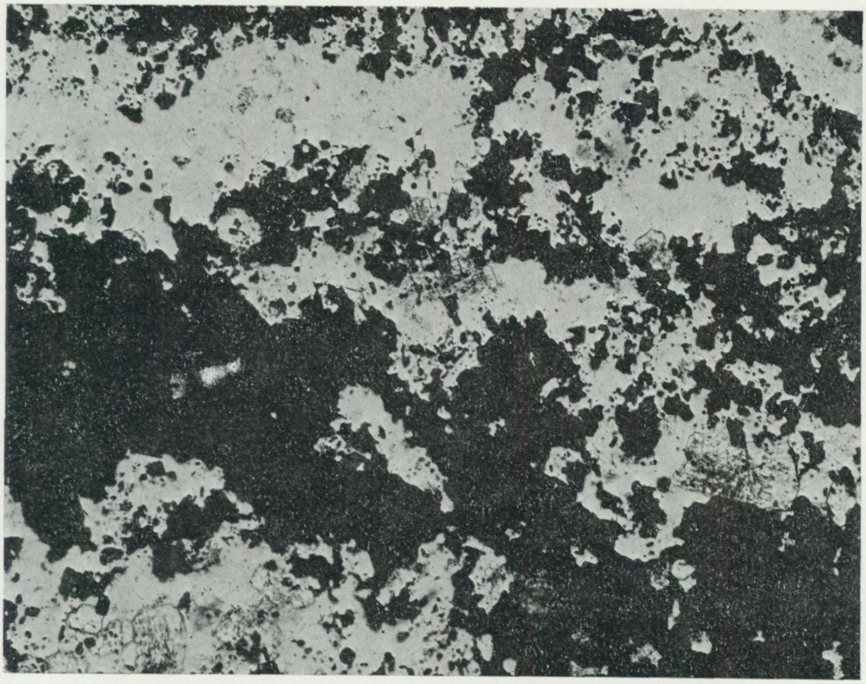


Fig. 32. *Hematite-bearing quartzite. Hematite (black) and quartz (grey). In the hematite, partly apatite (grey, subhedral grains with relief) and allanite (dark-grey) occur. 500 S/106 W. Thin section. Ord. light, x 130.*

amounts occur biotite, chlorite, apatite and allanite. These minerals generally occur in association with the iron oxides. The apatite, which sometimes forms euhedral crystals, occurs however evenly distributed throughout the rock.

The quartzites which occur in the magnetite ore show a pronounced interlayering between 0.1—5 mm wide layers of magnetite and quartz (Fig. 33), occasionally also of apatite and calcite. The quartz is quite similar to that of the hematite- and martite-bearing quartzites. The magnetite, which forms independent layers or occurs as a fine dissemination in the quartz layers, is mostly built up of 0.03—1 mm uneven grains. The magnetite also forms porphyroblastic grains up to some millimetres in size, which usually are somewhat martitized along the boundaries of the grains or the octahedral planes. Pyrite occurs as an accessory mineral forming 0.1—0.5 mm irregular grains in the magnetite layers. In the quartz-layers there are found sparingly, narrow aggregates of biotite with small amounts of apatite and allanite. Some quartz-layers are rich in sericite. At profile 900 S there occurs a quartz-apatite-calcite-layered magnetite. The apatite occurs mainly in the magnetite layers. In these chlorite, allanite, muscovite and fluorite occur as accessories.

The quartzites are with all probability primary layers of iron ore which have

Fig. 33. *Magnetite-layered quartzite. Magnetite (black) surrounded by quartz (grey). Mainly in the magnetite occur apatite (dark-grey small grains), biotite (dark-grey laths) and calcite (white). Drill-hole 66814, 162 m. Thin section. Ord. light, x 33.*

been affected by a later silicification. The secondary nature of the alteration is shown by the relative abundance of tourmaline, fluorite, allanite and sericite. The same mineral association is found in the sericite-altered zones in the quartz-bearing porphyry. Further, there are in the martite ore and hematite ore secondary quartz layers which are relatively rich in allanite and fluorite.

SKARN

Silicate skarn forms a quite unimportant element in the Ekströmsberg deposit. It occurs mainly in connection with magnetite ore. In the hematite ore skarn has not been observed, and it seems to occur only exceptionally in the martite ore. The largest continuous skarn mass is found around the north-western end of the main magnetite ore. The width reaches here about 40 m. Minor skarn bodies, with a width of about 5 m, occur between profiles 250 S and 400 S on both sides of the same ore body. The magnetite ore body also contains locally narrow veinlets and irregular aggregates of skarn.

The skarn is dominated by a pale-green tremolite-actinolite. There are also small amounts of magnetite and apatite, the latter mineral forms relatively round aggregates up to 1 cm in size. Sphene, zircon and allanite occur as accessories. The skarn is cut by veinlets of calcite and partly also quartz.

Locally, in the quartz-bearing porphyry breccias occur which contain angular or schlieren-like porphyry fragments in a matrix of skarn silicates. The skarn partly forms irregular schlieren some centimetres wide which brecciate and replace the porphyry. Quite exceptionally the skarn contains an impregnation of a fine-grained pyrite. The skarn minerals are tremolite-actinolite or exceptionally chlorite. They are accompanied by small amounts fine-grained quartz, calcite, apatite and magnetite. The skarn breccias probably have a magmatic origin and are simultaneous with the formation of the iron ore. To some extent the breccias can be of tectonic origin, the porphyry having been crushed and later healed by the skarn.

CHEMICAL COMPOSITION OF THE ORE

The chemical composition of the different varieties of ore is rather similar. With the exception of differences in the degree of oxidation, i.e. the relative content of magnetite and hematite, the contents of the different elements are in the main the same (Table 5). In the ore bodies the content of iron varies between 50 and 65 per cent, the average being about 55 to 60 per cent. As with the other apatite iron ores in Norrbotten, the content of phosphorus in the Ekströmsberg ore shows rapid alternations between relatively low values (0.3 per cent) and relatively high values (3 per cent) over small horizontal ranges, 1 metre or less. 50 per cent of the samples analysed contain between 0.7 and 1.6 per cent phosphorus (Fig. 34). On average the ore bodies contain 1.3 per cent phosphorus. Contents exceeding 3 per cent are rare. Low contents of phosphorus, about 0.2—0.4 per

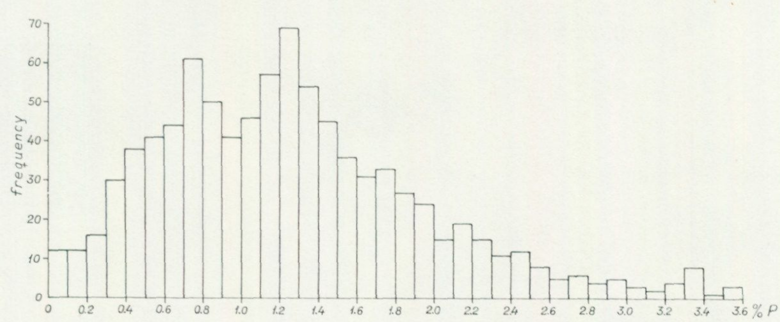


Fig. 34. *Distribution of the content of phosphorus in 770 samples of ore from Ekströmsberg. Drill-holes 65801—66815. 1 m sections with more than 20 per cent iron.*

TABLE 5. Chemical composition of the different ore varieties (values in weight per cent)

	Magnetite ore			Martite ore (hematite-rich)	Hematite ore		
Analysis No.	1	2	3	4	5	6	7
Fe	58.28	60.62	65.00	61.30	61.80	59.69	60.72
P	2.37	1.94	1.02	1.45	1.35	1.63	1.81
Fe^{2+}	19.53	20.08	18.04	6.12	2.75	1.02	0.63
S	0.016	0.016	0.005	0.032	0.023	0.009	0.007
(Martite %	3.1	8.9	12.7	68.5	81.7	90.8	94.0)
Fe_3O_4	80.33	83.25	74.80	25.37	11.40	4.23	2.61
Fe_2O_3	—	0.54	15.56	61.40	76.57	80.97	84.11
FeO	0.19	—	—	—	—	—	—
MnO	0.10	0.14	0.08	0.06	0.03	0.03	0.03
CaO	7.48	6.67	3.34	5.27	4.71	6.53	5.48
MgO	0.99	0.40	0.25	0.56	0.27	0.30	0.26
Al_2O_3	0.77	0.46	0.44	0.60	0.56	0.47	0.48
SiO_2	3.52	2.90	2.65	2.18	1.83	1.09	1.53
TiO_2	0.26	0.12	0.26	0.10	0.05	0.30	0.48
V_2O_5	0.10	0.09	0.09	0.10	0.08	0.10	0.11
P_2O_5	5.43	4.45	2.34	3.32	3.09	3.73	4.15
CO_2	0.40	0.98	0.33	0.94	0.63	1.41	0.17
Na_2O	0.04	0.05	0.03	0.04	0.08	0.02	0.02
K_2O	0.29	0.09	0.07	0.10	0.05	0.03	0.07

Analysis No. 1. Drill-hole 65803, 120.0—136.0 m. No. 2. Drill-hole 66802, 92.0—104.0 m.
No. 3. Drill-hole 66806, 72.0—87.0 m. No. 4. Drill-hole 65803, 94.0—111.0 m.
No. 5. Drill-hole 66813, 233.0—266.0 m. No. 6. Drill-hole 66808, 137.0—154.0 m.
No. 7. Drill-hole 65801, 43.0—54.0 m.

Analyst: Chemical laboratory of LKAB, Kiruna.

cent, are found in the hematite ores which occur furthest to the south-west of the north-western part of the deposit. These hematites are partly silicified and form quartzites. Similar low contents of phosphorus, 0.4—0.5 per cent, are found in the relatively poor ore zones which lie north-east of the main magnetite ore body in the north-western part of the deposit. The lowest phosphorus contents are, however, found in the ore zones north of Ratekjåkk. The magnetite ore in profile 340 N contains, over a width of 10 m, on an average only 0.045 per cent phosphorus. The phosphorus in all the ore bodies is bound to a fluorine-apatite with 2.8—3.4 per cent fluorine and 0.6 per cent or less chlorine (Frietsch 1974a).

The content of vanadium in the ore bodies varies between 0.08 and 0.11 per cent V_2O_5 and the content of titanium between 0.05 and 0.48 per cent TiO_2. The content of sulfur is low, varying between 0.005 and 0.032 per cent. The content of CO_2 varies between 0.17 and 1.41 per cent. It is bound to calcite and occurs in almost the same amount in all varities of the ore, perhaps with a slight predominance in the magnetite ore. The contents of the other elements are small, and similar to other ores of the Kiruna type (Table 5).

GEOLOGICAL EVOLUTION OF THE EKSTRÖMSBERG DEPOSIT

The iron ore of Ekströmsberg is in many respects similar to other apatite-bearing iron ores in Northern Sweden. The ore is of magmatic origin and forms an intrusion into the quartz-bearing porphyry and to some extent into the syenite-porphyry. Both rocks are evidently of extrusive origin. Into this sequence of lava rocks the ore intruded, most possibly when the sequence was still in a horizontal position. Later folding has placed the rocks and ores in an upright position. As mentioned earlier the nature of the ore veinlets is somewhat unclear. Geijer (1912) considered these to be closely associated with the quartz-bearing porphyry and not as later intrusions like the larger ore bodies. The veinlets are, however, so similar to the larger ore bodies in mode of occurrence that both most probably are formed in the same way. The difference between them seems only to be a difference in size. That there is a close connection between the veinlets and the larger ore bodies is also indicated by the fact that many of the larger ore bodies are split up, in the direction of strike, into a system of veinlets which form a direct continuation of the larger ore body. It is therefore not reasonable to suppose that the veinlets have formed at an earlier stage with the massive ore bodies being intruded at later stage. The veinlets must have been formed in a similar way and followed the same structures as the larger ore bodies. The question as to why the veinlets form a parallel system and not an irregular net-work, as in most deposits of the Kiruna type of ore, cannot be answered. A flattening out of an original irregular structure by tectonic forces seems to be an unsatisfactory explanation, as at least to some small extent the irregularity should have been preserved.

The ore at Ekströmsberg is mostly apatite-banded which is a primary feature formed during the crystallization. There seems to be no difference in this respect between the magnetite, martite and hematite ore types. If the variation in the content of magnetite and hematite is excluded, all the ore types have the same mineralogical and chemical composition. Besides apatite there occur in all the ore types small amounts of biotite and amphibole, which most probably are primary. In the hematite ore the content of secondary minerals such as quartz, sericite and fluorite is a prominent feature.

The relationship between magnetite and hematite in the different ore types is of special interest. Geijer (1912) considered both iron oxides to be primary and closely associated with the formation of the porphyries. Certain factors during the surface eruption caused the iron to crystalline now as magnetite now as hematite. The existence of the martite ore was at that time not known. The results from the present investigation show without doubt that magnetite is the primary mineral from which hematite is formed secondarily by oxidation. This is clearly indicated by the martitization phenomena, where the new formation of hematite follows the octahedral planes or the borders of the magnetite grains. The hematite must have recrystallized at least in part. That hematite is the final stage of the martitization process is shown by the fact that the martite ore always occurs in between the magnetite and hematite ore. These two ore types are only occasionally found in immediate contact with each other.

A detailed account of the mechanism which brought about the transformation of the iron oxides of Ekströmsberg has been previously given by the present author (Frietsch 1967, p. 11). The conversion of magnetite into hematite is related to the same process which caused the formation of the sericite-bearing zones in the enclosing quartz-bearing porphyry. This process is considered to be of metasomatic origin caused by hydrothermal fluids. In the quartz-bearing porphyry the secondary mineral association with quartz, sericite, chlorite and accessory amounts of calcite, zircon, allanite, tourmaline and fluorite is quite similar to that found in the host rocks of other metasomatically altered iron ores of the Kiruna type in Northern Sweden. The sericite-altered quartz-bearing porphyry of Ekströmsberg shows the same chemical characteristics as the altered wall-rocks of other deposits with a secondary formation of hematite from magnetite. The altered rocks usually have high $K/(Na+K)$- and $Fe^{3+}/(Fe^{2+}+Fe^{3+})$ -quotients and a low $Mg/(Mg + Fe^{2+} + Fe^{3+} + Mn)$-quotient. In Ekströmsberg these quotients in the sericite-altered porphyry are, however, in some respects not very different from those in the unaltered quartz-bearing porphyry. In the sericite-altered porphyry thus the $Fe^{3+}/(Fe^{2+} + Fe^{3+})$-ratio is similar or somewhat lower, and the $Mg/(Mg + Fe^{2+} + Fe^{3+} + Mn)$-ratio similar or somewhat higher than in the unaltered porphyry. The chemical changes in the porphyry of Ekströmsberg are therefore not as obvious as in many of the other rock-alterations which accompany the conversion of magnetite to hematite in other apatite iron ores in Northern Sweden. The alteration involved mainly a withdrawal of sodium and a minor addition of fluorine (0.67 per cent in analysis No. 2, Table 2), and barium (1.4 per cent BaO in analysis No. 1, Table 2). There was also some addition of boron (occurring in tourmaline) and cerium (occurring in allanite). Such an addition of fluorine and barium is known from other iron ores of the Kiruna type in connection with the alteration of magnetite to hematite, and is attributed to a metasomatic, hydrothermal activity (Frietsch 1967, 1973).

In many deposits of the Kiruna type of ore there is a spatial relationship between the occurrence of hematite in the ore and the metasomatic alteration of the wall-rock. The relationship is not quite obvious in all cases and the alteration processes do not necessarily occur in immediate proximity to each other. In Ekströmsberg the relationship in space between the sericite-alteration of the quartz-bearing porphyry and the alteration of magnetite to hematite is rather poor. Both alterations occur side by side but there is no positive correlation between the sericitization and the formation of hematite. The sericitization has, however, most heavily attacked the north-western part of the deposit where also the largest amount of hematite and martite is found.

The metasomatic alteration of Ekströmsberg possibly represents a late stage in the ore-forming process. Geijer (1912) considered the alteration of the quartz-bearing porphyry as a late- or postvolcanic thermal action. According to the opinion of the present author the alteration, both of the porphyry and the ore, is a late process in the same activity which produced the ore. The hydrothermal solutions had a high oxygen fugacity and brought about with-drawal of sodium and an addition of fluorine, barium, boron and cerium. It is of interest to note that cerium as allanite occurs both as "primary" in the apatite-bands in the ore, and as "secondary" accompanying the other hydrothermal minerals. This means that the concentration of cerium was about the same during the main ore-forming process and the later hydrothermal one.

Evidence of the late, metasomatic process, on a local extent, is found in the iron-oxide-bearing quartzites. Here primary ore layers have been silicified by the hydrothermal activity. The quartzites contain the same secondary minerals as the sericite-altered quartz-bearing porphyry and parts of the hematite ore, i.e. they are rich in quartz accompanied by small amounts of sericite, tourmaline, fluorite and allanite. There seems to be no doubt about the secondary origin of the quartzites, an opinion already stated by Geijer (1912). He considered the silicification to be volcanic after-action similar to the chemical alteration of the quartz-bearing porphyry. The quartzites of Ekströmsberg are thus nothing other than silicified layers of iron oxides.

REFERENCES

SGU = Sveriges geologiska undersökning

GFF = Geologiska Föreningens i Stockholm Förhandlingar

BERGLUND, E. S., 1924: Malmtillgången i Norrbottens län. In: Utredning angående nyttiggörande av statens norrländska malmfyndigheter. — Statens Offentliga Utredningar 1924:32, pp. 65—191.

BÄCKSTRÖM, H., 1904: Ekströmsberg och Mertainens järnmalmsfälts geologi. — GFF 26, pp. 180—185.

FRIETSCH, R., 1954: Ekströmsbergs järnmalmsfält. — Rapport. Malmbyråns arkiv, SGU.

— 1967: The relationship between magnetite and hematite in the iron ores of the Kiruna type and some other iron ore types. — SGU C 625.

— 1970: Trace elements in magnetite and hematite mainly from Northern Sweden. — SGU C 646.

— 1974a: The occurrence and composition of apatite with special reference to iron ores and rocks in Northern Sweden. — SGU C 694.

— 1974b: Ekströmsbergs järnmalmsfyndighet. — Rapport rörande resultaten av SGU:s undersökningar under åren 1961—1969. Malmbyråns arkiv, SGU.

GEIJER, P., 1910: Igneous rocks and iron ores of Kiirunavaara, Luossavaara and Tuolluvaara. — Scientific and practical researches in Lapland arranged by Luossavaara-Kiirunavaara Aktiebolag. Stockholm.

— 1912: Studies on the geology of the iron ores of Lapland. — GFF 34, pp. 727—789.

— 1931: Berggrunden inom malmtrakten Kiruna-Gällivare-Pajala. — SGU C 366.

GUMAELIUS, O., 1877: Berättelse till Chefen för Sveriges Geologiska Undersökning. In: Underdånig berättelse om en på nådig befallning år 1875 företagen undersökning af malmfyndigheter inom Gellivare och Jukkasjärvi socknar af Norrbottens län. — SGU C 23, pp. 43—86.

LUNDBOHM, Hj. & PETERSSON, W., 1910: Ekströmsberg. In: The iron ore resources of the world. — Stockholm. Pp. 581—582.

OFFERBERG, J., 1967: Beskrivning till berggrundskartbladen Kiruna NV, NO, SV, SO. — SGU Af 1—4.

ROMAN, A., 1818: Berättelse om Norrbotten och dess Lappmarker. — Z. Häggström, Stockholm.

SNYDER, F. G., 1968: Precambrian iron deposits in Missouri. In Wilson, H.D.B. (ed.): Magmatic ore deposits. A symposium. — Econ. Geol. Publ. Company. Lancaster Press, Lancaster. Pp. 231—238.

Stutzer, O., 1907: Die Eisenerzlagerstätten bei Ekströmsberg. In: Geologie und Genesis der lappländischen Eisenerzlagerstätten. — Neues Jahrb. Min. Beilage-Band 24, pp. 610—622.

Svenonius, F., 1900: Beskrifning öfver en del förut mindre kända malmfyndigheter inom Jukkasjärvi malmtrakt och dess omgifningar. In: Underdånig berättelse om en undersökning af mindre kända malmfyndigheter inom Jukkasjärvi malmtrakt och dess omgifningar. — SGU C 183, pp. 114—139.

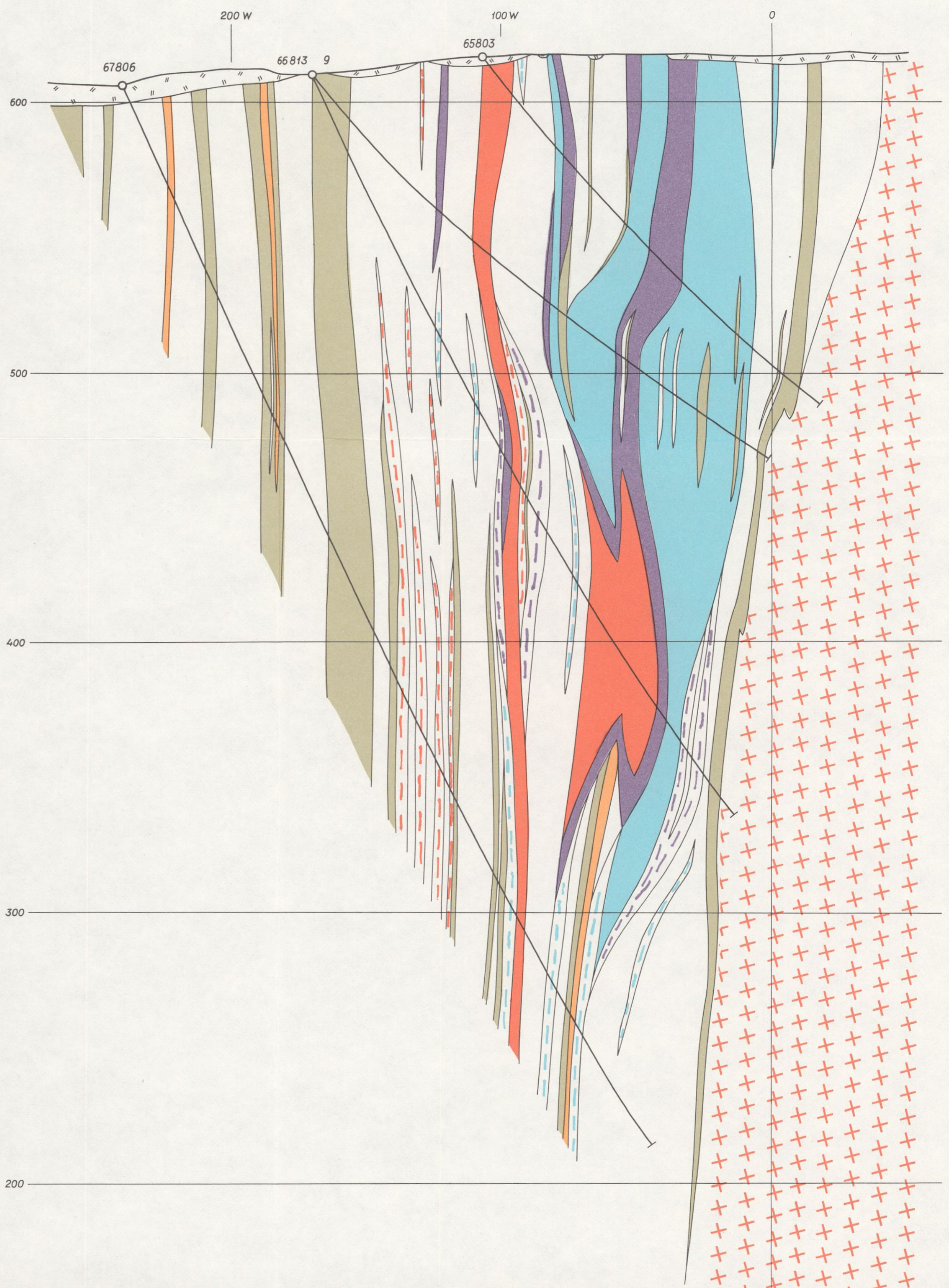
Welin, E., Christiansson, K. & Nilsson, Ö., 1971: Rb-Sr radiometric ages of extrusive and intrusive rocks in northern Sweden. I. — SGU C 666.

Geological map of THE EKSTRÖMSBERG IRON ORE

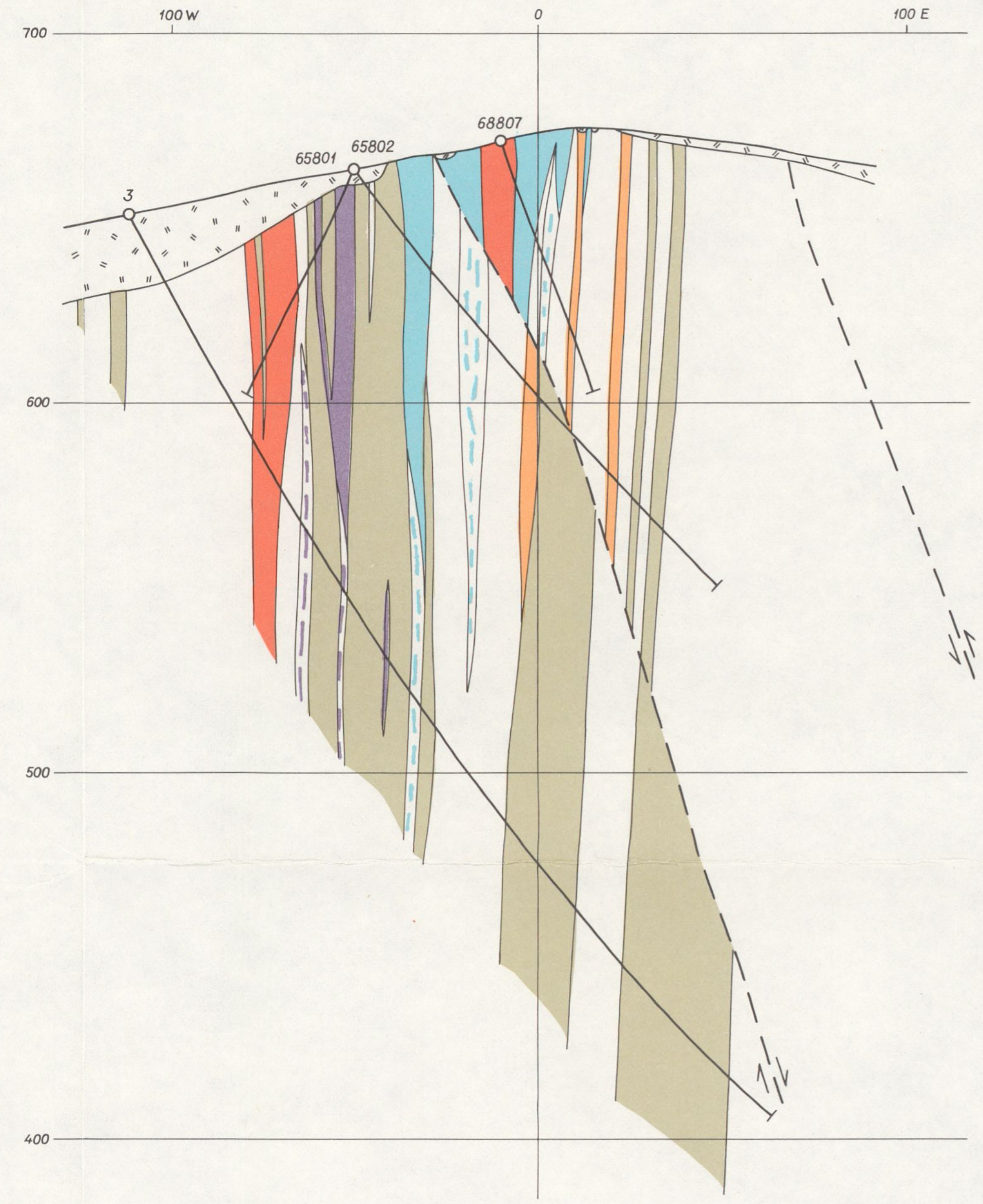
R. Frietsch 1974

C Davidsons Boktr./Offset, Växjö 1974

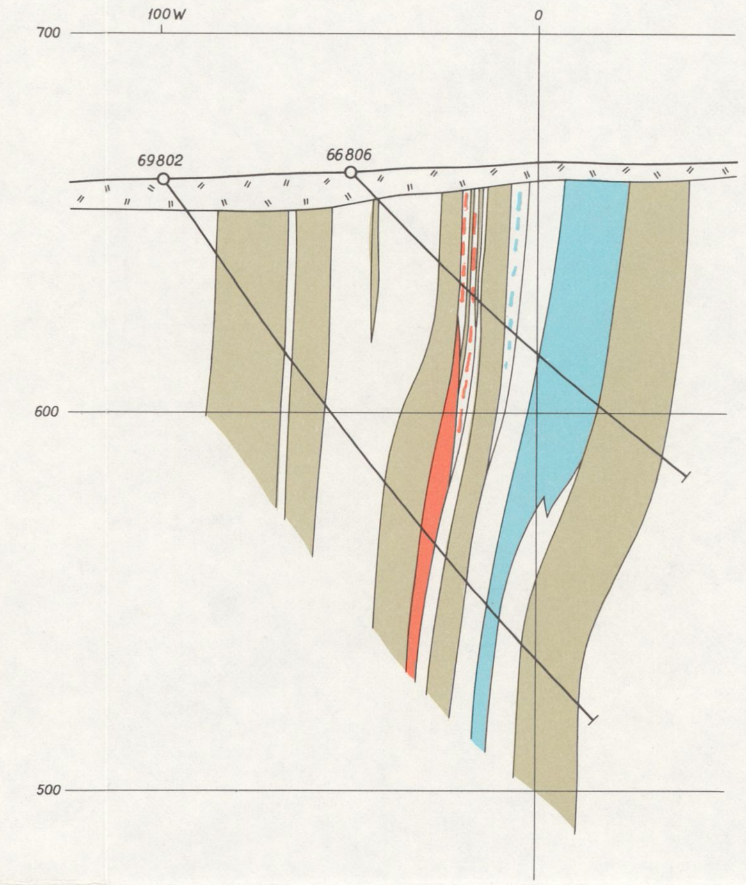
PROFILE 300 S



PROFILE 700 S



PROFILE 1100 S



Profiles through

THE EKSTRÖMSBERG IRON ORE

R. Frietsch 1974

0 50 100 m

1:2000

(Legend see Plate 1)

C Davidsons Boktr./Offset, Växjö 1974

PRISKLASS D

Distribution

LiberTryck

FACK, 162 10 VÄLLINGBY 1

ISBN 91-7158-068-9

Laholm 1974 . Trydells Boktryckeri AB