SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 695 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 68 NR 2

HARDY LINDROOS

THE STRATIGRAPHY OF THE KAUNISVAARA IRON ORE DISTRICT, NORTHERN SWEDEN

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Abstract

The paper deals essentially with the stratigraphy of the Kaunisvaara iron ore district, Northern Sweden. Lithostratigraphical studies indicate the occurrence of three conformable formations: the Greenstone Formation, the Iron Ore Formation and the Phyllite Formation. The lower two formations occur in a large, NE–SW striking anticline. On the western side of this structure, the Kaunisvaara skarn iron ores are situated. Here, in the Iron Ore Formation, three stratigraphically separate, economically important, ore horizons occur. The uppermost of them, the main ore horizon, includes the deposits Stora Sahavaara, Ruutijärvi, Tapuli and Palotieva. These deposits comprise c. 90 % of the known ore reserves, which have been evaluated to c. 180 million tons iron ore with an iron-content of 27–41 %. The main ore horizon, predominantly composed of skarn, dolomite and magnetite ore, has an extension of more than 10 km. The Phyllite Formation is found above the Iron Ore Formation. Rocks younger than the supracrustal rocks are granite and dolerites.

A tentative stratigraphical correlation with some other areas in Norrbotten is made. A certain similarity between the Kaunisvaara area and the Tärendö area, as described by Padget (1970), exists. Thus, the Iron Ore and Greenstone Formations are equivalent to the Veikkavaara Greenstone Group and the Phyllite Formation to the Pahakurkio Group. Further, the lower two formations in the Kaunisvaara area are equivalent to the Kiruna Greenstones as described by Offerberg (1967).

The whole sequence has a thickness of more than 2000 m, about half of which is of a pure sedimentary origin and believed to have been deposited in marine environments. Here the magnetite accumulations were deposited, too,

probably as a hydrous precipitate. Hence, a primarily sedimentary origin of the magnetite is suggested. Later, regional metamorphism extensively affected all the rocks and, different skarn reactions formed the ores.

The localizing of these iron ores and the construction of the geological map has been assisted by magnetic and gravity anomaly maps. The stratigraphy established here may perhaps serve as a guide in the further prospection for strata-bound iron ores in Northern Sweden.

Introduction and previous work

A series of skarn iron ores occur in a long, narrow zone north–west of the village of Pajala, Northern Sweden (Fig. 1). These ores are collectively known as the Kaunisvaara iron ore district. By 1918, the deposits of Södra Sahavaara, Stora Sahavaara, Tapuli (Tapulivuoma) and Palotieva had been discovered. South of the Tapuli ore a smaller ore body, named Ruutijärvi, was found by the Boliden Co. (Boliden AB) in 1949. Further to the south, in the continuation of the ore district, the Axel Johnsson Co. located two more ore bodies in 1958, Suksivuoma and Karhujärvi. Reinvestigation by the Geological Survey of Sweden (SGU) started in 1960. Diamond-drilling began in 1961 in the Sahavaara area and was continued in the Tapuli and Ruutijärvi areas until 1971. The investigation by SGU included an aeromagnetic map of the whole district, c. 44 km^2 of magnetic and gravimetric ground surveys and almost 19 000 m of diamond-drilling. This work located two new deposits, Östra Sahavaara and Ruutijärvi, the latter being a blind ore-body situated c. 300 m south of Boliden AB's Ruutijärvi ore.

Drill-hole profiles, geological and geophysical maps, petrographic studies and calculations of ore reserves have been presented in several SGU internal reports (Lundberg 1965, Lundberg and Werner 1965, Lindroos et al. 1972 a, b). The ore reserves known by drilling have recently been evaluated to about 180 million tons iron-ore containing 27–41 % Fe and 0.2–2.5 % S (Lindroos 1972 c).

The geology of the area has been treated by several authors including Fredholm (1886), Geijer (1931), Eriksson (1954), Ödman (1957), Lundberg (1965 and 1967) and Lindroos (1972 a). Lundberg's studies of the Stora Sahavaara deposit are mainly petrological. Several of his rock definitions are adopted in this paper. Quantitative geophysical calculations of the tonnage of the Stora Sahavaara and Tapuli deposits occur in papers by Werner (1965) and Johansson (in Lindroos et al. 1972 a), respectively. Johansson has interpreted all ground surveys carried out by SGU in the Ruutijärvi–Tapuli–Palotieva area. Some special electro-magnetic profile measurements over the Sahavaara ore-bodies are reported by Paal (1968). The distribution of the trace elements in the magnetite of the ores has been described by Frietsch (1970). The genesis of these

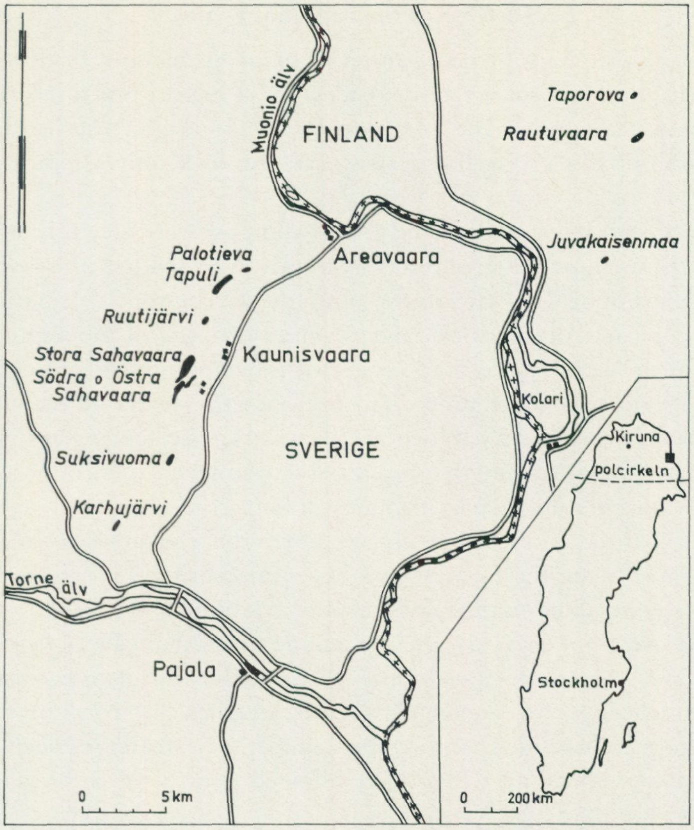

Fig. 1. Location of the iron ores of the Kaunisvaara area, Northern Sweden.

skarn iron ores (and most other similar iron ores in Sweden) is a subject on which there exists very divergent opinions. In some papers (Geijer 1931, Geijer and Magnusson 1952) they are considered as pyrometasomatic, while in others (Eriksson 1954, Ödman 1957 and Frietsch 1966, 1970) they are believed to be of mainly sedimentary origin.

The purpose of the present paper is two-fold: to record the results of a detailed lithostratigraphical investigation of this area, and in view of this evidence to contribute to the continuing debate on the origin of the ores. The general character of the stratigraphy and structure is shown on the geological map which includes a geological profile (Plate 1). The lithologies are described and shown in several columnar sections. The map is constructed from the results of the diamond-drilling, geophysical surveys and geological mapping (map sheets 29 M Huuki and 28 M Pajala).

Outline of the regional geology

Interpretation of the geophysical anomaly maps in relation to the sparse geological field data has shown the existence of a major anticline in the Sahavaara–Areavaara region. The area described here (Fig. 1) lies on the north–western limb of this NE-trending structure, the rock units dipping c. 50–65° NW.

The succession recognized in the area is composed of three formations, conformable throughout the area and apparently representing more or less continuous deposition. The lowermost unit, the Greenstone Formation, is dominated by basic volcanic rocks and occupies the core of the major anticline. The base of the formation is not exposed. It is overlain by the Iron Ore Formation, which includes the Kaunisvaara ore-bodies – strata-bound units interbanded with a variety of sedimentary members. The lower part of the Iron Ore Formation consists mainly of quartzose, micaceous and, in part, graphitic phyllites whilst the upper part includes dolomite, skarns and magnetite iron ore. At least three stratigraphically separate iron ore mineralizations occur, the uppermost being the thickest and best mineralized. The ore horizons are, in all cases, associated with dolomites and relationships between ore (in this paper iron ore is taken as a rock containing more than 20 % Fe magnetite), dolomite and skarns are transitional. The Phyllite Formation, composed of phyllitic arenaceous and argillaceous rocks, overlies the Iron Ore Formation. The units are well-bedded and exhibit sedimentary structures such as ripple-marks and cross-bedding which have allowed control of the relative age of the succession.

The supracrustal rocks are intruded by granites and dolerites. The former occur in the core and much of the eastern limb of the major anticline and also intrude the Phyllite Formation in the western parts of the area. Dolerites occur both concordant and discordant to the supracrustal sequence and, in places, intrude the granites.

Several faults, some with major displacement, have been detected in the course of the drilling and interpreted from the geophysical surveys. They are clearly later than all the rocks in the area.

Stratigraphy

The stratigraphic succession in the Kaunisvaara area is shown schematically in Fig. 2.

Lithostratigraphic terminology follows the general recommendations accepted internationally for stratigraphic nomenclature. The formation names employed here are used informally pending completion of the regional mapping and correlation elsewhere. Sediment terminology follows Pettijohn (1957).

Formation	Member
The Phyllite Formation	Quartzites and phyllites
The Iron Ore Formation	Skarn, iron ore, dolomite Graphite phyllite Phyllite with some dolomite, skarn and ore
The Greenstone Formation	Tuffitic, agglomeratic and amphibolitic greenstones with minor sediments

Fig. 2. The stratigraphical succession of the Kaunisvaara iron ore district.

The Greenstone Formation

The Greenstone Formation, consisting mainly of volcanic rocks, is the lowermost known formation in the area. It forms an approximately 20 km long, in part at least 5000 m wide area between the Muonio river in the north–east and the Kaunisjoki river in the south-west (Plate 1). Rocks of this formation have been found in outcrops, trenches and two drill-holes. The thickness of the formation varies due to folding and the primary thickness. It is amounted to c. 3000 m. The boundaries of the formation are magnetically very distinct. On the other hand there occur irregularities which are difficult to interprete. In the southern part, some hundred metres south of the Kaunisjoki river, the magnetic anomalies are diffuse. This appears to be related to intrusion of granites into the Greenstone Formation, producing weak magnetic anomaly patterns and smaller gravity anomalies. Immediately east of the village of Sahavaara there occur several magnetic sheets dipping to the west within an area where granite dominates. These have been interpreted as remnants of greenstone in granite. Furthermore, within the Greenstone Formation, several well-layered non-magnetic sheets (20–300 m thick), are interpreted as intraformational sediments (phyllitic or quartzitic). These are not found in any outcrops within the map area. The contact between the Greenstone Formation and the overlying Iron Ore Formation has been defined in a drill-hole at Södra Sahavaara. Lundberg (1967) described a transitional contact. In the drill-hole there occurs a small transition zone, where tuffitic beds are interbedded with phyllite. Whether or not this type of contact is characteristic for this boundary, is unknown.

The greenstone section drilled is c. 60 m thick. The rock is a green or greyish, fine-grained, layered tuffite. It is often schistose and mainly built up of amphibole, feldspar, scapolite and magnetite. There also occur beds of agglomerate c. 2–10 m thick. The clasts are angular, 0.5–3 cm in diameter, and composed of tuff material. Part of the tuffite is strongly metamorphosed – amphibolitic (Lundberg 1967).

Quite similar extrusive greenstones, often distinctly banded, have been found in outcrops near the village of Sahavaara, close to the Areajoki river and on the banks of the Muonio river in the north-east. The banded structure could indicate a resedimentation of volcanic material i.e. the rocks are tuffitic sediments. However, much of these rocks are altered and the only structure now visible is the schistosity. Some parts of these amphibolitic rocks are very coarse. Whether this results from a strong recrystallization or these parts represent altered, doleritic sills is not known, igneous textures not being observed.

An irregular geophysical anomaly pattern is met with south of the Sahavaara-village. There, several (one at least some hundred metres long) magnetic anomalies occur, oriented in a direction (NW–SE), discordant to the other anomalies. In one place, drilling showed the occurrence of two units (20 m thick) of a coarse, magnetite-bearing doleritic rock in a light-green, dense greenstone (Lindroos 1971). This dolerite and some others with discordant contacts have been shown on the map. However, most dolerite dikes revealed by drilling in the ore horizon are too small (thickness generally 1–5 m) for presentation in the mapscale chosen.

Whereas some of these basic intrusions are concentrated to the Greenstone Formation and may be genetically related to the volcanic rocks, others are discordant to the younger formations and the granite and are clearly the youngest rocks in the area.

Beds of grey, layered dolomite, intercalated in the greenstone, were found during the regional mapping (Lundberg 1962). The outcrops are situated about 800 m north-east of Areavaara, on the shores of the Muonio river. The thickest dolomite bed exposed is c. 10 m. The dolomite contains much impurities i.e. bands or lenses of a dark, amphibole-rich material. These "skarnic" beds represent impure clastic intercalations. In one outcrop there also occurs a bed which, according to Lundberg's observations, resembles a volcanogenic gravel. It is built up of angular fragments (1–8 mm in diameter) of magnetite and a reddish material (not defined) in a denser, lime-rich matrix. This occurrence is probably very local but it was reported earlier by Eriksson (1954), who interpreted it as a calcitic spilite.

Immediately south-west of the village of Sahavaara there is an old trench from where a corbonate-rich rock, probably a dolomite has been excavated (Lundberg 1962).

The non-magnetic layers within the greenstones are interpreted as phyllitic or quartzitic sediments.

The rocks of the Greenstone Formation give evidence of basic volcanism. Subordinate dolomite beds and phyllite-quartzite horizons favour a marine environment for the volcanism, the extrusion being partly in the form of lavas and partly pyroclastic (agglomeratic). Intercalated volcanogenic sediments testify to contemporaneous erosion of these volcanic rocks.

The Iron Ore Formation

The Iron Ore Formation overlies the Greenstone Formation, and is composed of phyllites (in part graphitic), dolomite and skarn iron ore. All rocks of this formation are believed to have been deposited in marine environments. Within the formation three thick horizons of dolomite and magnetite iron ore have been recognized and the total thickness of the formation is estimated to c. 500 to 1000 m.

The lowermost member (Fig. 3), deposited on the Greenstone Formation, is a grey or brownish, thinly bedded phyllite. Locally this rock is highly schistose. It is mainly composed of biotite, quartz, muscovite and feldspars. Here and there amphibole and scapolite is found, the latter as big, white porphyroblasts. The bedded structure is marked by a repeated alternation of dark biotite-rich and light quartz-rich layers. The thickness of this phyllite is about 150 m at the Södra Sahavaara deposit. Further to the north it becomes noticeably thicker, 500–800 m. This thickening is probably a depositional feature, certainly influenced by the subsequent folding.

In this phyllite two horizons with skarn iron ore and dolomite occur, viz. the Södra and Östra Sahavaara deposits. The ore-bearing horizons are both 10–40 m thick. The upper horizon (Södra Sahavaara) is about 1.5 km long. Economic concentrations are found only in the northern part (c. 1000 m). The lower ore-bearing horizon (Östra Sahavaara) is separated from the upper by 5–20 m of phyllites and is likewise conformable within the formation. It has a similar length to the upper unit but only a very small part shows a rich mineralization. Both horizons, especially the upper one, include green skarn, rich in amphibole. In both horizons the ore is associated with dolomite. The thickest dolomite bed is c. 40 m.

Dolomitic rocks also occur, in addition to these thicker horizons, as numerous thin beds in the phyllite. Indeed, successive transitions between phyllitic and dolomitic types are common.

The grey phyllites are overlain by a graphite-bearing phyllite. Boundaries between these rocks are not sharp. At Tapuli (Fig. 4) grey and graphitic phyllites are interbedded. When mapping core sections, transitions from light-grey, non-graphitic to dark, graphite-rich varieties have often been observed. In this paper only the darkest type (the graphite of which makes one's hand greasy), is referred to as "graphite phyllite". It is characterized by a relatively high content of graphite and sulphide minerals. The sulphides found here are mostly pyrite and pyrrhotite. The occurrence of chalcopyrite, generally as vein fillings, seems to be local.

The content of graphite and sulphides makes these rocks good electrical conductors. Geophysical surveys along a profile across the Södra Sahavaara deposit with VLF- and slingram methods proved to be excellent for detecting of graphite phyllites, even where the overburden was thick (Paal, 1968). The

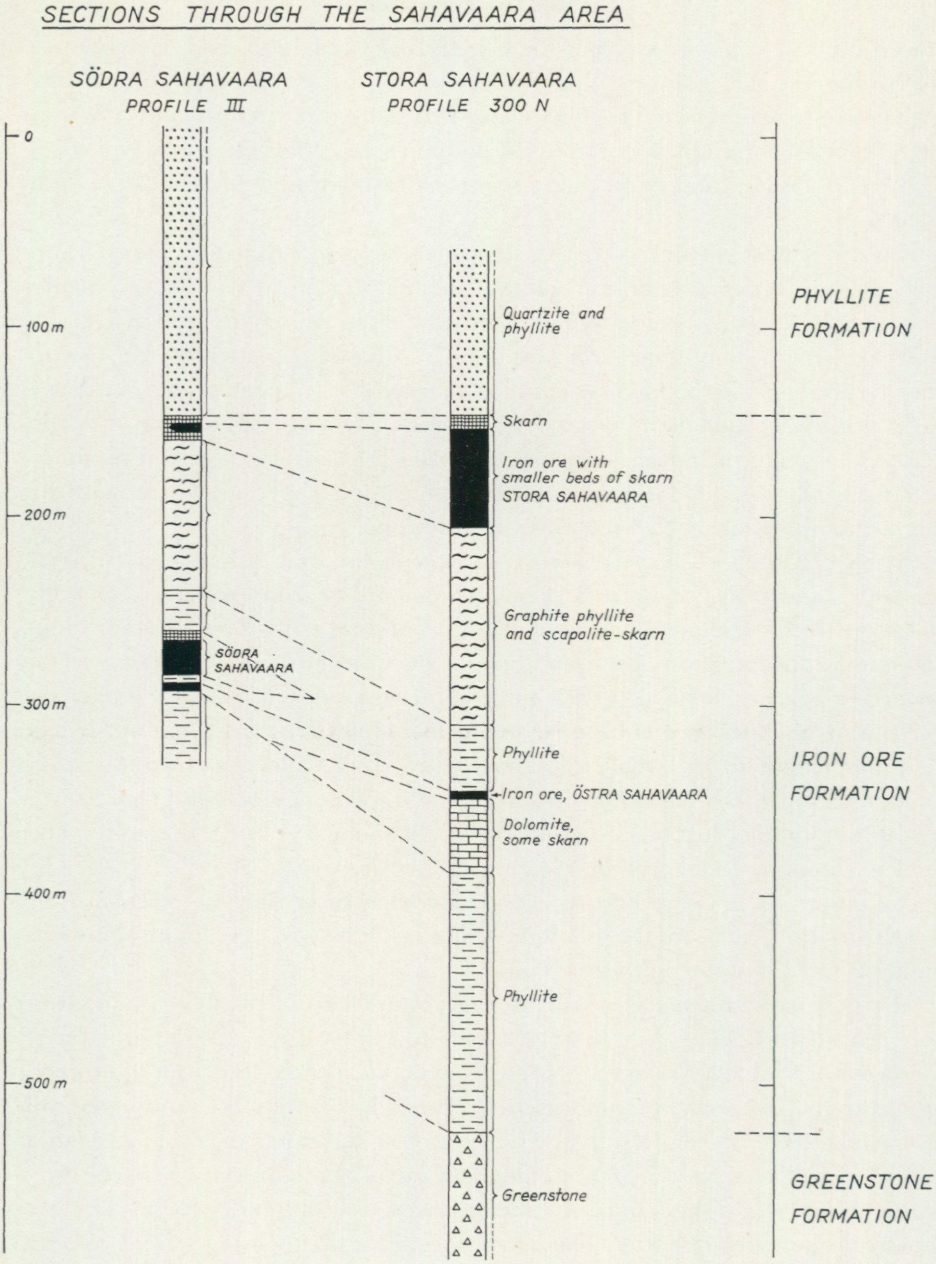

Fig. 3. Stratigraphy compiled from drill-holes in the Sahavaara area.

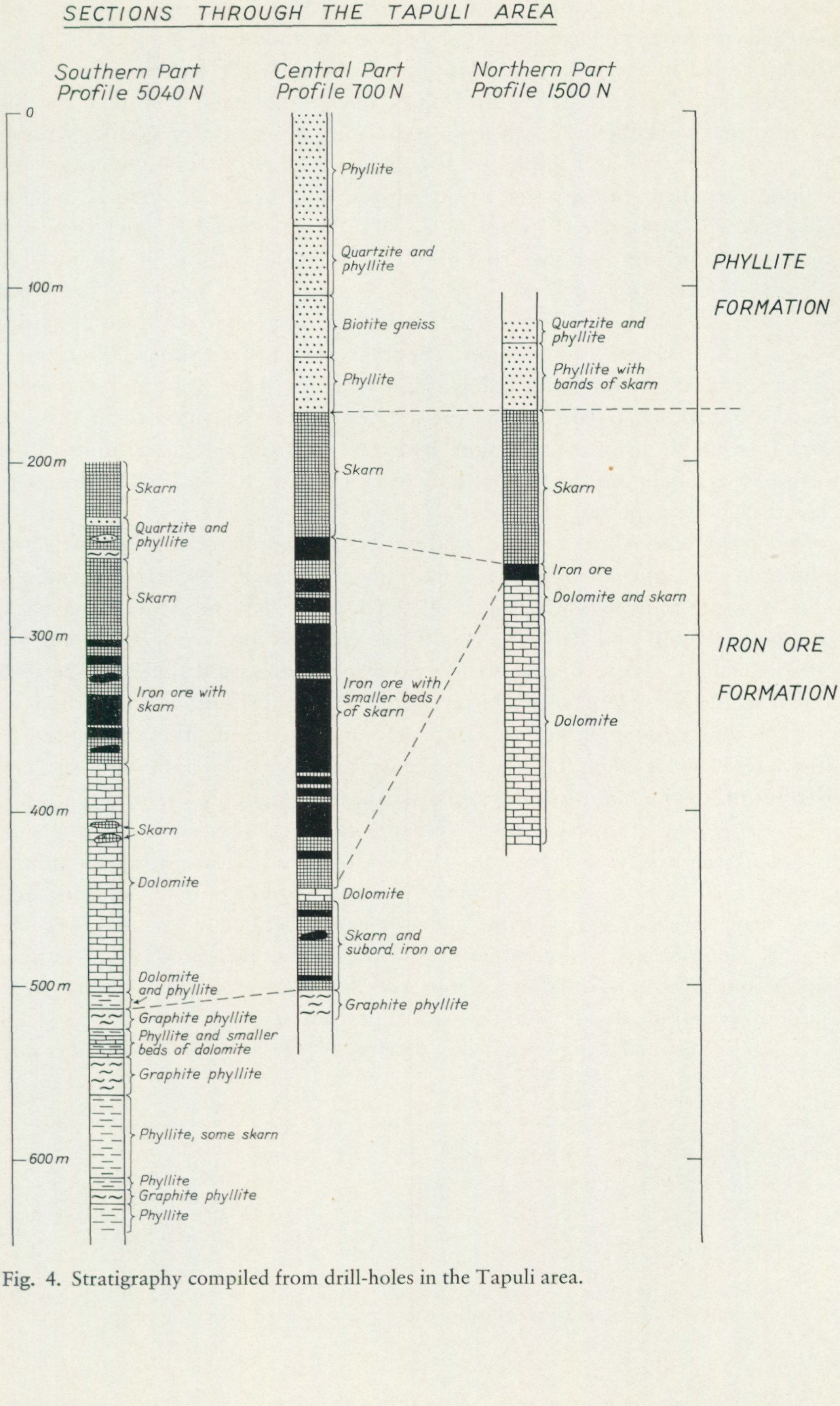

Fig. 4. Stratigraphy compiled from drill-holes in the Tapuli area.

measurements also indicated, as could be expected, the presence of other thin electrical conductors e.g. graphite-rich beds in the underlying phyllites.

Interbedded in the graphite phyllite are some beds or lenses of scapolite-bearing skarn. The beds are 1–25 m thick but are not easy to trace from one drill-profile to another. The rock in question is a mixture of quartz, amphibole, mica, scapolite and sulphides. It is coarse-grained, generally without any bedding structures. Some parts are strongly scapolitized. Lundberg calls these rocks "skarn-scapolitefels" (Lundberg 1967). As proposed by him they originally could present horizons rich in limestone in the graphite phyllite.

With the exception of some very thin dolomite layers found at the Stora Sahavaara deposit (Lundberg 1967) neither dolomite nor iron ore beds are present in the graphite phyllite unit. The thickness of this unit is very variable. In the northern part of Stora Sahavaara it reaches about 100 m. It has been detected by drilling from between the area of Södra Sahavaara to the central part of Tapuli, a distance of 7.5 km. Its extension from the latter point to the north-east is uncertain. Even the thickness of the unit is uncertain, for only a few drill-holes penetrate its base.

The graphite phyllite unit is overlain by a unit of skarn, iron ore and dolomite. This unit encloses two important and closely associated members, skarn iron ore and dolomite (Fig. 3–4). Hence, the deposits Stora Sahavaara, Ruutijärvi, Tapuli and Palotieva belong to the same horizon – the main ore horizon. This horizon, thanks to the extensive diamond-drilling, is the best known in the area. It has been investigated over a distance of more than 10 km. The thickness of the unit varies from some metres in the very southernmost part to more than 300 m in the central part of the Tapuli deposit. The distribution of the main members, the skarn, the magnetite ore and the dolomite, is also quite variable (Fig. 5). Where skarn and iron ore occur together the boundaries are always transitional (ore is defined here as a rock containing more than 20 % Fe magnetite). Furthermore, the limit between dolomite and skarn respectively is very diffuse and not easily defined when mapping the cores. The dolomites are sometimes somewhat calcitic. Dolomite from southern Tapuli contains approximately 28 % CaO, 21 % MgO and 41% CO_2; these compounds making up 90 % of the rock (Lindroos et al. 1972 a).

As can be seen from Fig. 5 and the sections in Fig. 3–4, the Stora Sahavaara

Locality	Skarn	Dolomite	Iron ore	Total
Tapuli, central part	150	20	160	330
Tapuli, southern part	100	110	60	270
Ruutijärvi (SGU)	50	50	100	200
Stora Sahavaara	20	thin	70	90

Fig. 5. Distribution of skarn, iron ore and dolomite in the main ore horizon of the Iron Ore Formation in the Kaunisvaara district (thickness in metres).

deposit is built up of iron ore and some skarn, while the Tapuli deposit contains much more skarn and dolomite. This is also expressed in the average iron values of the deposits; Stora Sahavaara c. 41 % Fe and Tapuli c. 29 % Fe. The Ruutijärvi deposits are, in this respect, very similar to Stora Sahavaara.

A common feature for all the Kaunisvaara skarn iron ores is a high sulphur content, whether they occur in the thick, main ore horizon or in the smaller, underlying horizons. Except for Tapuli (S=0.2 %) all objects can be classified as sulphur-rich (S=0.5–2.5 %). Their content of phosphorus is low (P <0.1 %). More detailed information about ore qualities and quantities is given in the internal SGU geological reports.

The dolomite is best known at Ruutijärvi and at southern Tapuli. It is a grey, white or sometimes reddish, mainly coarse-grained carbonate rock, containing minor amounts of skarn, iron ore and sulphides. Banding may occur due to the presence of skarn-rich impurities. The massive, more pure dolomites may show a banded structure, i.e. a succession of calcite-rich and dolomite-rich layers when subject to etching (Lindroos et al. 1972 a). Whether or not this calcite-dolomite banding is a primary structure is not known. In the dolomite from Södra Sahavaara, Lundberg (1965) observed the occurrence of thin layers of a grey fine-grained pelitic material. They are thinly bedded and appear to be better preserved meta-argillitic sedimentary beds in the dolomite. Similar layers have been observed in the Tapuli dolomite. At Ruutijärvi some of the skarnic beds of the dolomite contain iron ore. In the central part of the Tapuli deposit several dolomite beds are interfingering in skarn and iron ore.

All iron ores of the Kaunisvaara district are magnetite dominated. They are rich in sulphur and poor in phosphorus. Hematite has not been found. The ores are interbedded in or mixed with skarn in variable amounts. Though the iron-mineralization occurs in different stratigraphic positions, the ores are strata-bound in that they are restricted to the one sedimentary formation.

A typical feature is a skarn-magnetite banding, where lighter layers (some mm to several cm thick) of skarn minerals rhythmically alternate with darker magnetite layers. This banded structure has been reported from many other skarn iron ore deposits in Norrbotten i.a. some of the ores of the Svappavaara district (Frietsch 1966) and the Sautusvaara deposit (Hallgren 1970). One interpretation is that this structure is primary i.e. it was formed during sedimentation. It is the author's impression that all members of the whole formation are of sedimentary origin. Hence, during the sedimentation there was rhythmic repetition of the deposition of the iron, carbonate and silica compounds. However, it should be noticed, that a similar banded structure, which may have resulted from replacement phenomena, has been reported by Geijer (1959).

In places, especially along rock contacts, the ore is brecciated. Angular fragments of the wall-rock (mostly skarn) occur in a magnetite-rich matrix. In places an intensive fracturing occurs and the rock contains a large number of randomly oriented veinlets, filled mainly with calcite and sometimes with sulphides. The ore in these brecciated parts is often coarse-grained and of higher grade – a result of local remobilization and recrystallization. The thickness of the brecciated ore is highly variable but can reach c. 10 m. The formation of the breccia is of a secondary, tectonic origin.

Two major types of skarn occur: an older, green, diopside-tremolite-rich and a younger, dark, serpentine-phlogopite-rich type. The latter is closely associated with the iron ore and most of the economical ore is found in this skarn-type. All boundaries between ore and skarn are transitional (cf. p. 12).

Only in a few places has olivine been found together with serpentine. At Stora Sahavaara, Lundberg observed a strong serpentinization of olivine and this alteration was accompanied by the formation of magnetite (Lundberg 1967). This serpentine-skarn was originally richer in olivine. However, according to Lundberg, most of the serpentine-skarn was formed by alteration of the diopside-tremolite-skarn. In both cases the serpentine is an alteration product of the earlier skarn. The genetical relationship between these two skarn-types, one richer in iron than the other, and the association of magnesia-rich skarn and dolomite are features characteristic for many skarn iron ore districts in northern Sweden.

The Phyllite Formation

The Phyllite Formation consits of quartzose and phyllitic rocks overlying the Iron Ore Formation. These well-bedded meta-sediments are entirely detrital, containing arenaceous and argillaceous material. The best preserved rocks are found in some outcrops north of Tapuli (Areajoki) and in sections close to the contact with the underlying formation. To the west (cf. the map) these sediments become more and more metamorphosed until rocks of the biotite-gneiss or veined-gneiss type occur. This alteration is interpreted as progressive granitization. At Stora Sahavaara the strongest alteration results in a homogeneous, gneissic granite (Lundberg 1967). In these meta-sediments the bedding structure is gradually destroyed. However, a relict banded structure can generally be seen even in the migmatitic types. The thickness of the formation is at least 500 m, perhaps as much as 1000 m. The greatest thickness drilled (at Ruutijärvi) is 200 m.

As a rule the sediments are well-stratified. Two main types are met with; the one light and quartzitic, the other, darker and phyllitic. Transitions between these types are common. In drill-cores alternating biotite-rich and quartz-rich beds express a very distinct stratification (layering). Here and there a slight grading can be recognized.

The phyllitic type is rich in micas (biotite and muscovite). The dominating minerals are generally quartz and biotite. The content of feldspar is low;

both plagioclase and microcline are found. The quartzitic types contain variable amounts of heavy minerals including hematite, rutile and zircon.

About 2 km north-east of the Tapuli iron ore (cf. the map) well-bedded micaceous quartzites occur. They show cross-bedding indicating way-up of the beds to the north-west. Here, the bedding is well shown by dark and thin hematite layers. These laminae seem to be primary "black sand" beds. A similar lamination in quartzite has been reported from the Käymäjärvi area by Eriksson (1954, p. 11–12). Cross-bedding and ripple-marks are also met with in several exposures on the banks of the Muonio river immediately north-west of the Areavaara village. The strike here is E–W and the beds young northwards.

The sediments of the Phyllite Formation have, at least in the north, been deposited in a shallow sea. The graded units to the south may be indicative of deeper water.

The boundary between this formation and the underlying Iron Ore Formation appears to be conformable throughout the area. It has been penetrated by c. 60 drill-holes and is mostly transitional. In some parts, layers (1–10 m) of skarn are interbedded in the Phyllite Formation. However, there are lithological and depositional differences between the two formations. The lower one is characterised by chemical and the upper by clastic sediments.

The total thickness of the above described three formations is more than 2000 m (Fig. 6).

Formation	Thickness known by drilling	Calculated total thickness
The Phyllite Formation	200	500–1000
The Iron Ore Formation	500	500
The Greenstone Formation	60	1000–3500
	760	2000–5000

Fig. 6. Approximative estimates (m) of the thickness of the sedimentary formations of the Kaunisvaara district.

Regional correlation

The stratigraphic succession of the Kaunisvaara area (Fig. 2) can be compared with the stratigraphic succession in some other areas in Norrbotten. A strong similarity between the Kaunisvaara and the Tärendö area, described by Padget (1970), exists. In Tärendö, the Veikkavaara Greenstone Group, the upper part of which includes limestones and graphite phyllites, is overlain by a thick suite of mainly clastic sediments – the Pahakurkio Group. Members of this upper group are very similar to those of the Phyllite Formation, as here described. On the other hand members of the two lowermost formations of our area show similarities with those of Padget's Veikkavaara Greenstone Group. The Veikkavaara Greenstone Group may in turn, as shown by Padget (1970), be compared with the Kiruna Greenstones.

The stratigraphic successions of Kiruna, Tärendö and Kaunisvaara areas are schematically compared in Fig. 7. A basement to the succession has not been found in our map-area.

KIRUNA Offerberg 1967	TÄRENDÖ Padget 1970	KAUNISVAARA Present paper
Upper Hauki Complex	Rissavaara Quartzite	
Paittasjärvi Greenstones		
Kiruna Porphyries	Kalixälv Group	
Kurravaara Conglomerate	Pahakurkio Group	Phyllite Formation
Kiruna Greenstones	Veikkavaara Greenstone Group	Iron Ore Formation Greenstone Formation
Granite basement		

Fig. 7. Stratigraphical correlations suggested for the different groups of supracrustal rocks in Norrbotten.

Conclusions and discussion

The stratigraphy of the Kaunisvaara iron ore district has been described (Fig. 2) and tentatively correlated with some other areas in Norrbotten (Fig. 7). The skarn iron ores are strata-bound. They and some of their surrounding meta-sediments can be identified by modern geophysical surveys.

This study has also given some information of genetical importance. The iron deposits clearly belong to the same cycle of sedimentation as do the argillaceous, calcareous and graphite-bearing sediments. They have all been deposited in a marine environment. Subsequently, they have been subjected to different metamorphic processes, including the skarn reactions. Studies of many drill-core sections gave the author an impression that the formation of skarns leads to an enrichment of the ore-material. A remobilization and recrystallization separates the skarn from the magnetite yielding a coarser and better concentrated ore. Thus, it is concluded that skarn reactions have been the final and decisive influence in the formation of economic concentrations. The regional metamorphism is connected with the main folding of the supracrustal rocks and it has affected the whole sequence. The skarn reactions are perhaps similar to those giving rise to "reaction skarns", described i.a. by Geijer and Magnusson (1952). Further, the serpentine-skarn (cf. p 14) could be a retrograde alteration product of the "reaction skarn". A quite similar skarn development has been described from the Persberg-Odal District in central Sweden (Geijer and Magnusson 1944, Magnusson 1970).

In concluding that these ores were originally sediments which later were metamorphosed, the author is in agreement with Frietsch (1966), who interpreted many of the skarn iron ores in Norrbotten as sediments formed contemporaneously with the wall-rocks and later metamorphosed. A similar explanation was proposed for the origin of the skarn iron ores at Kolari, Northern Finland, by Mikkola (1960).

Economic evaluation of the ore during the recent investigations has indicated the presence of about 180 million tons of ore with an iron-content of 27–41 %. The Kaunisvaara ores contain the largest, shallow, unmined reserves at present known in Northern Sweden.

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GEOLOGICAL MAP OF THE KAUNISVAARA IRON ORE DISTRICT

NORRBOTTEN, N. SWEDEN

Hardy Lindroos 1973

Scale 1:20000

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