SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 620 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 61 NR 5

BO LUNDBERG

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Editor: Per H. Lundegårdh
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Contents

Abstract

The Stora Sahavaara deposit is a sulphide-bearing skarn iron ore, situated in Northern Sweden near the Finnish border. The tabular ore body is concordantly enclosed in Pre-Cambrian supra-crustal rocks (sediments and volcanics). The ore succeeds a dolomite horizon, lying in the strike direction of the latter..

Two types of skarn have been distinguished, viz. iron-poor diopside-tremolite skarn and serpentine skarn, the latter including certain amounts of phlogopite and olivine. The diopside-tremolite skarn occurs as separate masses between the ore and the hanging-wall quartzite. The serpentine skarn constitutes the gangue of the ore.

The magnetite is shown to be magnesium-bearing, with 2.6 % MgO entering the crystal lattice.

Granitization and scapolitization has affected the surrounding bedrock in varying degree.

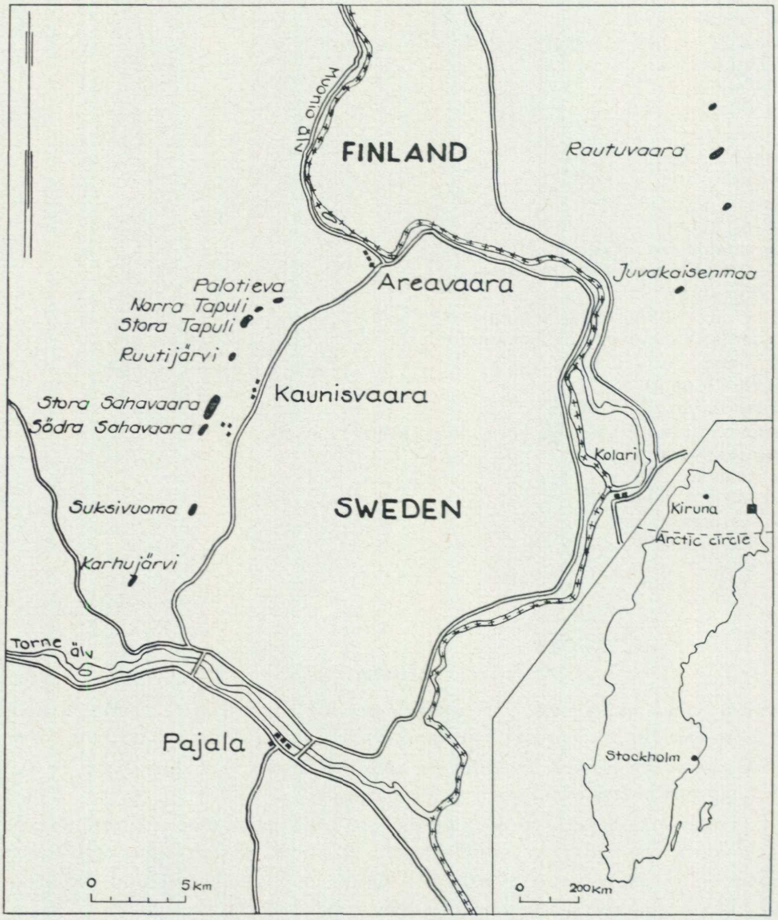

Fig. 1. Map showing the location of the ores of the Kaunisvaara field, NW of Pajala, Norrbotten, Sweden.

Introduction

Stora Sahavaara is one of a series of skarn iron ores occurring in a long narrow zone NW of Pajala, Norrbotten, Northern Sweden (fig. 1). These ores are collectively known as the Kaunisvaara field. Five separate ore bodies were discovered in 1918 by the geologist V. Tanner using a dip needle (Tanner 1919). They are from S to N: Södra Sahavaara, Stora Sahavaara, Stora Tapuli, Norra Tapuli and Palotieva. All are now state-owned. Another orebody, Ruutijärvi, was discovered by Boliden Mining Co. in 1949 and the Johnson Co. recently located two more, Suksivuoma and Karhujärvi, in the continuation of the zone towards the S. In the Kolari district, on the Finnish side of the border, ores of a similar type occur. The Stora Sahavaara orebody, however, seems to be the biggest and economically most important of the ores found to date in this part of Northern Scandinavia.

The ores and enclosing rocks are of Pre-Cambrian age. The geology of the area has been treated by a number of authors including Fredholm (1886),

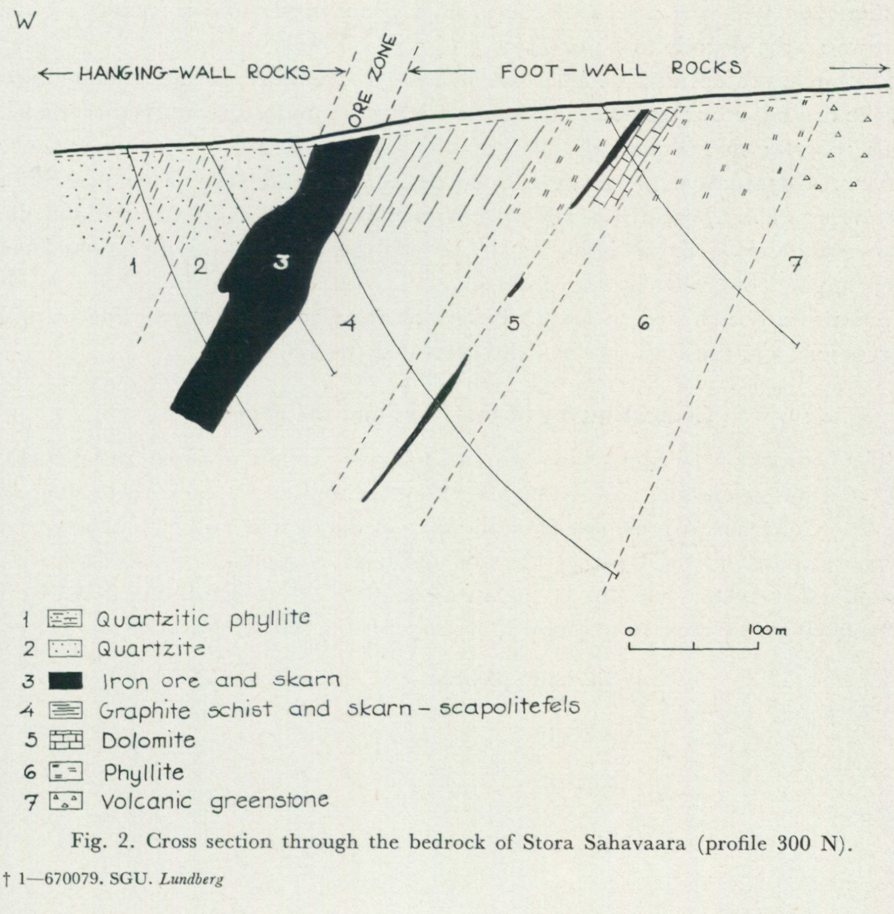

Fig. 2. Cross section through the bedrock of Stora Sahavaara (profile 300 N).

Geijer (1931) and more recently Eriksson (1952). The latter outlined in a general way the main features of the Kaunisvaara zone making use of all available exposures (1952, pl. 1).

The area is one of extensive bogs alternating with pine forests. The relief is gently undulating and the elevation above sea-level 150—250 m. The ores are entirely covered with moraine and bog. Outcrops of the enclosing rocks are very sparse.

The discovery in 1918 of significant magnetic anomalies was followed by diamond drilling. Two holes were sited on Stora Sahavaara and the deposit was further explored by trenching and shaft-sinking (B. Högbom 1921). Investigations were then abandoned until 1960 when the Geological Survey of Sweden carried out ground magnetic and gravimetric measurements over the Stora Sahavaara deposit. Drilling began in 1961 and has continued to the time of writing. 47 diamond drill holes have now been completed (approximately 13 000 m).

The holes allow the main features of the ore body and its associated rocks to be determined. Drill-hole profiles have been constructed and, when taken in conjunction with the results of the ground geophysical survey, enable a good picture of the deposit to be obtained.

Drill-hole profiles and detailed calculations of ore reserves and grades based on the drilling are presented in a stenciled report (Lundberg and Werner 1965). This report also includes an interpretation of the magnetic and gravimetric surveys. Quantitative geophysical calculations, partly dealing with the Stora Sahavaara deposit, occur in a paper by Werner (1965). The ore reserves and the shape of the ore body as shown by the original geophysical interpretations have been largely confirmed by the drilling.

I am greatly indebted to Dr. P. Padget of the Geological Survey for helpful suggestions and criticism. He has also corrected the English.

General survey of the rocks and the deposit

The bedrock of the Stora Sahavaara area consists largely of supracrustal rocks, viz. volcanic greenstone and sediments, clastic as well as chemical, belonging to the Pre-Cambrian. It is evident from the map of the deposit (pl. 1) and a typical profile through it (fig. 2), that the iron ore body is generally concordant with the enclosing rocks. The dip of the rocks is 50 to 70° towards the NW. It is convenient for descriptive purposes to distinguish the following units (fig. 2):

Hanging-wall rocks	Quartzitic phyllite Quartzite
Ore zone	Skarn Ore

Foot-wall rocks
- Graphite schist
- Skarn-scapolitefels
- Phyllite
- Dolomite
- Volcanic greenstone

Metadiabasic dikes intrude all the rocks listed above, including the ore and the skarn. Granitization and scapolization, however, are younger than all other rocks.

Description of the rocks

Hanging-wall rocks

QUARTZITE AND QUARTZITIC PHYLLITE. The area to the W of the ore is occupied by a thick, clastic sedimentary formation, consisting of alternating beds of quartzitic and phyllitic composition. In spite of transitional forms, two distinct rock types can be distinguished viz. a light grey, moderately biotite-bearing quartzite and a dark grey, biotite-rich quartzitic phyllite. The alternating beds

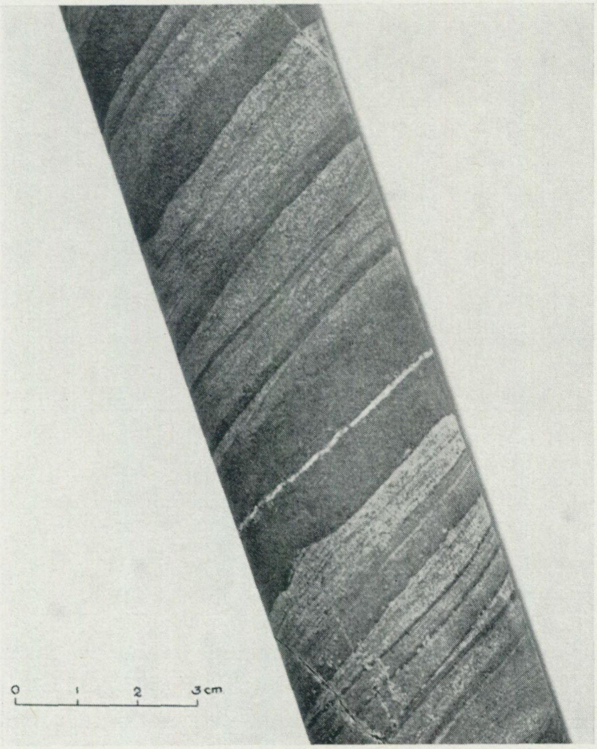

Fig. 3. Banded quartzitic phyllite. Dh (drill-hole) 63015, depth 258.5 m. Photo by R. Markström.

have a thickness of 30—100 m. Adjacent to the ore a quartzitic bed, about 40 m in thickness, is present. The western boundary of this formation is not known.

The stratification is often very distinct and regular with alternating dark, biotite-rich and light, quartz-rich bands, sometimes with indications of graded bedding (fig. 3). Both the quartzite and the quartzitic phyllite are in their well preserved state mineralogically simple. The quartzite is dominated by quartz with biotite in small or moderate amounts. Feldspar, muscovite and zoisite occur in small amounts. Magnetite is accessory. The quartzitic phyllite is distinguished from the quartzite mainly through a higher biotite and a smaller quartz content. This also appears clearly in the chemical analyses, tab. 1, No. 1—2. The microscopic texture is for both rocks generally granoblastic. The clastic texture is only rarely preserved. The grain size varies between 0.05 and 0.5 mm.

Table. 1. Chemical analyses of rocks. Analyst: B Johannesson

	1	2	3	4	5	6	7	8
SiO_2	61.4	80.6	53.5	47.9	46.8	31.0	58.7	50.2
TiO_2	0.91	0.53	0.93	0.69	0.77	0.48	1.25	1.15
Al_2O_3	16.8	8.4	9.0	10.9	11.1	7.0	12.6	14.3
Fe_2O_3	2.4	1.7	0.7	1.8	0.5	2.6	0.6	5.2
FeO	4.7	1.5	8.0	7.9	11.1	31.2	7.4	7.8
MnO	0.09	0.01	0.07	0.08	0.11	0.03	0.39	0.24
CaO	1.5	0.6	8.4	10.8	5.7	1.9	4.5	8.4
MgO	3.9	1.7	7.6	7.9	5.4	1.8	3.4	7.4
Na_2O	2.1	1.8	2.9	3.9	2.4	2.6	1.4	3.5
K_2O	4.3	2.4	1.7	1.3	3.8	1.3	5.6	0.4
$H_2O > 105°$ C	1.6	0.7	1.3	1.3	1.2	0.4	1.4	1.1
$H_2O < 105°$ C	0.12	0.06	0.1	0.4	0.1	0.1	0.2	0.1
P_2O_5	0.16	0.10	0.10	0.16	0.21	0.14	0.06	0.11
CO_2	0.01	0.01	1.0	1.0	0.2	0.1	1.20	0.02
S	0.01	0.01	4.1	3.9	5.6	17.6	0.4	0.27
F	0.09	0.03	0.12	0.06	0.11	0.08	0.15	0.02
Cl	0.01	0.02	0.9	1.6	1.1	1.0	0.42	0.01
C (graphite)	n.d.	n.d.	0.67	0.05	6.4	8.0	n.d.	n.d.
Total	100.1	100.2	101.1	101.7	102.6	107.3	99.7	100.2
Subtr. O	—	—	1.5	1.8	3.0	8.0	0.2	0.1
Total corr.	100.1	100.2	99.6	99.9	99.6	99.3	99.5	100.1

1. Quartzitic phyllite, dh 62002 23.25— 23.38 m.
2. Quartzite, dh 62002 118.08—118.14 m.
3. Skarn-scapolitefels, dh 63005 140.00—144.00 m.
4. Skarn-scapolitefels, dh 62001 127.00—135.00 m.
5. Graphite schist, dh 62001 140.00—160.00 m.
6. Graphite schist, dh 63005 125.00—135.00 m.
7. Phyllite, dh 63005 156.50—159.50 m.
8. Greenstone agglomerate from a well at the crossroads in Södra Kaunisvaara village.

The quartz-phyllitic beds in particular are frequently micro-folded, flow-folded or entirely transformed to granitic gneiss (fig. 23). This is connected with the granitization process which has affected these rocks in varying degrees and whose intensity seems to increase towards the W.

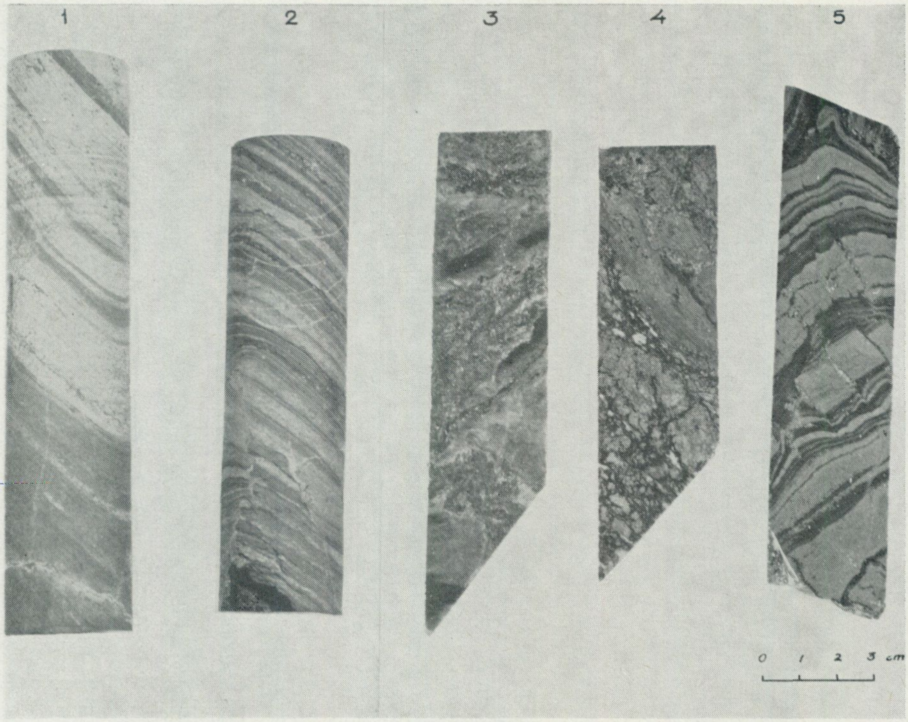

Fig. 4. 1—2 graphite schist, 3—5 skarn-scapolitefels. Locality: 1 dh 63018 72.4 m, 2 dh 63018 72.7 m, 3 dh 62014 110.6 m, 4 dh 62005 206.2 m, 5 dh 61001 103.5 m. Photo by B. Rönnberg.

Foot-wall rocks

GRAPHITE SCHIST AND SKARN-SCAPOLITEFELS. Immediately to the E of the Stora Sahavaara deposit, graphite schist and skarn-scapolitefels occur. The thickness in the N is about 170 m but decreases towards the S to about 50 m. Graphite schist and skarn-scapolitefels are found in about equal proportions, but their mutual distribution is very irregular and it has not been possible to separate them on the geological map (pl. 1). Carbonate zones, some dm in thickness, occur in both rock types.

The graphite schist is best characterized as a greyish black, graphite and sulphide-rich phyllite, which has been strongly scapolitized. The original bedding structure is frequently preserved (fig. 4), though seldom in the sulphide-rich variants where the sulphides "brecciate" the schist (fig. 5).

Besides sulphides and graphite the graphite schist consists essentially of quartz, scapolite, tremolite and biotite. Sphene and apatite are accessory. Quartz, scapolite and graphite build up a fine-grained ground mass in which tremolite prisms and coarse biotite aggregates lie. The scapolite is optically uniaxial with a negative character; the birefringence is low. The tremolite is colourless in thin section and with γ:z$=18°$.

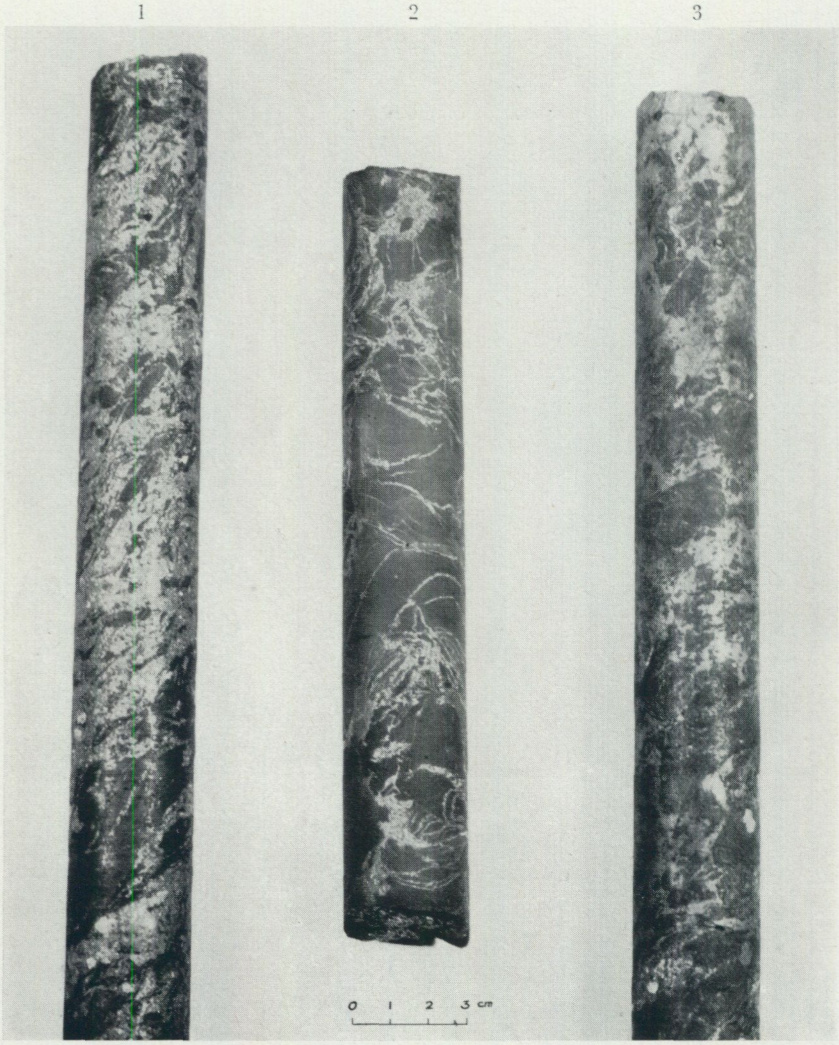

Fig. 5. Graphite schist with high content of graphite, pyrrhotite and pyrite. 1 dh 63018 85.4 m, 2 dh 62001 217.6 m, 3 dh 63018 85.6 m. Photo by B. Rönnberg.

The sulphur content is on the average 3—5 percent. Most of the sulphur is represented by pyrrhotite, a smaller part by pyrite. The graphite content is rather high, 6—8 percent according to the analyses 5 and 6 in tab. 1, and seems to increase with the sulphur content.

The skarn-scapolitefels sometimes exhibits a relict bedding structure but generally the structure is veined or irregular (fig. 4). The colour is greyish white to green. The rocks vary from quartz-rich, fine-grained types to skarn-scapolite-dominated ones with a coarse texture. The skarn is principally made up of pale green diopside or tremolite. These skarn minerals lie as scattered crystals or crystal

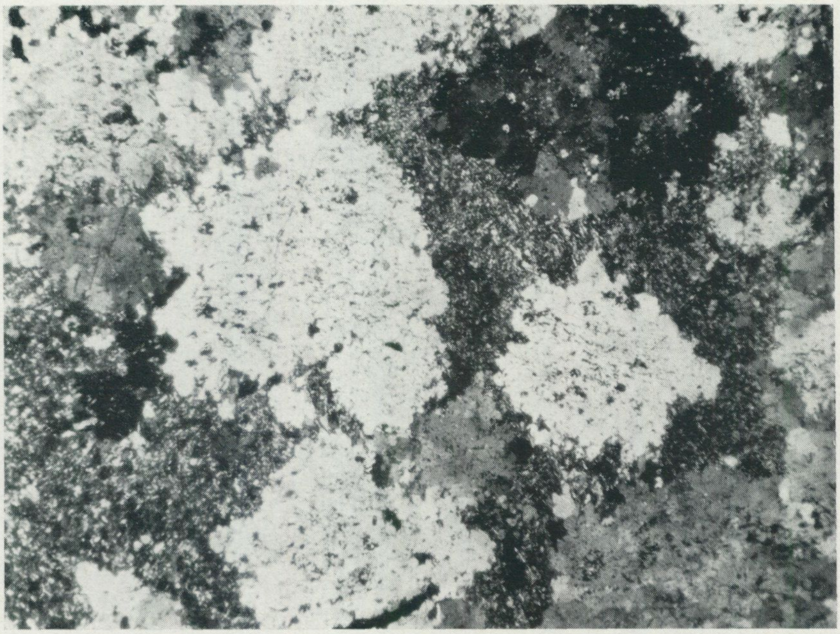

Fig. 6. Skarn-scapolitefels. Rounded aggregates of scapolite surrounded by narrow zones of fine-grained quartz and biotite. Dh 62008 185.2 m. Thin section. Nic. +. × 20.

aggregates inside large scapolite porphyroblasts which have to a greater or lesser degree grown together (fig. 6). Sulphides (mainly pyrrhotite) appear as irregular veins, which often strongly brecciate the rock.

In tab. 1 there are two chemical analyses of skarn-scapolitefels (Nos 3 and 4) and two of grapholite schist (Nos 5 and 6), each analysis representing a zone several metres in width. The essential difference between the rocks is a higher content of calcium and magnesium in the scarn-scapolitefels, which is reflected in the presence of appropriate skarn minerals (diopside and tremolite). Furthermore the difference in graphite content is great. These differences seems to be primary, the skarn-scapolitefels probably representing original lenses or local horizons of dolomite-rich phyllite in graphite phyllite. Perhaps this original dolomite-rich phyllite was later impregnated with sulphur coming from the graphite schist. The high content of scapolite accounts for the high content of chlorine in the analyses.

Phyllite. To the E of the graphite schist complex a layered phyllite occurs. It has a thickness of 150—200 m and encloses a dolomite horizon 30—40 m in width. The boundary between phyllite and the eastern greenstone is diffuse with a transition zone some dm in width. At certain places within the phyllite thin gravel-like beds occur, consisting of volcanic fragments.

The phyllite is distinctly layered with bands which vary in thickness from some

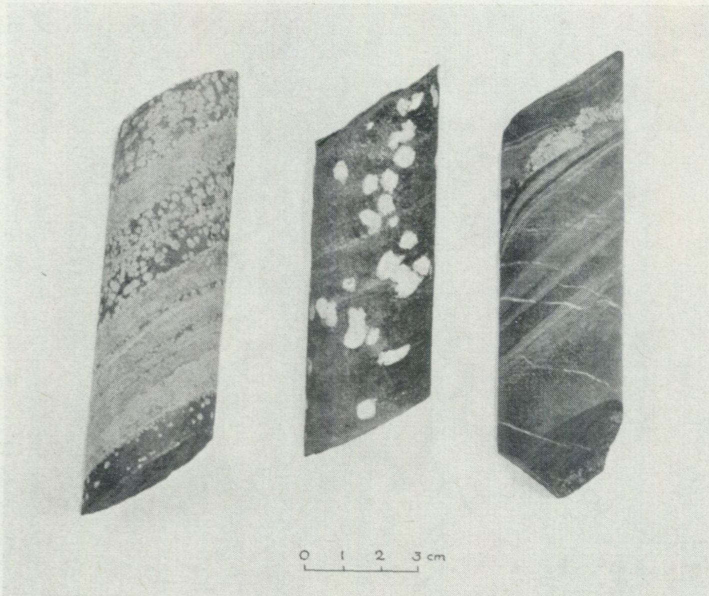

Fig. 7. Layered phyllite with white, rounded aggregates of scapolite. Dh 62010 240 m. Photo by B. Rönnberg.

mm to 1 or 2 dm. The alternating bands are principally of two kinds viz. dark, biotite-rich ones and light, quartz-rich ones. The biotite in the brown-black bands is of dark red-brown colour and exhibits parallel orientation.

Besides biotite the dark bands consist mainly of a colourless or faint green-coloured tremolite. The light bands consist essentially of quartz but also include fine-grained tremolite and as a rule some biotite.

Scapolite is abundant in the form of big white porphyroblastic aggregates (fig. 7).

In that part of the phyllite horizon, which lies nearest the greenstone, numerous porphyroblasts of a red-brown garnet occur. The crystal size is 1—4 mm.

Dolomite. Dolomite occurs, as mentioned, partly as a 30—40 m thick horizon in phyllite, and partly as numerous thin beds in phyllite and graphite schist. The thick horizon is to some extent replaced by magnetite and skarn. In the southernmost part of the map (pl. 1) a dolomite horizon is present and wedges out in phyllite. This horizon is occupied by magnetite ore to the south and constitutes the Södra Sahavaara deposit. Even the Stora Sahavaara ore is succeeded towards the N by dolomite. This dolomite horizon, skarn included, has a thickness of 30—40 m which is approximately the same as the ore-skarn horizon in its northern part.

The dolomite always contains small amounts of skarn minerals, the latter sometimes making a diffuse bedding structure visible. This skarn chiefly consists

Table. 2. Partial chemical analyses of dolomite. Analyst: LKAB Kiruna

Drill-hole Metre	62016 164.8—164.9		62016 169.2—169.3	
	%	Moles ×10 000	%	Moles ×10 000
CaO	29.7	5296	28.5	5082
MgO	20.00	4960	20.3	5035
MnO	0.11	16	0.14	20
FeO	0.71	99	0.81	113
Fe_2O_3	0.30	19	1.03	64
Al_2O_3	0.43	42	0.10	10
SiO_2	2.22	369	4.71	784

of serpentine and diopside. Tab. 2 shows two partial analyses of the carbonate rock, which succeeds the Stora Sahavaara ore to the N, showing it to be a dolomite with some calcite. The calcite is sometimes macroscopically visible in the form of lighter veins in the carbonate mass.

Volcanic greenstone. Farthest E in the area volcanic greenstone of considerable thickness occurs. Its eastern border is not known but the width of the zone at the surface is definitely more than 500 m, perhaps considerably more. This greenstone consists for the most part of layered, greyish green tuff or tuffite, but agglomerate is also rather common. The latter occurs in drill-hole 63020 as repeated beds, 2—10 m in width and also further to the E in outcrops on the summit of the mountain Sahavaara. Some parts of the greenstone are strongly metamorphosed and should be named amphibolite.

The tuffite is often schistose to a greater or lesser extent. It is very fine-grained and is built up by a dense felt of divergent needles or prisms of amphibole, with interstitial feldspar, scapolite and magnetite.

The agglomerate has a well developed fragmental structure. The size of the fragments is as a rule around 0.5 cm but sometimes reaches 3 cm. The fragments are angular or slightly rounded and often stretched or flattened out in the schistosity plane. They are chiefly composed of tuff material. The surrounding mass is in most cases coarser grained but consists of the same minerals as the fragments viz. amphibole, magnetite, plagioclase and quartz.

The coarser amphibolitic parts are essentially made up of hornblende and plagioclase with a grain size of 1—5 mm. Biotite and magnetite occur in rather small amounts, but scapolite is rather common. Pyrite sometimes occurs in the greenstone as single grains or small aggregates.

Metadiabase

Metadiabasic dikes are abundant in the area. They can be 10—15 m wide but are generally a couple of metres or less in thickness. At places where the contacts are sharp, the dikes strike in the same direction as the surrounding rocks (NNE)

1 2 3

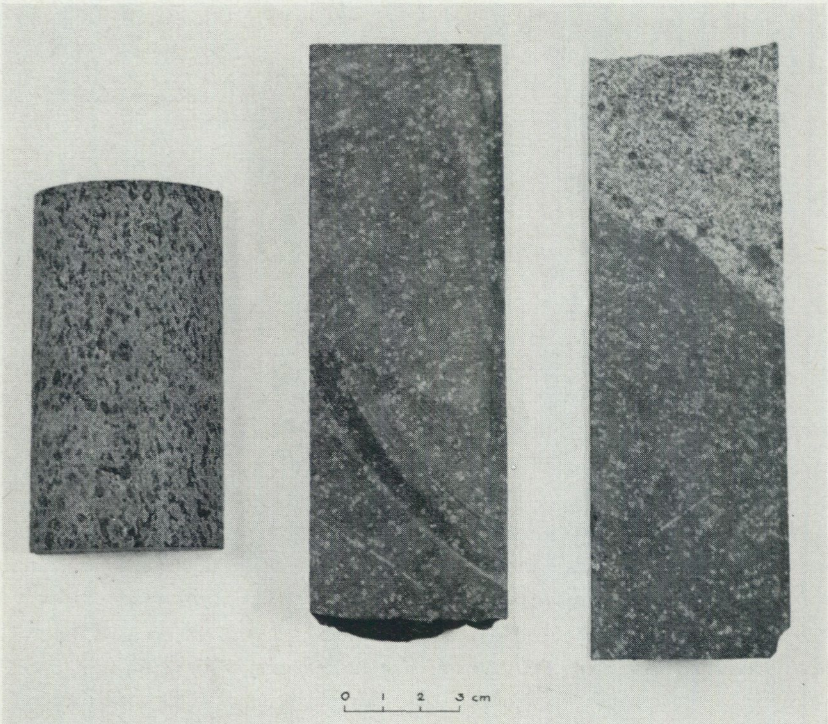

Fig. 8. Metadiabase. The light dots in 2 and 3 consist of scapolite. Sample 3 is partly granitized. 1 dh 63015 38.6 m, 2 dh 63015 51.1 m, 3 dh 63015 51.2 m. Photo by B. Rönnberg.

and dip steeply towards the E. The dikes cut the sedimentary rocks as well as ore and skarn. On the other hand the dikes are sometimes affected by granitic alteration and may be completely altered to gneissic granite. Those dikes, which have not been granitized, are strongly scapolitized.

The colour of the metadiabase is dark grey. On the even surface of the drill core a "porphyritic" texture with greenish black, 1—5 mm large, diffusely defined spots of hornblende and biotite is apparent in a lighter groundmass (fig. 8). Generally the green hornblende forms the core in these spots and is rimmed with black biotite. This spotted texture is sometimes masked by scapolite which appears as light coloured, rounded aggregates, some mm in size.

In well preserved samples a distinct ophitic texture with divergent, 0.2—0.8 mm long plagioclase prisms, is apparent under the microscope. The plagioclase is never quite fresh but altered to scapolite to a greater or lesser extent. The hornblende occurs as scattered, irregular grains in the plagioclase mass or gathered in aggregates together with biotite and magnetite. These aggregates of dark minerals, which constitutes the earlier named dark spots, seem to have formed simultaneously with the scapolite; the aggregates increase in size and

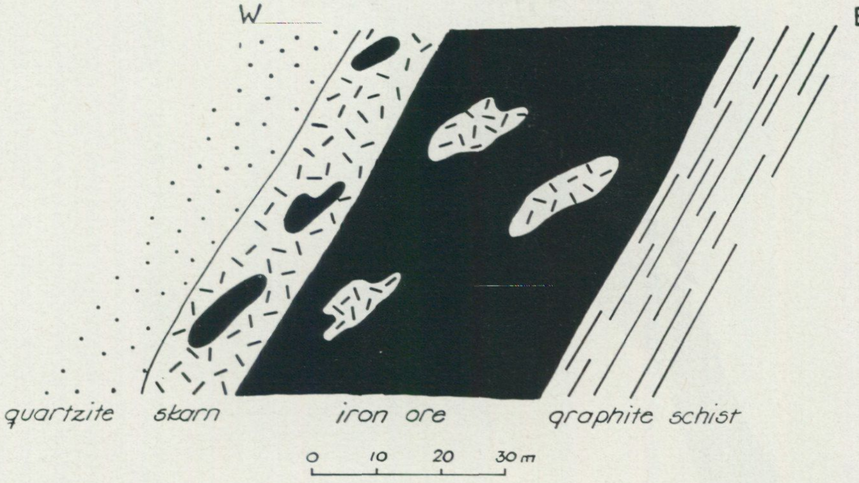

Fig. 9. Sketch of the relation between ore and skarn. Vertical section at right angles to the strike of the ore.

number as the scapolitization proceeds. Sphene is abundant. Apatite is accessory and occurs in the form of very small prisms.

The ore zone

General

The ore zone consists of magnetite ore and skarn. Its width at the surface is 50 to 100 m. To the S the ore becomes thinner and wedges out in a narrow zone with skarn (pl. 1). This skarn zone can be traced for a distance of about 1 km further south outside the map (pl. 1). To the N the ore is succeeded by dolomite in the strike direction.

The skarn appears partly as gangue in the iron ore, partly as magnetite-free aggregates enclosed in or connected with the ore. The magnetite-free skarn aggregates constitute about 20 volume percent of the whole ore zone and are situated preferably adjacent to the hanging wall; these skarn masses enclose in their turn small magnetite concentrations (fig. 9).

The ore

TYPE OF ORE. The Stora Sahavaraara ore is a skarn-rich magnetite ore. Hematite has nowhere been found. The sulphide content is high with pyrrhotite and pyrite as the most prominent minerals. The gangue consists mainly of skarn. It is of magnesium-rich type with serpentine as the dominating mineral. Furthermore, considerable quantities of diopside, tremolite and phlogopite occur. This gangue skarn is described together with the separate skarn masses under the heading "Skarn".

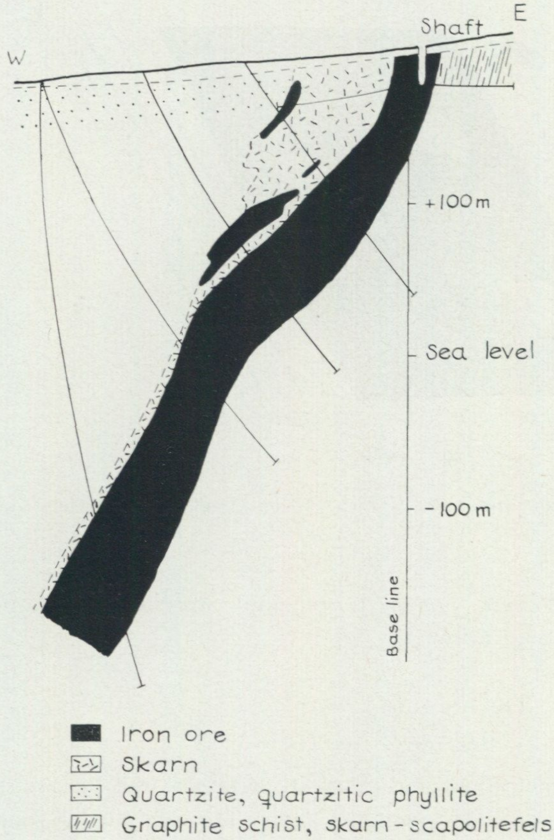

Fig. 10. Vertical profile through the ore body (700 N).

Form and size of the ore body. The ore body has a rather regular, tabular form and is concordantly enclosed in the surrounding sedimentary rocks. In vertical section the ore body is slightly folded in long folds with small amplitude, which gives a variation in the dip of 50° to 70° towards the W (fig. 10). The mean dip is 60°. The ore body has a length of about 1 300 m. The width is between 10 and 90 m, but on the average is 40 m in the upper part of the ore body.

The area of the deposit is about 53 000m² and the total tonnage about 100 million tons.

As may be seen from fig. 11, the depth of the ore body is moderate in its southern part but gradually increases towards the N. In the profile 900 N it reaches a depth of about 750 m. To the N of this profile the deeper parts of the ore body are not known.

Structure and contact relations. The ore is generally massive with the gangue uniformly distributed in the magnetite mass as rounded or irregular aggregates of different size (fig. 12). However it is sometimes distinctly banded

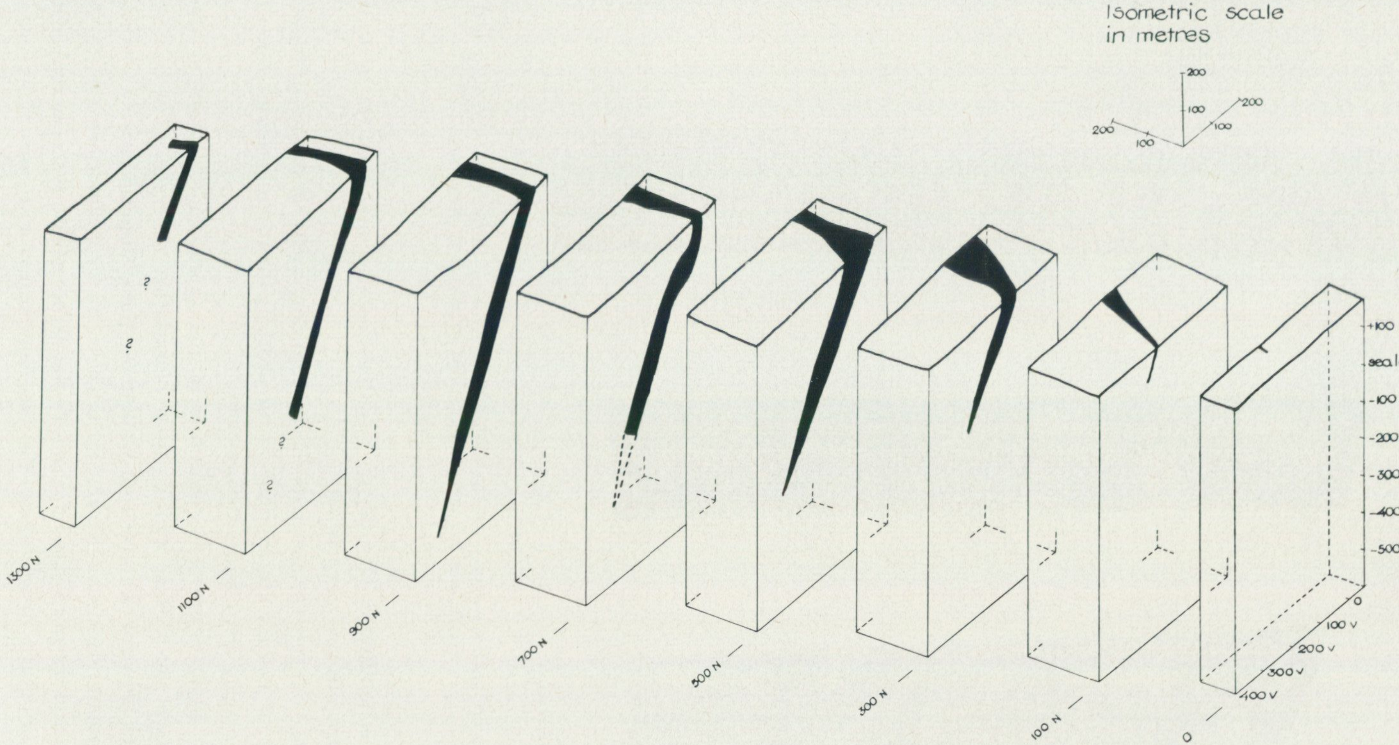

Fig. 11. Isometric projection of the Stora Sahavaara iron ore body. Overburden omitted.

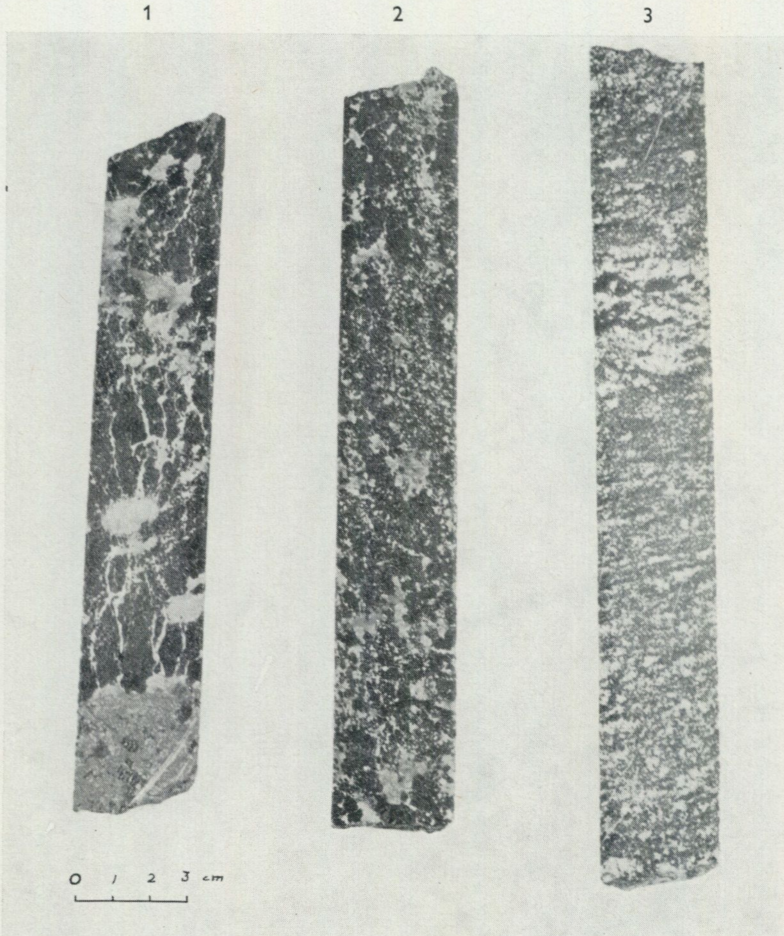

Fig. 12. Magnetite ore with serpentine skarn. 1 dh 63002 426.7 m, 2 dh 63002 425.5 m, 3 dh 63013 77.5 m. Sawn and varnished drill cores. Photo by B. Rönnberg.

(fig. 13). Such a banding usually occurs near the foot-wall and then the gangue consists of phlogopite and serpentine.

The transition between the ore and the surrounding rocks is mostly gradual. The transition zone is some cm to some dm in width, with the magnetite content successively decreasing away from the ore body.

A few small, isolated ore concentrations in the skarn zone, adjoining the hanging-wall, have very diffuse and irregular boundaries.

At the contact between ore and foot-wall schist there sometimes occur lenses of stratified carbonate rock some metres in thickness. At the contact between these carbonate lenses and the ore it can be seen how the carbonate is gradually replaced by magnetite and skarn, often along the bedding planes but sometimes even

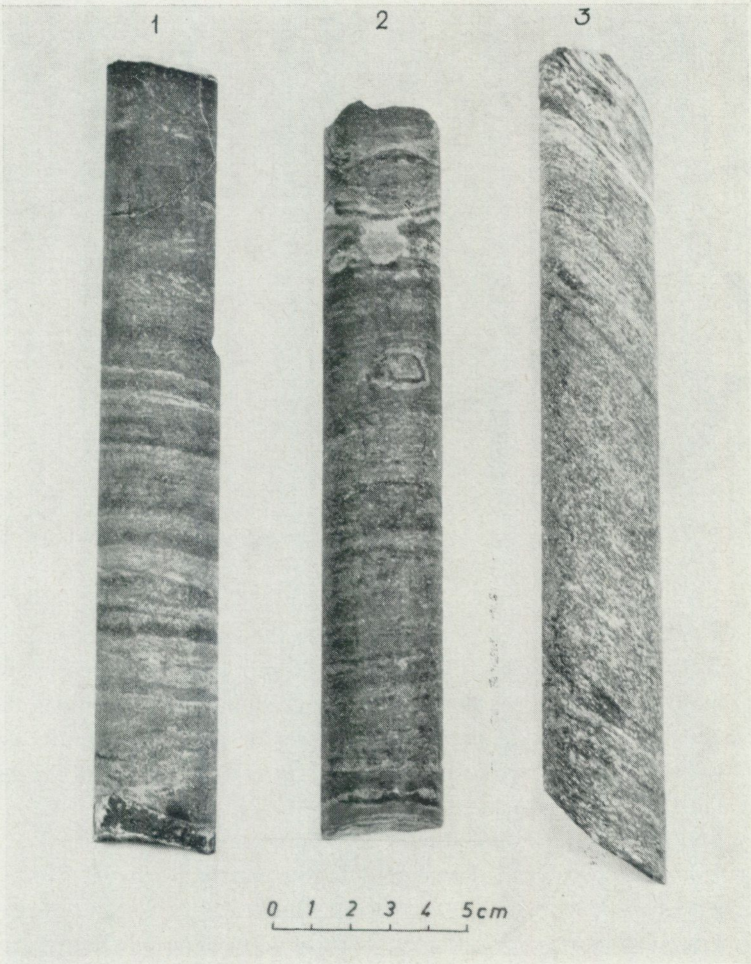

Fig. 13. Banded magnetite ore containing phlogopite and serpentine, in 3 even calcite. 1 dh 63013 45.0 m, 2 dh 63012 27.9 m, 3 dh 63014 121.3 m. Photo by B. Rönnberg.

traversing them. In a few places small carbonate lenses occur enclosed in the ore. However, such carbonate lenses never occur in the hanging-wall contact.

MINERALOGY. The magnetite normally occurs in the form of nearly isometric grains with rather simple grain boundaries. Generally speaking the ore can be divided into a fine-grained and a coarse-grained type. The latter possibly represents a recrystallization and coarsening of fine-grained ore. The coarse-grained type often appears as thin or thick veins which transect the fine-grained type. The fine-grained type seems to dominate. The grain size of the fine-grained magnetite averages 0.1—0.4 mm, and the coarser ore 0.8—1.0 mm. The magnetite is homogeneous except for small inclusions of gangue (fig. 14). When determinable these inclusions consist of serpentine.

Fig. 14. Magnetite ore with magnetite (white) and serpentine (black). Drawing from polished specimen. Dh 62014 47.3 m.

Pyrrhotite and pyrite are very abundant in the ore. They occur intimately mixed, even if the proportions vary. In the southern part of the deposit pyrrhotite is the dominant sulphide. Towards the N pyrite gradually becomes more abundant and in the northern part of the deposit the proportion pyrite : pyrrhotite generally varies between 1 : 2 and 1 : 1. Drill-hole 61001 in tab. 3 represents the northern part and 62010 the southern part of the deposit.

Mostly pyrite and pyrrhotite appear as approximately isometrical grains of varying size and rather evenly distributed in the magnetite mass. More seldom they appear as real veins, which may reach 1 cm in width. The grain size varies greatly but in general resembles that of the magnetite. The pyrrhotite grains are generally angularly rounded but sometimes irregular in form. Inclusions of very small skarn grains are abundant. The pyrite is partly primary and partly an alteration product of pyrrhotite. In the former case, which seems to dominate, the pyrite occurs as rounded homogeneous grains without inclusions.

The alteration of pyrrhotite to pyrite is abundant only in the northern part of the deposit. The pyrrhotite seems to have dissolved in carbonate-bearing solutions after which the material has been redeposited in the form of pyrite and magnetite, the latter in small amounts. The alteration has begun from grain boundaries or along crystallographic planes in the pyrrhotite. Very often the process is incomplete so that irregular pyrrhotite remnants lie in the newly-formed mass of pyrite. The latter is generally very inhomogeneous and contains very thin magnetite veins and calcite. The calcite sometimes remains as a rim round the pyrrhotite remnants (fig. 16). This type of alteration has been described by Edwards (1954, p. 123) and others. In connection with this alteration the magne-

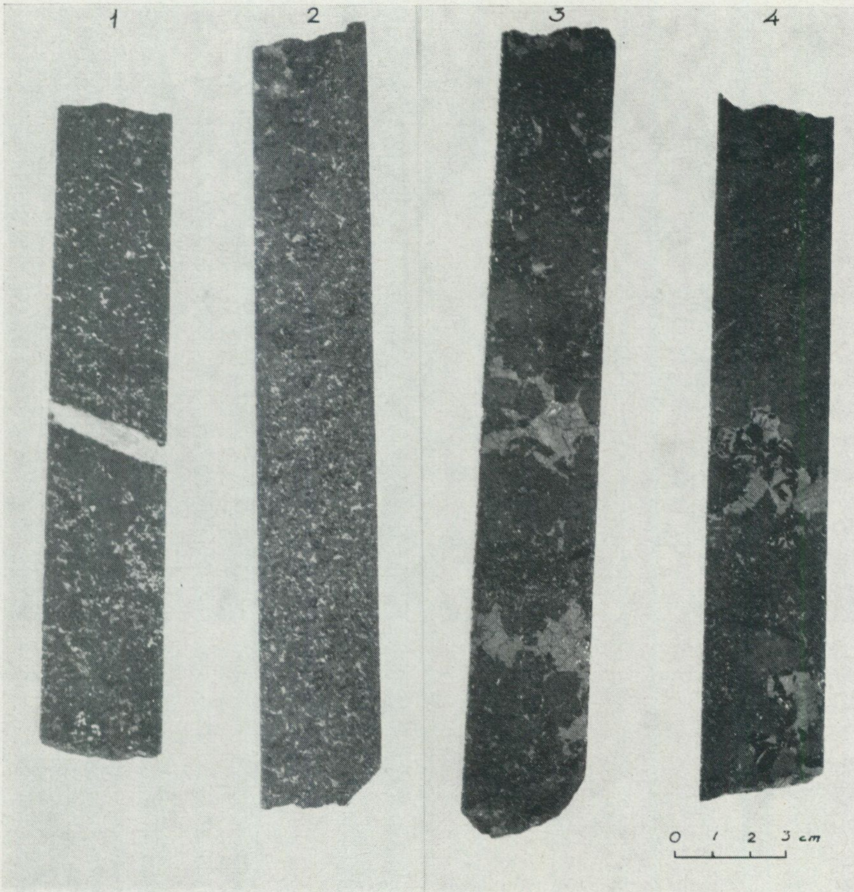

Fig. 15. Sulphide- and skarn-bearing magnetite ore, 1—2 fine-grained, 3—4 coarse-grained. Grey-black = magnetite, black = skarn, white-grey = sulphides. 1 dh 62013 111.3 m, 2 dh 62015 252.1 m, 3 dh 62003 100.1m, 4 dh 62013 89.9 m. Sawn and varnished drill cores. Photo by B. Rönnberg.

tite mass has, at certain places, been cut and brecciated by pyrite (fig. 17). These pyrite veins are often very thin. Under the microscope pyrite laminae down to 0.005 mm in thickness have been discerned along the crystal planes of the magnetite.

Chalcopyrite is scarce compared with pyrrhotite and pyrite, but occurs as veins or scattered grains. It often impregnates skarn aggregates lying in the ore. The grain size varies greatly, but lies generally between 0.1 and 5 mm.

Apatite occurs as small prisms or rounded grains in both ore and skarn. The apatite content of the ore is moderate or roughly the same as in adjacent rocks. When apatite occurs more richly in the ore the rounded grains are wholly enclosed in fine-grained magnetite. Thus the apatite seems to have crystallized prior to or simultaneous with the magnetite.

Fig. 16. Alteration of pyrrhotite to pyrite. The pyrrhotite (po) appears as light crystals with prominent cleavages, surrounded by pyrite (py) and calcite (ca). Dh 62014 47.3 m. Polished specimen. ×20.

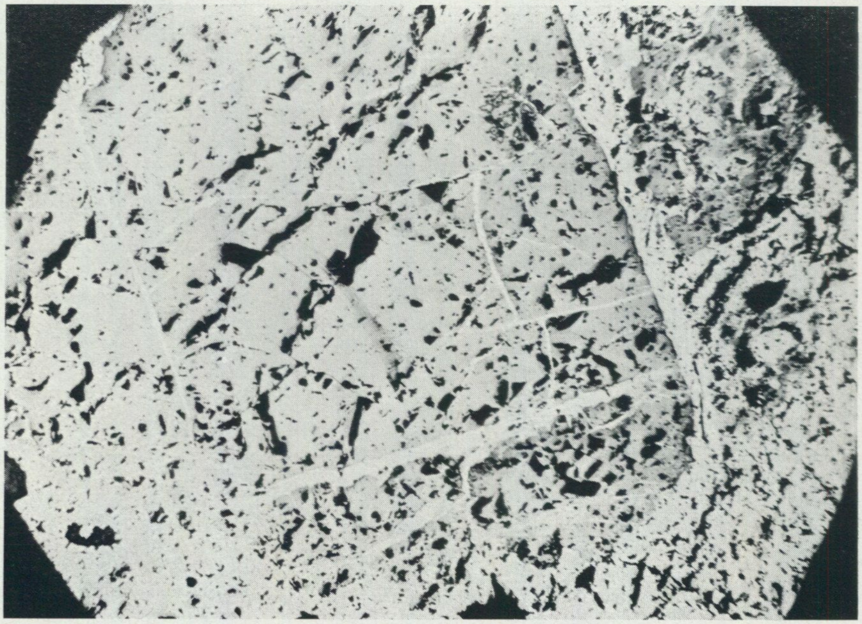

Fig. 17. Magnetite (grey) with brecciating pyrite (white). Dh 62005 180.9 m. Polished specimen. ×20.

Table. 3. Partly recalculated chemical analyses of ore. Analyst: LKAB Kiruna

Drill-hole Metre	62010 174.0—214.5	61001 31.0—80.0
SiO_2	17.2	14.4
TiO_2	0.02	0.08
Al_2O_3	0.71	1.30
Fe_2O_3	36.64	43.02
FeO	16.52	15.94
MnO	0.11	0.13
CaO	1.00	0.64
MgO	18.8	16.9
Na_2O	0.03	0.12
K_2O	0.10	0.12
$H_2O > 105°$ C	0.5	0.6
P_2O_5	0.27	0.19
CO_2	2.17	1.85
V_2O_5	0.02	0.01
FeS_2 (Pyrite)	0.01	1.63
Fe_9S_{10} (Pyrrhotite)	5.08	2.26
$CuFeS_2$ (Chalcopyrite)	0.29	0.27
Total	99.5	99.3

Table. 4. Partial analyses of six ore-sections. Analyst: LKAB Kiruna

Profile	Drill-hole	Length of section m	Fe_3O_4 %	MgO %	CaO %
300 N	62008	58.0	39.4	16.0	2.6
700 N	62009	81.0	56.9	13.5	1.0
700 N	62012	48.0	57.8	13.7	1.2
1100 N	61001	49.0	59.0	16.7	0.6
1100 N	62005	22.0	57.1	15.2	0.8
1300 N	62013	60.5	53.6	16.9	2.3

Graphite occurs in small amounts in most of the ore body. Sometimes the content is rather high and gives rise to a very dirty drill core. Shear fracture planes often glisten with graphite. Analyses of the ore sections in three drill holes showed 0.6, 0.7 and 0.8 % graphite respectively. Most of it is very finely distributed in the serpentine skarn, usually in connection with pyrrhotite and pyrite.

Chemical composition of the ore. The average iron content for the deposit is 44.5 % and of this total 41 % is present in magnetite and 3.5 % in sulphides. These figures represent an average for the whole body and include metadiabases and small enclosed skarn aggregates; excluding the latter an iron content in magnetite of 43.7 % is obtained. The local variations in iron content are great and rapid while the variations between one part of the deposit and another are small.

The Stora Sahavaara ore is very sulphur-rich throughout. The average sulphur content for the whole deposit is 2.5 %. Ore with a marked low sulphur content is almost absent; an exception is an ore section of about 25 m width (along the drill-hole) in profile 900 N at a depth of 400 m containing only 0.03 % S. The sulphur is contained mainly in pyrrhotite and pyrite, to some extent even in chalcopyrite. The average content of pyrrhotite is 4.9 %, of pyrite 1.1 % and of chalcopyrite 0.23 %.

The average phosphorus content for the whole deposit is 0.072 %. The average content in the different drill-holes varies between 0.021 and 0.136 % while separate, metre-long sections may have values from 0.004 to 0.6 % P. Compared with the skarn iron ores in Central Sweden these phosphorus contents are high. Geijer and Magnusson (1944, p. 117) state: "In skarn and limestone ores the phosphorus content seldom exceeds 0.020 % and very often lies below 0.010 %".[1] Regarding the skarn iron ores in Norrbotten the same, regularly low contents of phosphorus do not seem to be valid; even if they often lie below 0.03 %, several exceptions occur. One example is the small Vuoma ore in the Masugnsby field which contains about 0.1 % P (Geijer 1929, p. 30). Another interesting exception is the recently discovered Karhujärvi ore situated in the prolongation to the S of the Kaunisvaara field (fig. 1). Here the phosphorus content is said to vary between 0.1 and 0.8 % (Frietsch 1963).

Magnesium and silica are, next to iron, the most prominent constituents of the ore. The contents of MgO and SiO_2 are roughly the same, ranging from 10 to 20 % (tab. 3 and 4). Most of these two elements enter serpentine. The content of calcium varies between 0.5 and 3 % CaO, the higher figures caused by inclusions of diopside-tremolite skarn.

Chemical composition of magnetite. As already mentioned the ore is very rich in magnesium most of which enters serpentine. But some magnesium also enters the crystal lattice of magnetite as indicated by chemical analyses. In connection with beneficiation experiments (LKAB) a large number of partial analyses were performed on ore samples from the shaft at Stora Sahavaara. These samples were ground and concentrated in different ways and had as a result variable amounts of impurity (gangue and sulphides). Available analyses are used in fig. 18 to plot the percentage of MgO against the percentage of SiO_2. The dots give an approximately straight line which cuts the vertical axis at 2.6 %. This is the amount of MgO which does not enter any silicate mineral but could enter some nonsilicate gangue mineral (e.g. brucite, dolomite) or the magnetite lattice.

According to macro- and microscopic investigations non-silicate magnesium minerals do not exist in amounts likely to cause this "MgO-surplus". Furthermore, even these minerals ought to be removed during the beneficiation process and in the diagram a curve rather than a straight line should result. So it is reasonable to assume that magnesium enters the magnetite. A chemical analysis of separated magnetite (tab. 5) confirms this assumption. It gives the MgO-content of 2.60 % in magnetite, the same figure as the "MgO-surplus" in the diagram (fig. 18).

[1] Translated from the Swedish.

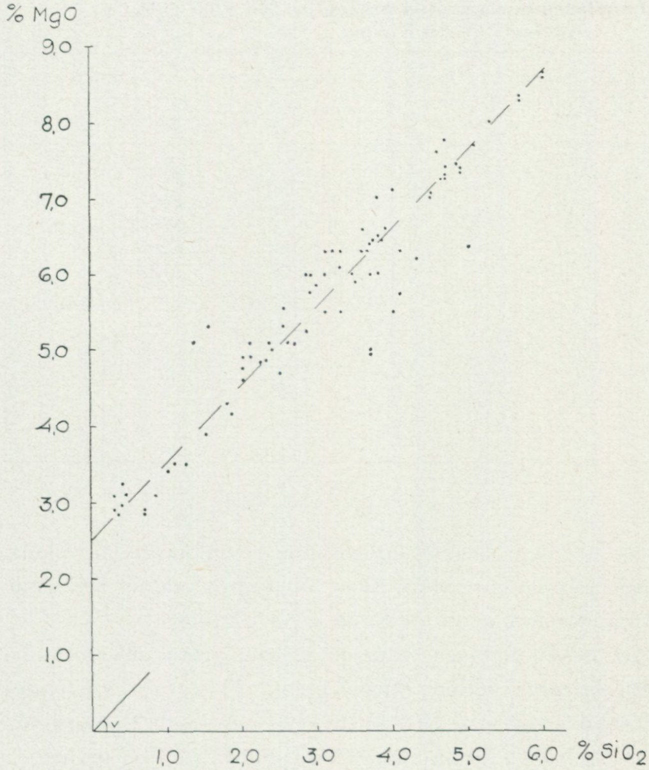

Fig. 18. Relationship between percentages MgO and SiO_2 in magnetite ore from the shaft in the central part of the Stora Sahavaara deposit.

The magnesium in the magnetite lattice is probably evenly distributed replacing bi-valent iron. Because of similarities in load and ion radius, Mg^{2+}- and Fe^{2+}-ions replace each other in several minerals. In natural magnetite such a substitution is not too pronounced. A few percent of MgO may enter the lattice, usually together with some titanium, manganese or aluminum (Dana 1944, Deer et.al. 1962).

The skarn

Types of skarn. Two types of skarn may be discerned in the ore zone, viz. (1) diopside-tremolite skarn and (2) serpentine skarn.

The diopside-tremolite skarn preferably builds up a zone between the ore and the hanging-wall quartzite but even appears as large magnetite-free aggregates in the ore. The serpentine skarn constitutes the gangue of the ore.

Description of the skarn. The skarn type 1 is entirely dominated by diopside and tremolite. Magnetite only seldom appears in it. Diopside and tremolite occur closely connected with one another. The proportions between them are difficult

Table. 5. Chemical analyses of separated magnetite. Dh 62009 304.1 m. Analyst: LKAB Kiruna

	Weight %	Moles x 10 000	Serpentine	Dolomite	Magnetite	Oxide in surplus	Magnetite	
							Weight %	
Fe_2O_3	68.47	4287			4287		Fe_2O_3	69.89
FeO	26.39	3673			3673		FeO	26.93
MnO	0.14	20			20		MnO	0.14
CaO	0.14	25		25			MgO	2.60
MgO	3.45	856	174	25	636	21	Al_2O_3	0.44
Al_2O_3	0.43	42			42			
SiO_2	0.70	116	116					100.00
CO_2	0.43	98		50		48		
TiO_2	0.01							
V_2O_5	0.03							
S	0.02							
	100.21							

to determine owing to this intricate association and the resemblance in colour. However, the general impression is that they occur in approximately the same amounts or with a slight predominance of tremolite over diopside.

The diopside is macroscopically greenish white to greyish green in colour. In thin section it is colourless or more seldom faintly green. The grain size varies but lies mostly between 0.5 and 5 mm (fig. 19). In the coarse diopside fine-grained areas sometimes occur, which have a grain size of 0.1—0.3 mm. The texture is generally isometrically granular but sometimes even coarse-prismatically radiated. The two chemical analyses in tab. 6 show that the pyroxene is a diopside with 8—10 % hedenbergite content, or with the approximate formula $Ca\ Mg_{0.90-0.92}\ Fe_{0.08-0.10}\ Si_2O_6$.

The macroscopic colour of the tremolite is greenish white to greyish green. The microscopic texture is granular or radiating when the amphibole prisms are 0.5—1.0 mm long. In thin section it is colourless. The chemical analyses in tab. 6 show, like the microscopical data, that the iron content in the tremolite is low; approximate formula $Ca_2\ (Mg_{0.96}\ Fe_{0.04})_5\ Si_8O_{22}\ (OH)_2$.

The gangue consists for the main part of serpentine but significant amounts of phlogopite, diopside and tremolite also occur. Olivine and chlorite appear in small amounts. The dominance of serpentine may be seen from the analyses in tab. 3 if the following facts are taken into account. Serpentine, according to the formula $Mg_3\ Si_2\ O_5\ (OH)_4$, contains about equivalent quantities by weight of MgO and SiO_2. The calculated $MgO:SiO_2$ ratios of the other essential gangue minerals vary between 2 : 3 and 1 : 3. The present analyses of the ore show figures closely corresponding to the serpentine ratio 1 : 1, indicating a dominating serpentine content. A slight surplus of MgO may be due to the entrance of magnesium into the magnetite lattice (see above).

Table. 6. Chemical analyses of skarn minerals. Analyst: B Johannesson

	1	2	3	4	5
SiO_2	52.6	53.3	57.5	39.9	39.0
TiO_2	0.01	0.02	0.01	0.08	0.01
Al_2O_3	0.2	0.2	0.55	14.5	0.4
Fe_2O_3	0.75	0.65	0.2	1.1	2.4
FeO	3.5	2.8	1.7	2.1	0.3
MnO	0.23	0.19	0.08	0.01	0.11
CaO	23.3	24.4	13.1	0.02	0.3
MgO	16.8	17.1	24.1	26.3	41.2
Na_2O	0.25	0.12	0.06	1.1	0.02
K_2O	0.02	0.02	0.03	9.0	0.02
$H_2O > 105°$ C	1.0	0.4	2.7	4.05	13.9
$H_2O < 105°$ C	0.01	0.12	0.15	1.70	2.2
P_2O_5	0.01	0.14	0.15	0.01	0.05
CO_2	0.24	0.44	n.d.	n.d.	0.49
S	0.01	0.20	0.01	0.1	0.08
F	0.01	0.01	0.03	0.48	0.01
Cl	0.07	0.05	n.d.	n.d.	0.11
Total	99.0	100.1	100.3	100.4	100.6

Numbers of ions on the basis of	6 O		6 O		24 (O, OH, F)		24 (O, OH, F)		9 (O, OH)	
Si	1.98		1.98		7.79		5.67	8.00	1.85	
Al	0.01		0.01		0.09	7.88	2.33		0.02	
Al	—	2.01	—	2.01	—		0.10		—	1.95
Ti	—		—		—		0.01		—	
Fe^{3+}	0.02		0.02		0.03		0.12	6.05	0.08	
Fe^{2+}	0.11		0.09		0.20	5.11	0.25		0.01	
Mg	0.94		0.94		4.87		5.57		2.91	
Mn	0.01	2.01	0.01	2.02	0.01		—		—	2.92
Ca	0.94		0.97		1.90		—		—	
Na	0.02		0.01		0.02	1.92	0.30	1.93	—	
K	—		—		—		1.63		—	
F					0.01	2.45	0.22	4.06	—	
Cl					2.44		3.84		4.40	

1. Diopside, dh 62003 51.94—52.00 m.
2. Diopside, dh 62007 115.18—115.28 m.
3. Tremolite, dh 62002 149.53—149.63 m.
4. Phlogopite, dh 62015 294.83—294.97 m.
5. Serpentine, dh 62013 83.52—83.70 m.

Serpentine appears as pseudomorphs, veins, irregular fields or big, homogeneous portions in the ore. In its pure state the serpentine is yellowish white to green. However, the colour generally is greenish black dependent on the admixture of very fine-grained magnetite. Under the microscope the serpentine appears in aggregates of fibro-lamellar structure (fig. 20). Tab. 6 shows an analysis of a rather pure serpentine, macroscopically of light green colour. In this analysis the rather high iron content, of which the greater part exists in the tri-valent state, is pronounced. Hematite has not been observed under the microscope so it is

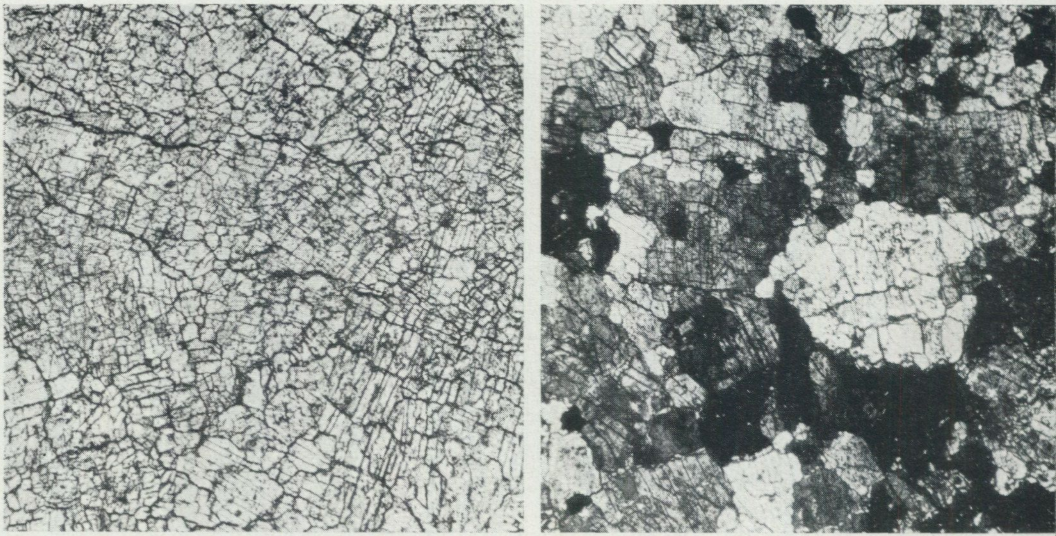

Fig. 19. Diopside in thin section. Dh 62007 115.2 m. Ord. light (left) and nic. + (right). ×30

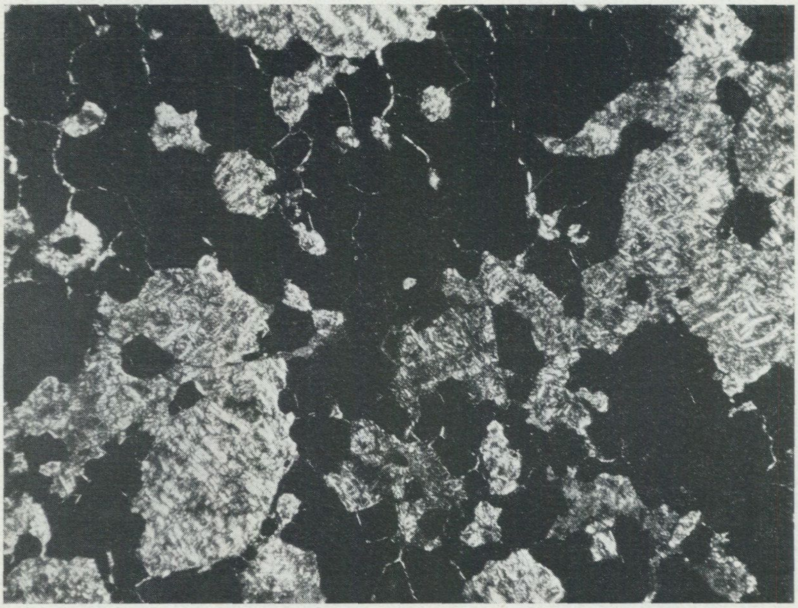

Fig. 20. Magnetite ore with serpentine skarn. Dh 62009 304.1 m. Thin section. Nic. +. ×20.

plausible that the iron to a great extent enters the serpentine lattice. The bi-valent iron probably enters into magnetite together with the required amounts of tri-valent iron.

Phlogopite occurs exclusively in the ore. In a few places it appears as the

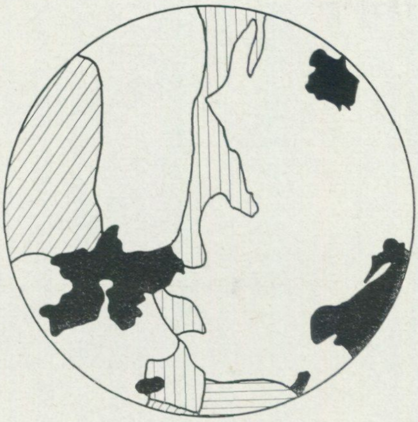

Fig. 21. Drawing from thin section illustrating the relationship between tremolite (hatched), olivine (white) and magnetite (black). ×30.

sole gangue mineral but serpentine is usually present also, often in dominant amounts. It seems to be most abundant near the foot-wall.

The phlogopite occurs principally as small, light green flakes which are so arranged in the magnetite mass that a stratification may be distinguished (fig. 13). Sometimes these flakes form irregular aggregates of dm-size, in which magnetite occurs only in the form of scattered, extremely fine grains. The size of the separate phlogopite flakes varies between 0.02 and 0.2 mm. In some coarse-grained parts of the ore phlogopite crystals some mm in size, occur. In thin section the phlogopite is colourless or slightly yellow and pleochroic. It is optically negative with a very small optic angle.

Olivine has been discovered only in thin sections and then generally as small relicts in serpentine.

During alteration of olivine to serpentine much magnetite seems to have formed, which points to a rather iron-rich composition of the olivine.

Diopside and tremolite sometimes appear as part of the gangue, especially in ore bordering on skarn masses. These minerals have the same properties in the gangue as in the separate skarn assemblages.

Age relationships within the skarn and magnetite. When the age relationship between diopside and tremolite is clear, tremolite is younger and often replaces diopside.

Where olivine is associated with tremolite, the olivine seems to be younger than the amphibole. It replaces and cuts across the tremolite crystals (fig. 21). Magnetite is frequently intimately associated with olivine, mostly in the form of irregular grains of varying size.

Magnetite which is ~~in~~ contact with crystals of diopside or tremolite encloses or cuts across these crystals, which indicates that the magnetite is younger than the diopside-tremolite skarn.

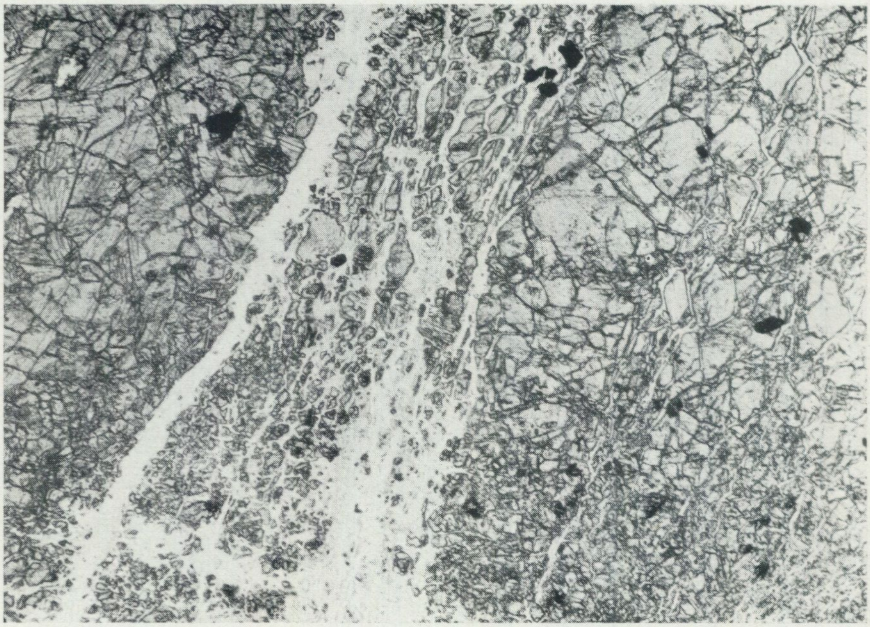

Fig. 22. Serpentinization (white) in tremolite (grey). Dh 61001 67.8 m. Thin section. Ord. light. ×30.

SERPENTINIZATION. At several places it can be seen how the serpentine alteration occurs as an irregular front or in the form of thick or thin veins penetrating the diopside-tremolite skarn (fig. 22). Furthermore, serpentine-pseudomorphs frequently occur with the idiomorphic crystal forms of pyroxene or amphibole. Evidently considerable amounts of diopside and tremolite have been subjected to this alteration to serpentine. If the volume is assumed to be constant, the alteration requires large additions of magnesium and water and subtractions of silica and calcium (tab. 7).

Conversion in moles at a constant volume of 1 dm^3:

diopside → serpentine

$$\frac{+12.6\ MgO + 18.4\ H_2O}{-11.6\ SiO_2 - 15.0\ CaO}$$

tremolite → serpentine

$$\frac{+9.2\ MgO + 14.7\ H_2O}{-11.0\ SiO_2 - 7.4\ CaO}$$

Olivine has been noticed at a few places in the ore as small relicts in serpentine. Whether large amounts or perhaps the main part of the serpentine skarn derive from olivine and/or some humite mineral is difficult to decide but certain facts speak in favour of this.

Table. 7. The composition of some skarn minerals calculated as the number of moles per dm³ of the oxides of the entering cations

	Diopside $CaMgSi_2O_6$	Tremolite $Ca_2Mg_5Si_8O_{22}(OH)_2$	Serpentine $Mg_3Si_2O_5(OH)_4$	Forsterite Mg_2SiO_4	Chondrodite $Mg_5Si_2O_8(OH)_2$
Approx. density g/cm³	3.25	2.99	2.55	3.20	3.20
CaO moles/dm³	15.0	7.4	—	—	—
MgO »	15.0	18.4	27.6	45.5	47.1
SiO_2 »	30.0	29.4	18.4	22.7	18.8
H_2O »	—	3.7	18.4	—	9.4
CO_2 »	—	—	—	—	—

On serpentinization much magnetite formed. This magnetite is finely divided and occurs in the form of dust-like clouds or borders in serpentine. The iron in this magnetite seems to be derived from an iron-rich mineral, perhaps olivine. Such an alteration of olivine to "magnetite-dusted" serpentine have been observed in a few thin sections. Adjacent tremolite has not given rise to any magnetite on serpentinization or only to very small amounts. It is noticeable in this connection that serpentine is the main alteration mineral in the ore sections, while magnetite-free skarn masses (diopside-tremolite) are serpentinized only to a small degree.

In the serpentine ores of Central Sweden the serpentine could be shown to be derived in most cases from olivine or some humite mineral (Geijer-Magnusson 1944). Concerning the Masugnsbyn field, located 100 km SW of the Stora Sahavaara deposit and containing ores of a similar type, Geijer says (1929, p. 26): "The occurrence of considerable quantities of chondrodite makes it plausible that the serpentine skarn . . . is derived from the alteration of chondrodite or a related mineral"[1]. From tab. 7 we conclude that an alteration of forsterite (Mg-olivine) or chondrodite to serpentine at constant volume essentially implies supply of water and removal of magnesium. In this way liberated magnesium perhaps contributed to the alteration of diopside-tremolite to serpentine and was neither supplied nor removed, just redistributed within the skarn-masses on serpentinization.

Granitization

Large parts of the quartzitic phyllite to the W of the ore are slightly, sometimes strongly, gneissic or granitic. This alteration has also affected the metadiabases. The intensity of the granitization seems to increase towards the W. In the quartzite the alteration is macroscopically marked by a gradual disappearance of the bedding structure and a transition from grey to red colour. Frequently the rock becomes traversed by numerous thin veins of quartz and feldspar, which run in all directions. In the quartzitic phyllite with its originally more clayish composition, the alteration has given more obvious results. It begins with a coarsening in

[1] Translated from the Swedish.

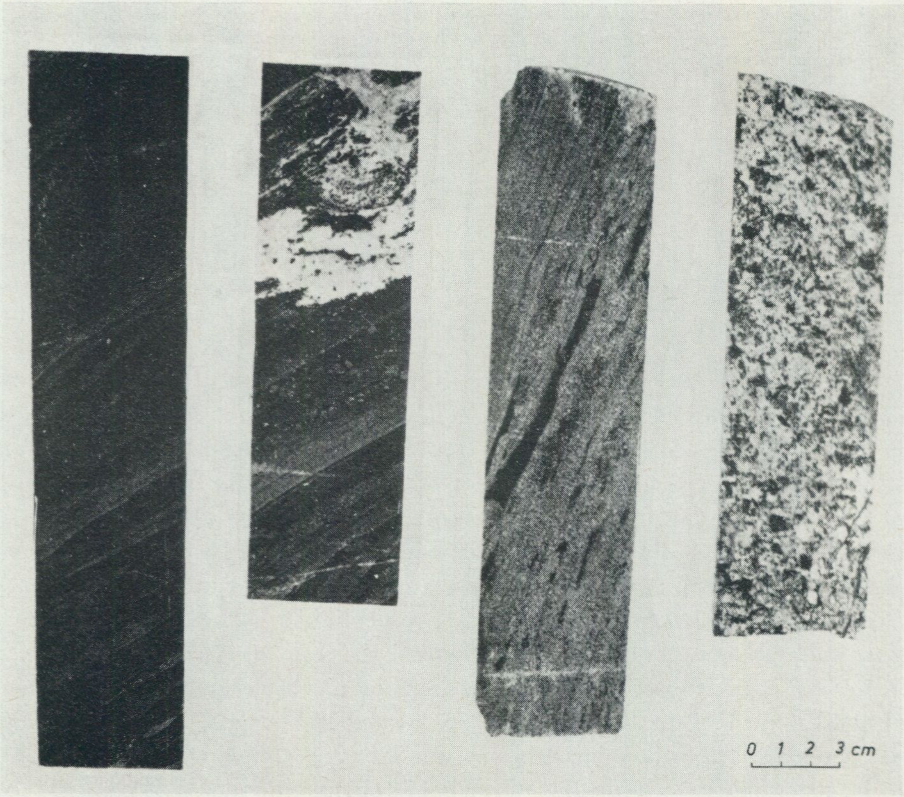

Fig. 23. Progressive granitization of quartzitic phyllite. Sawn and varnished drill-cores. Dh 63015 between 21 and 103 m. Photo by B. Rönnberg.

grain size of the light, quartz-rich laminae, which gradually become undulating, cut through and deform to varying degrees the adjacent biotite laminae. As a result intensive flow-folding occurs in the still fine-grained phyllite. Stronger alteration gives migmatitic gneisses with bands of coarse-grained quartz and feldspar in a dark biotite mass (fig. 24). The strongest alteration gives rise to a homogeneous, light grey, medium-grained gneissic granite (fig. 23).

The granite is dominated by quartz and plagioclase but also contains biotite, microcline and perthite. The plagioclase, which shows polysynthetic twinning, has a composition which varies between An_8 and An_{15}. Frequently it encloses microcline or perthite; the latter minerals also occur independent of, but in less amounts than the plagioclase. Plagioclase and quartz are sometimes intergrown graphically. Magnetite occurs in moderate amounts, epidote, apatite and zircon in small amounts. Tourmaline is comparatively abundant. It occurs in the form of veins (fig. 24) or as small scattered grains.

Chemical analyses of the granite have not been carried out. However, the high content of albitic plagioclase in comparison with the rather low sodium

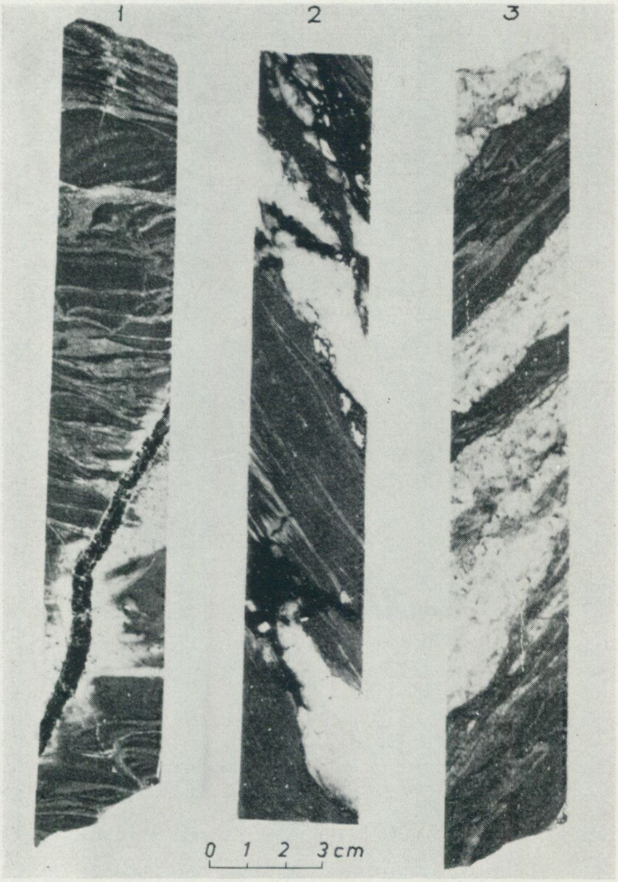

Fig. 24. Migmatitic gneiss. The black vein in 1 is tourmaline. Sawn and varnished drill-cores. 1 dh 63007 39.7 m, 2 dh 62009 169.5 m, 3 dh 62015 72.9 m. Photo by B. Rönnberg.

content in quartzite and quartzitic phyllite (tab. 1) point to an alteration in connection with the supply of sodium. Of interest is the occurrence of the volatile elements boron and chlorine, the former entering tourmaline, the latter scapolite.

Scapolitization

Scapolite occurs on a regional scale and in varying amounts in most rock types in the Kaunisvaara field. The chemical-mineralogical composition of the original rocks seems to have controlled the intensity and extent of the scapolitization. Thus it is very common in the phyllitic rocks and the metadiabases, but less marked in quartzite and granite. Large parts of the rocks just to the E of the ore are strongly altered to a skarn-bearing scapolitefels. The greenstone is scapolite-bearing to a moderate degree but no scapolite has been observed in the ore and its skarn.

The scapolitization generally begins with the alteration of the plagioclase in the rock. More intensive alteration gives rounded porphyroblastic aggregates of scapolite, often with frequent inclusions (fig. 7). Sometimes these aggregates grow

Fig. 25. Scapolitization of plagioclase in granite. The scapolite occurs as white irregular garlands which penetrate the polysynthetically twinned plagioclase. Dh 63015 54.4 m. Thin section. Nic. +. ×40.

together and build up a scapolitefels where skarn minerals are embedded in scapolite (fig. 6).

No special analyses or determinations have been carried out but the birefringence of the scapolite enables the approximate chemical composition to be determined. Scapolite in quartzite and quartzitic phyllite shows low birefringence (0.005—0.009) while scapolite in phyllite, scapolitefels and metadiabase has higher birefringence (up to 0.020). If the dominating anion in marialite is Cl and in meionite CO_3, the diagram of Tröger (1959) gives in the first case a marialite content of 80—100 %, while the birefringence 0.020 gives the approximative composition $Ma_{45}Me_{55}$. Thus an original material rich in calcium seems to give a more calcium-rich scapolite, even if the marialite molecule generally dominates and the maximum content of meionite is 50—60 %. The scapolite contains much chlorine as is obvious from the chemical analyses of graphite schist and scapolitefels in tab. 1, where the contents of chlorine vary between 0.9 and 1.6 %.

As already stated the scapolitization has affected most rocks in the area. Even the plagioclase in the granite is shown in thin section to be partly altered to scapolite (fig. 25). Nevertheless the scapolitization seems to be intimately connected with the granitization. Thus the scapolitization in quartzitic phyllite is strongest near granite areas and decreases away from them. Remnants of diabase

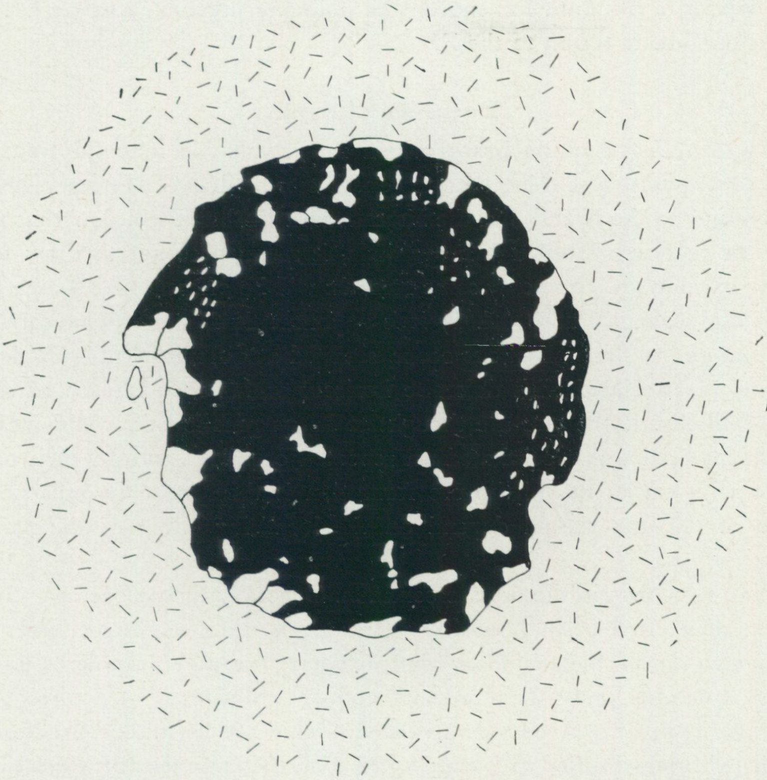

Fig. 26. Remnant of metadiabase (black) in granite (hatched). Scapolite aggregates (white) are abundant near the boundary of the remnant and decrease in number towards the centre. Drawing from drill-core. Natural scale.

in granite often contain scapolite, the mineral occurring most abundantly near the boundary but decreasing towards the center (fig. 26). It gives the impression that the Cl-bearing solutions existed in the granite as a mobile fraction and caused scapolitization by penetrating into pre-existing rocks such as the diabase. Evidently even newly crystallized granite sometimes was affected by the scapolitization.

Tectonic Features

As already stated the rocks at Stora Sahavaara are conformable with each other and dip 50—70° towards the NW. Within these formations microfolding and folds with amplitudes up to 5 m are frequent. The bigger folds occur in the quartzite and the quartzitic phyllite at some distance from the ore and in connection with granitization. The ore body shows in vertical section a slightly undalating form. Even to the E of the ore, in the graphite schist, small folds occur, while the phyllite further E has never been seen to be folded at all.

No faults are known to affect the ore body. However, immediately to the N of the deposit, a big fault has moved the dolomite horizon (corresponds to the ore horizon) about 100 m to the E.

Discussion of results

The present investigation has provided much valuable material from which certain conclusions concerning the ore genesis can be drawn. However, investigations continue to the N and S in the Kaunisvaara field and will doubtless provide even more material. Until this is available, it seems wise not to draw too far-reaching conclusions. Here only some remarks will be offered.

From the geological map (pl. 1) it is apparent that in the Sahavaara region three separate ore mineralizations occur, situated at different stratigraphic levels. They are all associated with dolomite horizons which they replace or succeed, partly or wholly. If the ores are thought to be syngenetic this would mean that iron-rich material was precipitated on repeated occasions and on each occasion together with carbonate. If the ore formation is thought to be epigenetic the location of the ores should depend on the localizing effect of the carbonate rocks.

Bedding structures in the ore are common. Generally they occur near the foot-wall and then often in the transition zone to the thin carbonate lenses which sometimes occur in the boundary zone between ore and graphite schist. The bedding structures probably represent original sedimentary structures but are not necessarily proof of a sedimentary origin for the ore itself. The structures may be inherited from stratified carbonate formations, the main part of which has been replaced by magnetite and skarn. Several examples of this are known (Holser 1950, Geijer 1959).

The existence of two skarn types, one markedly weaker in iron than the other, is of considerable interest. It is, however, difficult to say if these two skarn types even represent two stages in the formation of skarn and ore. Such hypotheses will have to await further investigations of the composition of the skarn minerals and a better knowledge of the application of thermodynamical principles to metamorphic differentiation.

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GFF = Geologiska Föreningens i Stockholm Förhandlingar

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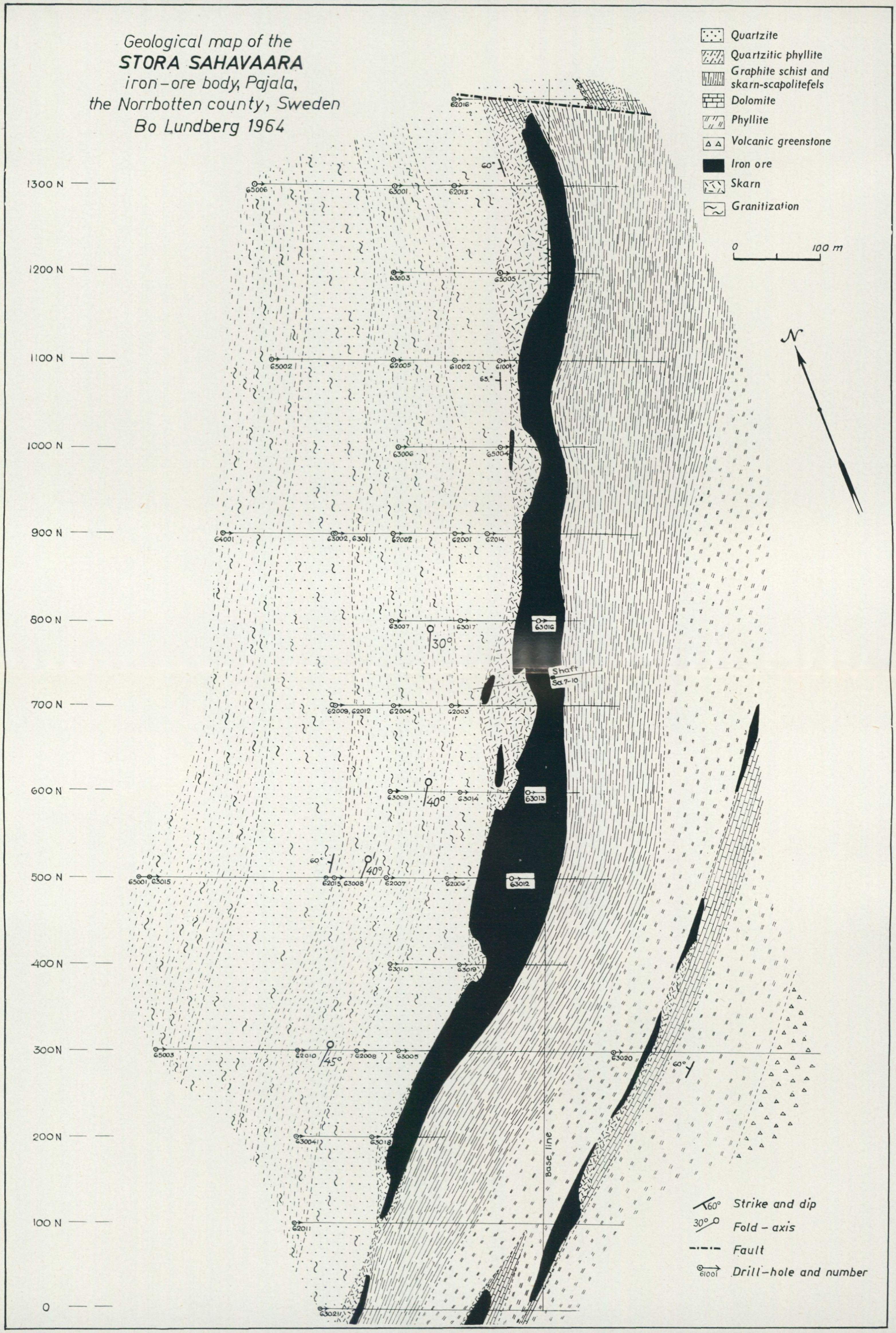
Geological map of the
STORA SAHAVAARA
iron-ore body, Pajala,
the Norrbotten county, Sweden
Bo Lundberg 1964
Quartzite
Quartzitic phyllite
Graphite schist and skarn-scapolitefels
Dolomite
Phyllite
Volcanic greenstone
Iron ore
Skarn
Granitization
0
100 m
N
1300 N
1200 N
1100 N
1000 N
900 N
800 N
700 N
600 N
500 N
400 N
300 N
200 N
100 N
0
Shaft
Sa 7-10
Base line
30°
40°
45°
60°
Strike and dip
Fold - axis
Fault
Drill-hole and number

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