SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C AVHANDLINGAR OCH UPPSATSER N:o 577

ÅRSBOK 55 (1961) N:o 1

GEOLOGY OF THE NICKEL DEPOSIT AT LAINIJAUR IN NORTHERN SWEDEN

AND A SUMMARY OF OTHER NICKEL DEPOSITS IN SWEDEN

BY

ERLAND GRIP

WITH FOUR PLATES

STOCKHOLM 1961

Sveriges Geologiska Undersöknings senast utkomna publikationer

Geological survey of Sweden. Recent publications

Ser. Aa. Geologiska kartblad i skalan 1:50 000 med beskrivningar

Geological maps, scale 1:50 000, with explanations

Priset för karta i Ser. Aa med beskrivning är 10:— kr, för karta enbart 8:— kr.
(Price: map sheet + descriptive text Sw. cr. 10:—, map sheet Sw. cr. 8:—)

N:o 197 *Laholm* av W. Larsson och C. Caldenius { Beskr. under utarbetande / Expl. in preparation.
» 198 *Halmstad* av W. Larsson och C. Caldenius » » »
» 199 *Uppsala* av P. H. Lundegårdh och G. Lundqvist. With English summaries. 1956
» 200 *Eskilstuna* av P. H. Lundegårdh och G. Lundqvist. English summaries. 1959

Ser. Ad. Agrogeologiska kartblad i skalan 1:20 000 med beskrivningar

Agrogeological maps, scale 1:20 000, with explanations

Priset för karta i Ser. Ad med beskrivning är 8:— kr, för karta enbart 6:— kr.
(Price: map sheet + descriptive text Sw. cr. 8:—, map sheet Sw. cr. 6:—)

N:o 2 *Lund* av G. Ekström. Karta 1948 med beskrivning 1953
» 3 *Revinge* » » 1951, t. v. utan beskrivning
» 4 *Löberöd* » » 1951 med beskrivning 1960
» 5 *Örtofta* » » 1952, t. v. utan beskrivning
» 6 *Kävlinge* » » 1955, t. v. » »
» 7 *Teckomatorp* » » 1955, t. v. » »
» 8 *Trollenäs* » » 1955, t. v. » »
» 9 *Bosjökloster* » » 1956, t. v. » »
} Explanations in preparation

Ser. C. *Årsbok 53 (1959)*

N:o 563 Sandegren, R., Register över Sveriges geologiska undersöknings publikationer 1858—1958. [Index of publications of the Geological survey of Sweden 1858—1958] 1959 10,00
» 564 Offerberg, J., Rocks and stratigraphy of the Ledfat area, Västerbotten county, Northern Sweden. 1959. With two plates 10,00
» 565 Lundqvist, G., C 14-daterade tallstubbar i fjällen. Summary: C 14-dated pine stumps from the High Mountains of Western Sweden. 1959 . . 3,00
» 566 Möller, H., Från nordostis till lågbaltisk is. En glacialgeologisk studie i sydvästra Skåne. Zusammenfassung: Vom Nordosteis zum Niederbaltischen Eis. Eine glazialgeologische Studie in SW-Schonen. 1959 9,00
» 567 Nilsson, K., Isströmmar och isavsmältning i sydvästra Skånes backlandskap. Zusammenfassung: Eisströme und Eisabschmelzung im Hügelland des südwestlichen Schonens. Mit zwei Tafeln. 1959 6,50
» 568 Du Rietz, T., Tectonic conditions in the front range of the Swedish Caledonian in Central Norrland. 1960 9,50
» 569 Hjelmqvist, S., Förekomsten av tungmineral i kaolinen på Ivö. Abstract: Occurrence of heavy minerals in the kaolin of Ivö. 1959 2,00

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C AVHANDLINGAR OCH UPPSATSER N:O 577

ÅRSBOK 55 (1961) N:O 1

GEOLOGY OF THE NICKEL DEPOSIT AT LAINIJAUR IN NORTHERN SWEDEN

AND A SUMMARY OF OTHER NICKEL DEPOSITS IN SWEDEN

BY

ERLAND GRIP

STOCKHOLM 1961

CONTENTS

Preface

In January 1940 a small pit sited on an electrical anomaly exposed the Lainijaur Nickel Deposit for the first time. From then on I had the opportunity of following the development of the Lainijaur Mine during the whole of its life time till it was closed down in September 1945. During this time I carried out the geological survey there and in 1942 published a preliminary paper on the Lainijaur Deposit. When the mine was closed down I wrote a geological report on it for use within the Boliden Mining Company. During the survey I collected material, carried out microscopical work and had samples analysed. My intention was to write a complete description of this remarkable deposit but due to other occupations this work has only been intermittent, and the final paper much delayed. The collected material and all the drill-cores constitute a basis for much more research work than I have done, but as I am unable to spend more time on this investigation I believe it is better to publish my results now.

For the survey in the mine and in the field and for laboratory work I have had many co-workers, and I wish to thank them all for their help and good collaboration. Thus during the last year of the survey in the mine I was assisted by Mr Å. Wirstam, who did a large part of the mapping work. In the mapping and sampling work also Mr G. Lindgren has taken part to a large extent. All the analyses have been done at the Research Laboratory of the Boliden Mining Co. Most of them were made in long series as routine analyses, and if their accuracy is not so high it is in any case high enough for the statistical purpose for which I have used them. The signed analyses, however, are all of a very high quality made by the skilled analysts Th. Berggren, B. Helger, I. Heyman, and A. G. Hybbinette.

During 1941—1942 an extensive nickel prospecting campaign was carried out by the Boliden Minig Co over the whole of Sweden. I give an account of the results of this investigation for a comparison with Lainijaur. In the northern part of the country the survey was managed by me while for the Gävleborg County and southwards Dr E. Dahlström was responsible. Several geologists joined the survey for longer or shorter periods, namely, T. Du Rietz, P. Forsell, W. Larsson, P. H. Lundegårdh, and F. R. Tegengren.

For checking my mineral determinations in polished sections I am indebted to Professor O. H. Ödman. — Professor S. Gavelin, an expert on the Skellefte District, has been kind enough to look through and criticize my manuscript and I thank him very much for this and for encouraging discussions during many years.

The English language of my manuscript has been revised and corrected by Dr P. Padget and I am very grateful to him for this work.

For due permission to publish this paper I am indebted to the Boliden Mining Company, through the President, Mr B. Norén and the General Mining Manager, Mr F. Agri.

I am very glad for permission to publish this paper in the series of the Geological Survery of Sweden, where most of the monographs on Swedish mineral deposits have been printed, and I thank Mr K. A. Lindbergson, Director of the Geological Survey, and Dr P. H. Lundegårdh, member of the Publishing Committee.

Introduction

The nickel deposit at Lainijaur is situated at long. 18°59′E, lat. 65°14′N, 13 km NE of the village of Malåträsk in the Västerbotten County and 1 km E of the road Malåträsk—Abborrträsk (Fig. 1). By road it is 43 km to the Abborrträsk station at the railway Jörn—Arvidsjaur. In that part of the Skellefte District where the Lainijaur nickel mine is situated the country is flat and

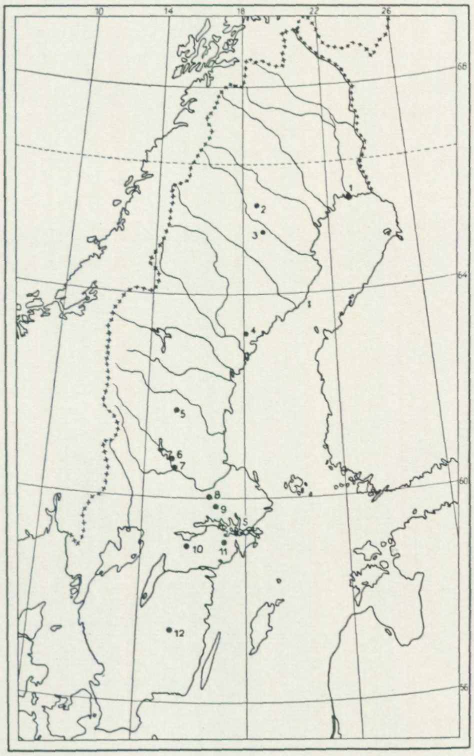


Fig. 1. The situation of the nickel deposits in Sweden. 1 Ö. Skogträsk, 2 Storbodsund, 3 Lainijaur, 4 Förnätra, 5 Loos, 6 Slättberg, 7 Kuså, 8 Ekedal, 9 Gaddbo, 10 Ruda, 11 Frustuna, 12 Kleva. — (S = Stockholm).

covered with wide swamps and intervening moraine ridges which at the surface are mostly poor in boulders. The rare outcrops do not give sufficient information to permit a fairly exact geological map of the Pre-Cambrian bedrock to be drawn. As only geological surveying alone was not sufficient for deciding if it was ore-bearing or not, the Boliden Mining Company in 1939 started electrical prospecting in the area. Among the anomalies found was one situated just at the present Lainijaur mine. It looked promising and therefore in January 1940 was investigated with some excavations. One of these exposed copper-pyrrhotite ore under a cover of 6 m of moraine. In May 1940 the first analysis was available and showed besides a good copper content also aconsiderable percentage of nickel.

Diamond drilling as well as detailed gravimetric and magnetic measurements were then started. Through electrical deep measurements it was possible to follow the contours of the ore-body a little farther. In all, 53 diamond drillholes have been put down from the surface for investigation of the deposit.

In 1941 a shaft was sunk to the 32 m level and mining between this level and the surface was started. In Januari 1942 sinking of a new shaft began (Shaft II), which was sunk to the 82 m level. At 70 m a haulage level was developed and in April 1943 sinking of an inclined shaft approximately along the pitch of the ore-bodies was started. This shaft sinking was finished in May 1945 when it had reached the 213 m level. From this inclined shaft, drift rippings and raises to the ore-bodies have been made at the 90, 110, 150, 170 and 190 m levels.

The mine was closed in 1945 and after that time has not been worked. The

Fig. 2. The Lainijaur Mine at the closing down in 1945.

total output has been 140 224 metric tons from which 100 526 tons of ore with an average of 2.20 % Ni, 0.93 % Cu and 0.1 % Co have been recovered.

Geological survey and mapping of the two flat lying parallel ore ribbons has been carried out, especially by mapping of the walls of the stopes. On the basis of the wall-sections and other observations in the mine and in the drill-cores, parallel vertical sections 10 m apart have been drawn both in the direction of plunge and at right angles to it (cf. Grip-Ödman 1944). The geological conditions in the exhausted part of the mine going down to about the 100 m level are thus well known. Deeper down, the ore is incompletely exhausted and therefore its boundaries have not been exactly fixed. Below the 150 m level the eastern ore-body is known in more detail only at the levels 170 and 185 m, while the western ore-body has not been investigated at all. Compare Pls. 1, 2, and 3.

Geology of the Lainijaur Area

The deposit of Lainijaur is situated in the northwestern part of the Skellefte District. The Pre-Cambrian bedrock of the area is extremely rarely exposed and knowledge of it rests on a small number of outcrops, studies of the moraine, geophysical anomalies and, in the mine area itself underground drill-holes and exposures.

The mineralized area is covered with thick moraine which at the outcrop of the ore-bodies is 6 m thick but rapidly increases towards the NW. In a drill-hole 1 km NNW of the mine the thickness of the soil is 52 m, one of the greatest in the Skellefte District.

The supracrustal rocks of the Skellefte District strike from the mineralized area Mensträsk — Rakkejaur NW, and here mostly consist of rocks of the upper series, the Phyllite Series. West of the Lainijaur deposit the supracrustal series is cut by a large granite massif, the “Adak granite”, with a contact line running about NE—SW (Gavelin 1948). The sediments are generally shallow folded along flat-lying fold-axes striking approximately NW and with a gentle dip in this direction (Grip 1941). Local deviations, however, occur and the most obvious example is at Lainijaur.

On the basis of abundant information from drill-holes and underground exposures I have drawn the geological map of the Lainijaur mineralized area and the section crossing it. They appear in Fig. 3 and show how the sediments form a syncline with fold-axis dipping about 25° towards N 35° E. The sediments often have a beautiful banding structure with layers varying from psefite to pelite and their composition from quartzite to limestone. Dacitic tuff material is common, at least in the lower layers of the mine. A metamorphism especially strong in the sediments over the ore-bodies makes it difficult to determine the original character of the different rock types. The series exposed in the mine, however, very well belongs to the lower part of the Phyllite Series of the Skellefte District and probably also to the underlying series of coarse clastic sediments, arkoses and intermediate volcanics. The same stratigraphic layers

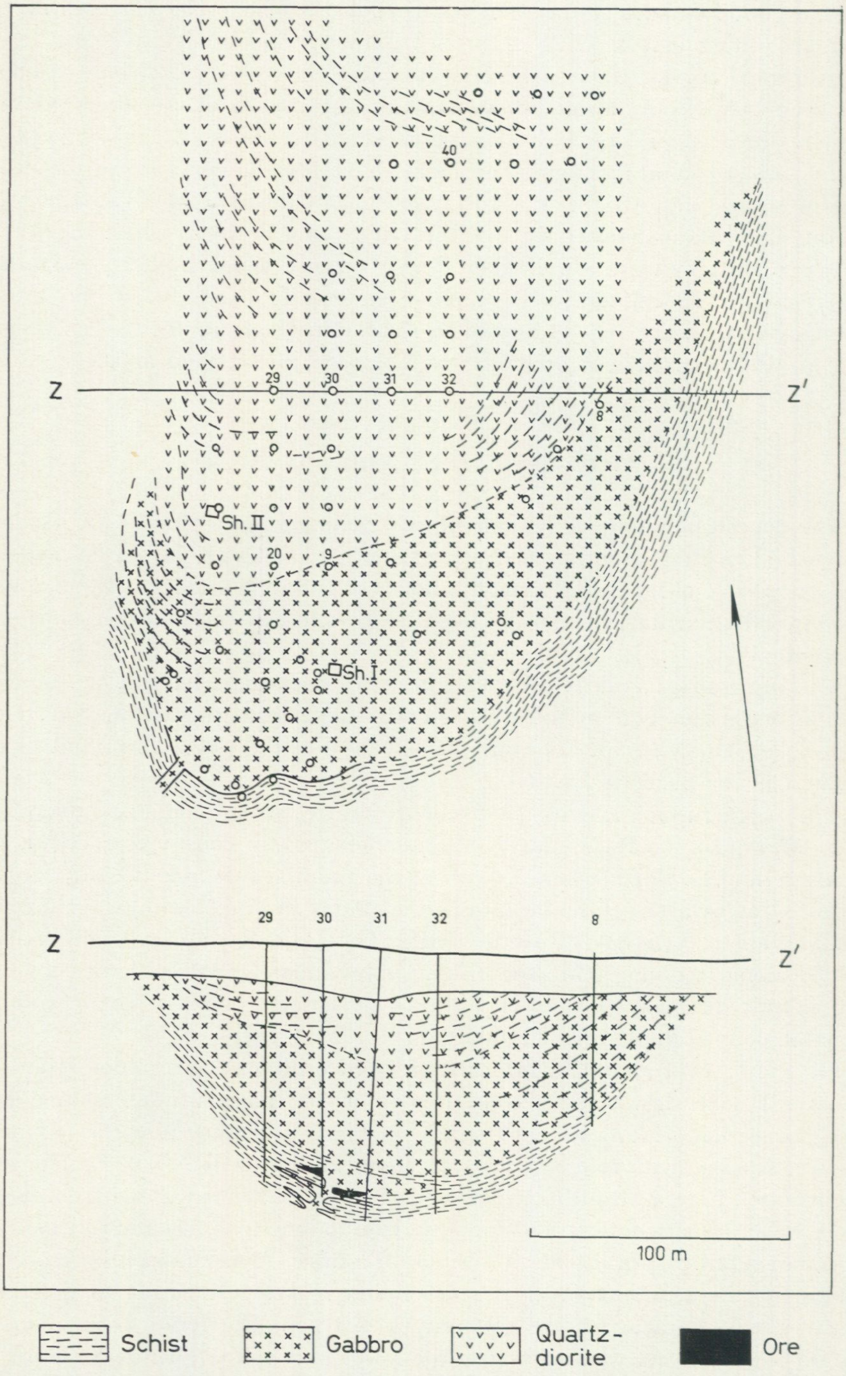


Fig. 3. Geological map of the Lainijaur nickel deposit and its immediate surroundings, and a section through the ore-bodies and the gabbro phacolith. The area is covered by a thick overburden of moraine and the map is entirely founded on diamond drillings and mine exposures. E. Grip 1955.

were described before at the Mensträsk Deposit, lying 27 km to the southeast (Grip 1951). There they are developed as banded schists and underlying polymict conglomerates with pebbles of intermediate volcanics.

The sediments in the bottom of the syncline are cut by a gabbro dike running N 45° E and dipping about 55° NW. This gabbro dike runs all through the mine and could be especially well studied in the inclined shaft and in drifts going out from it. Particularly around the part shown in the section of Fig. 3 the gabbro dike has sent out several wing-shaped sills in both directions. These increase in thickness upwards and suddenly the gabbro expands into a phacolith-shaped body following the trough of the syncline and spreading out laterally where wedges of sedimentary rock appear. These are less and less assimilated by the gabbro outwards. The central parts of the gabbro-body as well as the cutting dike are richly disseminated by nickel-pyrrhotite.

The central part of the gabbro all over the mine area has a rather even thickness of about 50 m. Above the gabbro comes a bed of sedimentary rock which, especially in its central part, is more or less completely replaced by diorite and quartz-diorite. Particularly is this the case in the direction from the gabbro dike and upwards (cf. Fig. 3). This fact indicates that originally the fissure also penetrated the sediments to this point and formed a feeding channel for ascending material. No direct observations of the upward continuation of the fissure have, however, been possible.

Diorite and quartz-diorite follow above the gabbro without any sharp contact. They have been able to assimilate sedimentary material to a considerably less degree than the gabbro, and the content of sulphides here is much lower than in the gabbro.

The composition and grain-size of the sedimentary rocks is very variable in the beds, which are about 100 m thick in the mine area. Siliceous beds have been assimilated more easily than those more rich in lime. Remains of calcareous beds occur in the form of lime-silicate skarn and in psefitic sediments sometimes the matrix but not the pebbles has been assimilated. Stripes of skarn are found from the highest to the lowest parts of the profile, Fig. 3.

The nickel ore is of three different types: disseminated ore, nickel-pyrrhotite ore and nickel-arsenic ore.

The disseminated ore consists of gabbro with dispersed nickel-pyrrhotite and chalcopyrite. It was formed in at least three different stages, and occurs in large quantities. It seldom, however, contains percentages high enough to make it profitable to mine. The nickel-pyrrhotite ore consists of more or less solid and often coarse-grained nickel-pyrrhotite accompanied by some chalcopyrite and nickel-arsenic minerals. From an economic point of view it is the most important of the ore types and the one which has contributed the largest quantities during the mining period. It forms two parallel, partly broken but generally very prolonged ore ribbons lying on both sides of the gabbro dike just below the line where the gabbro spreads to form the phacolith intrusion. Commonly the hanging-wall consists of gabbro and the foot-wall of sedimentary rocks, but local deviations may occur.

The shape of the ore-bodies appears from the isopachyte map Pl. 1, from the longitudinal sections Pls. 2—3 and from the cross sections Pl. 4.

The nickel-pyrrhotite ore brecciates sediments as well as gabbro and disseminated ore and fragments of these rocks are more or less replaced by the ore (cf. Figs. 31 and 37). Against the gabbro dike the eastern ore-body in some parts, e.g. on the 70 m level, is limited by a slickensided fault along which small movements have taken place and between the 20 and 30 m levels there is a marked fault against the gabbro in the hanging-wall.

The nickel-arsenic ore consists of a number of nickel-arsenic and sulphide minerals (cf. the paragenetic scheme in Tab. VIII) and occurs in veins and especially in veins radiating from the bodies of nickel-pyrrhotite ore. It also occurs as veins within this solid ore and rarely has been found in veins both far down in the foot-wall sediments and high up in the gabbro and granodiorite of the hanging-wall.

As mentioned before the grade of metamorphism is high in the mine area. Naturally, this is especially true for the parts where real assimilation phenomena have taken place. A granitization, however, also occurs in the sediments in the foot-wall of the ore and it is especially pronounced around fissures radiating from ore points and traversing sandy sediments of dacitic composition. Here sometimes real granite "secretions" occur (cf. p. 16). Otherwise the rocks are in the amphibole-biotite-epidote facies. A late alteration (deuteric) in some parts leads to chlorite facies.

In a drill-hole 1 km NW of the mine occurs the nearest exposure of granite belonging to the large massif extending from Malåträsk in the south to the Skellefte River and the Adak cupola in the north (Gavelin 1948). This granite is probably a parallel one to the Arjeplog granite (Grip 1944). According to exposures in the drill-hole mentioned above (dh 71) and to glacial boulders this granite massif in the east has a porphyritic rand facies similar to that of the Sorsele granite (Högbom 1931).

The weathering within the mine area is commonly insignificant. At the surface the ore is a little weathered but a few meters down it is almost unaffected. Traces of weathering, however, are found deep down. Thus carbonate veins at the 94 m level are weathered and 4 m deeper down some gabbro is also affected by weathering.

Bedrock of the Lainijaur Deposit

Sedimentary Rocks

The sedimentary rocks occurring around the Lainijaur Deposit and exposed in drill-holes and in the mine vary greatly from bed to bed both as regards grain-size and composition. As to the texture psephites, psammites and pelites can be distinguished. The acidity also varies but the most common chemical composition of the sediment corresponds with that of a quartz-diorite. The

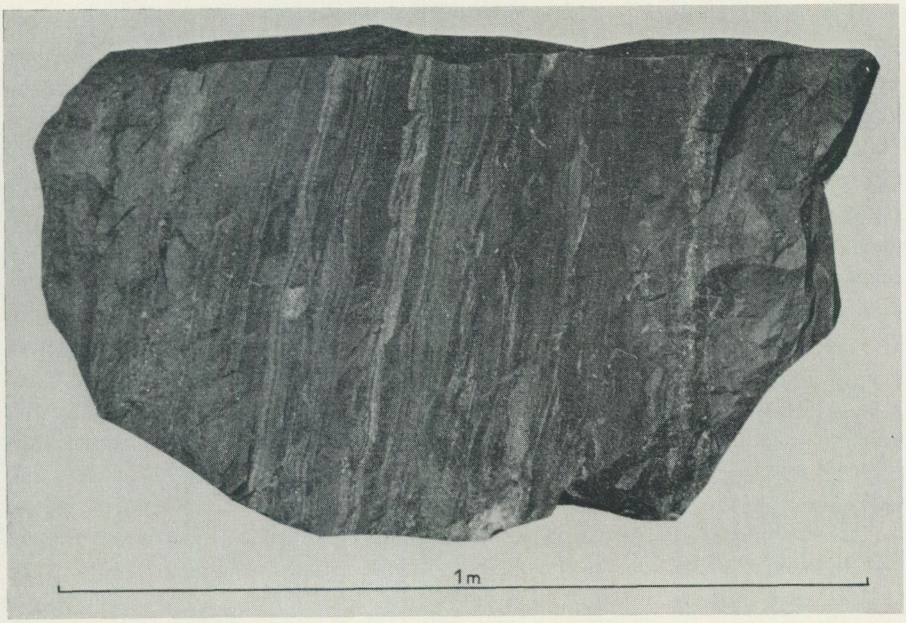


Fig. 4. Banded pelite.

metamorphism has given new mineral parageneses and most of the sediments at present can be classified as amphibolites. The sedimentary rocks are mostly more or less well banded. The banding is often sharpened by light-coloured layers rich in clinozoisite, epidote, diopside and garnet contrasting with the dark surroundings. Such layers indicate that the sediments have also had calcareous or marly beds (Fig. 4).

The inclined shaft between the 120 and 220 m levels runs in the strike direction of the sedimentary rocks and the dip is here about 30° SE. Between these levels the following stratigraphic series is exposed.

120—145 m level	Pelite with solitary layers rich in clinozoisite.
145—154 » »	Psammite, partly granitized.
154—158 » »	Psephite with pebbles of dacite and quartz-porphyry.
158—164 » »	Pelite, clinozoisite banded.
164—165 » »	Psammite-psephite,
165—171 » »	Pelite, clinozoisite banded.
171—190 » »	Strongly recrystallized sediments of dacitic composition.
190—212 » »	Sediments altered to amphibolite with very rare clinozoisite bands.
212—217 » »	Psephite with pebbles of dacite (dacite agglomerate).

The pelite continues higher up in the series but is there tectonically very disturbed and intruded by gabbro sills. High up in the phacolith occur schist relics sometimes with psephitic or psammitic layers.

Generally the deepest stratigraphic layers in the mine consist of coarser sediments while the grain-size decreases upwards.

Psephites and Psammites

In the inclined shaft the pebbles of the psephite are up to some cm in size and principally consist of amphibolitized dacite. In the dacite there are plagioclase phenocrysts of irregular shape. They are zoned and have an anorthite content varying between 30 and 70 % An. The matrix between the phenocrysts consists of quartz, plagioclase, biotite, chlorite, hornblende, calcite, some opaque minerals and titanite. The composition of the pebbles is dacitic and also the texture indicates that the original rock has been a dacite. Pebbles of quartz-porphyry have also been found but sparsely.

The matrix of the sediment principally has the same composition as that of the pebbles, but clinozoisite also occurs and in some layers clinozoisite-epidote is a dominant mineral. The dacitic composition of the pebbles as well as of the matrix indicates a volcanic origin for the coarse clastic rock. The rounded pebbles on the other hand bear evidense of water treatment. Probably the sediment is a water washed tuff-agglomerate.

At the 150 m level there occurs a psammite with angular fragments up to 5 mm of dacite with phenocrysts of basic plagioclase in a fine-grained matrix rich in chlorite. This rock is considered to be a resorted dacite tuff (cf. further under "granitization" p. 15).

Schists

In the banded schists it is not possible to see any primary grain textures. The banding is caused by varying percentages of quartz and dark minerals (Fig. 5). The analysis in Table III, Col. A shows the chemical composition of a fresh type of schist. This schist has a granoblastic texture and a grain-size of about 0.04 mm. The rock is very even-grained and consists of oligoclase showing

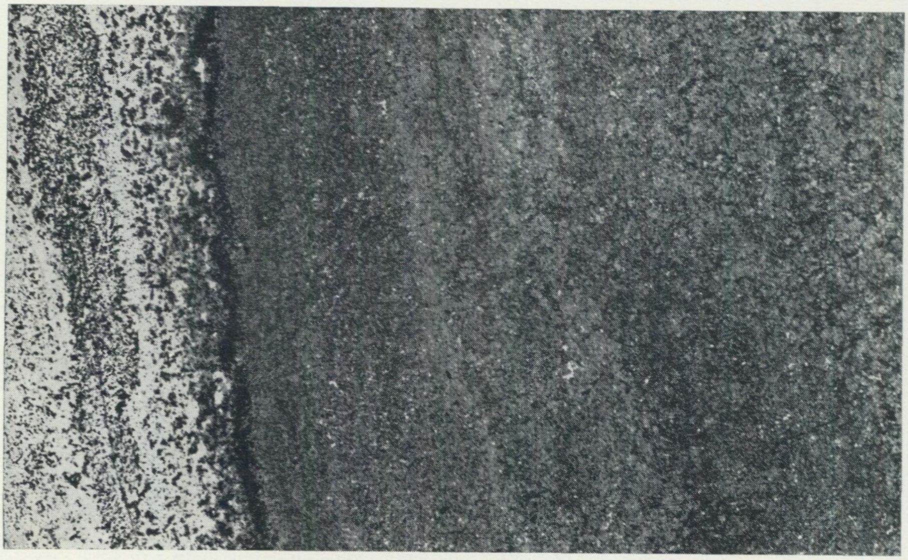


Fig. 5. Banded pelite in thin section. Scale 5 : 1.

traces of twin formation, biotite with pleochroism in straw-yellow and sepia, chlorite, quartz varying in quantity from layer to layer, sericite in small quantities, opaque minerals as a fine dissemination, some apatite and calcite often along fissures. The chemical composition of the schist is approximately dacitic and thus it seems to consist of volcanic material as do the coarser sediments.

Calcareous Schist and Lime Silicate Skarn

The schists in many cases are rich in lime and then often well banded (Fig. 4). In the parts strongly tectonized the calcareous beds sometime show a boudinage structure. In the calcareous beds always a more or less complete alteration with the development of lime-silicates has taken place. — Immediately below the 30 m level in Shaft I there occurs a fine-banded, calcareous schist, which may serve as an example of this sediment type. Dark and light, one or several mm thick bands alternate. The dark bands having a granoblastic texture with a grain size of about 0.1 mm consist of quartz, biotite, hornblende, chlorite and disseminated opaque minerals. The light-coloured, almost white bands are dominated by clinozoisite and to a lesser degree calcite and garnet, some quartz and accessory rutile. There is no dissemination of opaque minerals.

The thicker of the calcareous bands are often torn off and form lenses or "secretions" often with a zoned structure. The following example is taken from the head-drift at the 32 m level. The inner part of such a lens principally consists of clinozoisite accompanied by some calcite and chlorite. Outwards there is more and more grossularite of a red-yellow colour. The grossularite forms idiomorphic crystals a few mm in size. (The biggest garnet found in the mine is 20 mm in diameter). A spectrographic investigation of the grossularite shows Al, Ca, (Fe), Si (analyst Funke). The following determination of the grossularite was made by Frans E. Wickman: X-ray-investigation with a powder camera gave the unit cell edge $a_w = 11.80 \pm 0.01$ Å. The specific gravity was found to be $d_4^{20} = 3.615 \pm 0.005$. These figures correspond to a rather pure grossularite in Stillwell's diagram (Am.Min. 1927). — Around the white core with the red-yellow cover rich in garnet follows a light-green shell rich in diopside. The diopside forms idiomorphic crystalloblasts some mm in diameter and has the following optical properties: $2V\gamma = 58°$; $c: \gamma = 45°$ (determined on universal stage). The pleochroism is weak.

In the same band or lens the birefringence of the clinozoisite often varies and some crystals go over to epidote. Curiously enough zoisite (opt. $+$, $\varrho > v$) and epidote have also been found together. — Even wollastonite, but it is rarely found, belongs to this lime-silicate paragenesis.

Between extremely calcareous beds and quartzitic or amphibolitic beds there are all transition forms when clinozoisite-epidote and calcite on one side and quartz and amphibole-biotite-chlorite on the other occur in varying proportions. The light coloured clinozoisite-banded schists are found most abundantly in the vicinity of the gabbro contact, and here also the garnet and diopside occur. It has been stated that the cause of this fact is not only the primary composition of the schist, but also contributions from the gabbro (magma) and

Table I. Magnetite ore. Dh 8: 59.94—60.06 m. Lainijaur

	%	Calculated mineral composition	
TiO_2	0.06	Fe_3O_4	81
S	0.4	FeSAs	1.7
Cr	0.02	FeS	0.8
Mn	0.12	$FeTiO_3$	0.1
Fe	59.2	$FeCr_2O_4$	0.04
Ni	0.00		
As	0.27		

the ore (solutions). These have produced mineralizors in particular, but they may also have contributed some Ca and Mg. Lumps of garnet-zoisite-diopside skarn somtimes swim in nickel-pyrrhotite ore. The lumps often are well zoned. Clinozoisite-epidote-chlorite skarn sometimes occurs as a breccia cement and fissure-filling. Magnetite schlieren then also may occur as, for example, in dh 8. Here the magnetite is intermixed with arsenopyrite. Table I shows its chemical composition and a calculation of the mineral composition of this ore.

Amphibolitic Schists

Some of the schist beds are amphibolitic. The richness in amphibole sometimes depends upon metasomatic influence from ore and gabbro solutions, but in other cases upon the fact that the sediments here have had a primary composition, which has favoured the formation of amphibole. Such an amphibolite with a primary psammitic texture was found in a stope at about 100 m level. Its original grain-size has been up to 5 mm. The hornblende forms small porphyroblasts often surrounded by some biotite. These lie in a matrix of chlorite, calcite and small quantities of quartz and ore minerals.

In the peripheral parts of the sills protruding from the gabbro dike there is a diffuse transition from gabbro to schist. Both the gabbro and the schist are amphibolized and chloritized and ion exchanges have occurred between the two rock types.

Granitization Products

Psammitic beds of dacitic composition in several places have been recrystallized and received a texture similar to that of an intrusive rock. Where the alteration has been most intense a quartz-diorite has been formed. In many cases it has been mobile and is now found as secretions and veins in both the sedimentary rocks and the gabbro. On the 130 m level there is such a granitization in the psammites outside an ore apophysis from which chalcopyrite-bearing veins radiate, Fig. 6. Here the granitization is clearly connected with the ore and mineralizing solutions emanating from it. The rock has a quartz-dioritic composition and its panidiomorphic plagioclases have a composition of about An_{50}. They are about 1 mm in size and lie in a matrix of quartz, chlorite, calcite, biotite and ore minerals (Fig. 7).

At the 150 m level the sediments just below the ore and about 10 m down are more or less strong granitized. The different beds in the banded rock have

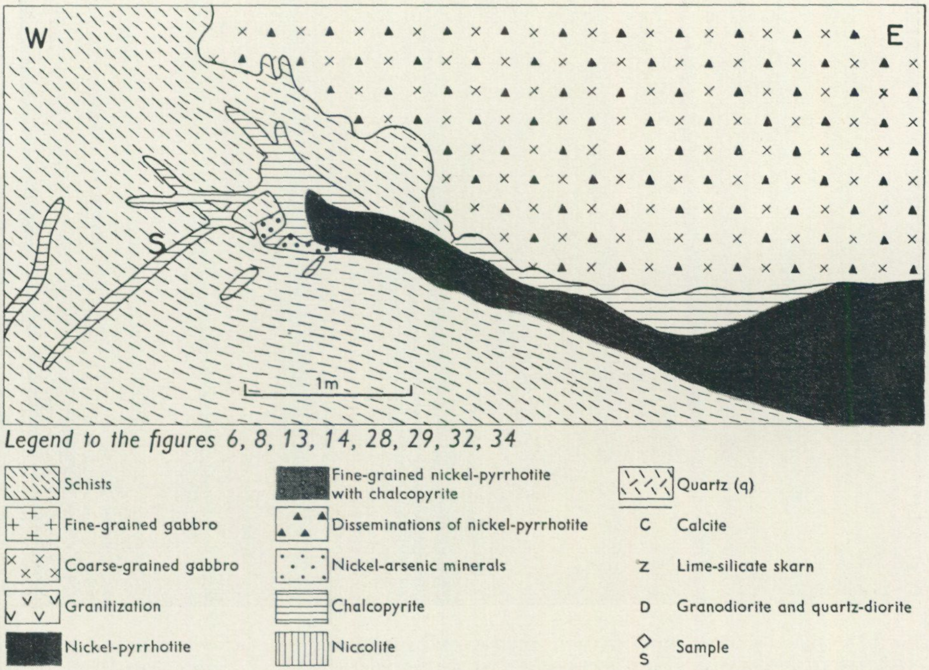


Fig. 6. Tapering nickel-pyrrhotite ore with gabbro in the hanging-wall and sedimentary rocks in the foot-wall. The massive ore towards the tip of the "finger" becomes rich in copper. Chalcopyrite together with some nickel-arsenic minerals are concentrated around it and radiate outwards in the form of veinlets. The schist around these veins is strongly granitized. Lainijaur, 130 m level. North wall of an adit farthest west. S = sample, see Fig. 7. E. Grip 1945.

been recrystallized in varying degrees dependent on their composition. Generally the composition here is dacitic and the sediments seem to consist of resorted dacitic tuffs and perhaps eroded lavas. Minor, detached remnants of bands rich in clinozoisite-epidote are found in the otherwise very slightly banded rock.

On the 150 m level there is a drift going from the ore contact to the east (cf. Pl. 4). In its walls the sedimentary rocks (dipping about 25° to the east) and their alteration products were well exposed and could be excellently studied (Fig. 8). The freshest of the microscopically investigated samples taken from here (S 112 in Fig. 8) has small angular fragments up to 5 mm in size with phenocrysts of basic plagioclase 2 mm in size lying in a fine grained matrix rich in chlorite. Other fragments consist of a fine felt of chlorite, uralite, biotite, plagioclase, quartz, calcite and disseminated ore minerals. The rock seems to be a resorted dacite tuff or dacitic sandstone (Fig. 9).

Another sample taken a few meters from the former (S 109 in Fig. 8) has a half granitic texture. Plagioclase with An_{40-78} forms rounded grains about 2 mm in size. The texture of the rock is shown in Fig. 10. Except for the plagioclase which is dominant biotite, chlorite, amphibole in sparse clusters, small amounts of quartz, apatite and ore minerals occur.

Fig. 7. Quartz-dioritic granitization product of psammite. Plagioclase crystals (An_{50}) with interstitial quartz. Thin section, + nicols. Scale 5: 1. 130 m level, 1 m W of the edge of an ore-body. See "S" in Fig. 6 (S 122).

A part a few meters from the former sample has been more granitized (S 110 in Fig. 8). The granitic texture is shown in Fig. 11. The grain size reaches 3.5 mm. The mineral composition is shown in Table II, Col. A. The plagioclase is sharply zoned and sometimes has albite in the outer shell while in the center the composition is An $_{55-60}$. Sericite and calcite occur as inclusions. The quartz is strongly undulatory. The biotite has a pleochroism of weak yellow and sepia. It forms individuals reaching more than 3 mm in size but they are to a large extent altered to a grey-green chlorite. Ore minerals occur as very fine disseminations, especially in chlorite and biotite.

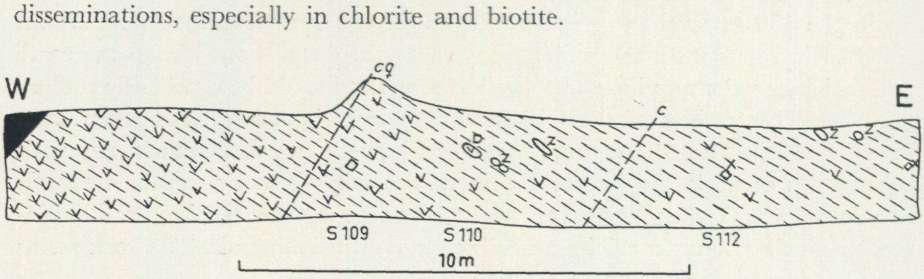


Fig. 8. Vertical section through psammites, partly granitized. The granitization process has extended from the ore in the west and decreases towards the east. In the middle part of the section the psammites are well banded having a dip of about 25° E. Here there is a secretion of granodiorite in a layer some dm farther down in the direction of dip containing clinozoisite lenses. Legend see Fig. 6. N-wall in a crossdrift east of the ore-bodies. 150 m level. Å. Wirstam 1945.

Fig. 9. Psammite, probably of dacite tuff origin. The angular fragments consist of altered dacite. + nicols. Scale 5: 1. 150 m level. Situation "S 112" in Fig. 8.

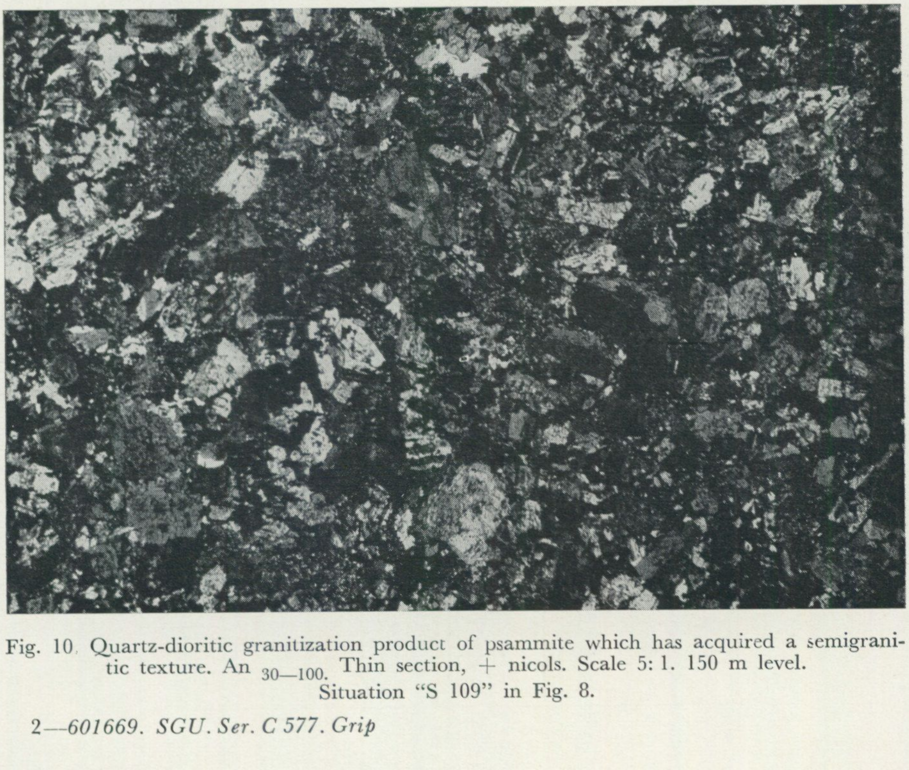


Fig. 10. Quartz-dioritic granitization product of psammite which has acquired a semigranitic texture. An $_{30-100}$. Thin section, + nicols. Scale 5: 1. 150 m level. Situation "S 109" in Fig. 8.

Fig. 11. Granite secretion in semi-granitized psammite. An $_{10-60}$. Cf Table II, Col. A. Thin section, + nicols. Scale 8: 1. 150 m level. Situation "S 110" in Fig. 3.

Another sample of a granitization product from about the 110 m level on the W side of the ore-body has a more alkalic composition and the plagioclase here is an albite. Table II, Col. B shows a volumetric analysis of this rock (see Fig. 12).

Quartz-dioritic secretions and veins have been found in several places in the mine, especially around the ore-bodies. Somewhere, e.g. below the eastern ore-body at the 10 m level, the quartz-diorite is rich in sulphide minerals crystallized at random in the vein. The fact that granitization products prefer the vicinity of an ore contact to the vicinity of a gabbro contact indicates that mineralizing solutions have emanated from ore solutions, but not or to a much less degree from the gabbro magma.

Table II. Volumetric analyses of granitization products: A, from the 150 m level and B, from the 110 m level in Lainijaur (% by vol.)

Component	A	B
Plagioclase	56	28
Microcline		27
Quartz	26	38
Biotite	4	3
Chlorite	5	
Sericite	3	1
Calcite	5	
Ore min. + apatite	1	1
Total	100	100

Fig. 12. Fine-grained alkali-granite developed by granitization of a psammite. Small veins of this granite are found in many places in the mine. Thin section, + nicols. Scale 8 : 1. Cf, Table II, Col. B. 110 m level.

The Origin of the Sedimentary Series

The microscopic investigation of the sedimentary series exposed in the mine indicates that both coarse and fine sediments are mainly composed of dacitic material. Bands of lime silicate skarn occur abundantly in the sediments at different levels and indicate that they were originally calcareous layers. The material of the sediments is well sorted and the sediments seem to have been formed by water sedimentation of volcanic material of dominantly dacitic composition. The sedimentary series of Lainijaur is very similar to that of the Mensträsk mine in which rock the ore-bodies occur (cf. Grip 1951) and it is probable that they belong to corresponding stratigraphic horizons. As exposures are extremely rare in the area betwen the two mines an accurate connection is not possible.

Intrusive Rocks

Gabbros

Along the bottom of the sediment syncline there is a gabbro dike intruded in a fracture running N 45° E and dipping about 55° NW. Upwards the gabbro spreads out as sills and finally as a phacolith. As shown in Fig. 3 the gabbro cuts the schists nearly perpendicular to their bedding. The cutting dike as well as the sills and the bottom of the phacolith have very sharp contacts against the schist and the contact metamorphism from the gabbro is very weak. Laterally from the phacolith, on the contrary, the limit of the gabbro is very diffuse and irregular, and relict fragments of strongly amphibolitized sedimentary rock indicate that a significant assimilation of these rocks has taken place.

Below, the gabbro dike, the gabbro sills and the gabbro phacolith will be described separately.

Gabbro Dike

The gabbro dike cutting the schists is 1.5—8 m thick. In the exposed parts the dike often tapers downwards and widens in its uppermost parts passing into the phacolith-shaped body (cf. Pl. 4). As mentioned before, the contacts against the host rock are mostly sharp even if the schist is a little influenced and amphibolitized. In the more amphibolitic beds of the sediments, however, it is often difficult to determine exactly the contact line.

Parallel with the contact between gabbro and schist there are more or less well developed slickensides along which movements have occurred in several directions and at several periods.

The intrusion along the fault-line has occurred in two or locally in three stages. Along the walls a fine-grained chilled margin of the gabbro is mainly found (cf. Fig. 13—14). This rock first intruded and crystallized has then been broken up, commonly in the middle part of the dike, and magma intruded again. By this, fragments of the fine-grained gabbro were also detached from the walls and enclosed in the magma. Such fine-grained fragments are found here and there in the younger, much more coarse-grained gabbro. A sample from the gabbro dike taken at the 100 m level shows under the microscope an ophitic texture with laths of plagioclase up to 4 mm long (Fig. 15—16) having the composition An_{42-67}. These laths lie in a matrix of biotite with γ light yellow, needles of hornblende with γ light blue, insignificant relics of pyroxene and lastly chlorite and calcite. The pentlandite-bearing pyrrhotite occurs as rich disseminations. Sometimes it is skeleton-shaped and then mostly

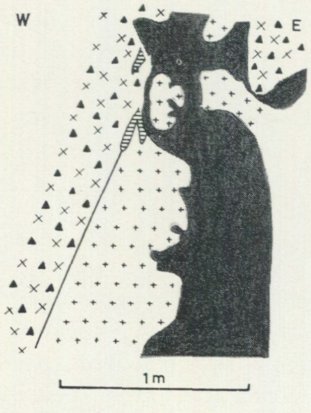


Fig. 13. Nickel-pyrrhotite ore cutting a contact between fine-grained gabbro and younger coarse-grained sulphide-disseminated gabbro. The ore replaces both gabbro types. As the latest crystallization copper and arsenic-nickel minerals occur. Legend see Fig. 6. About the 135 m level. E. Grip. 1943.

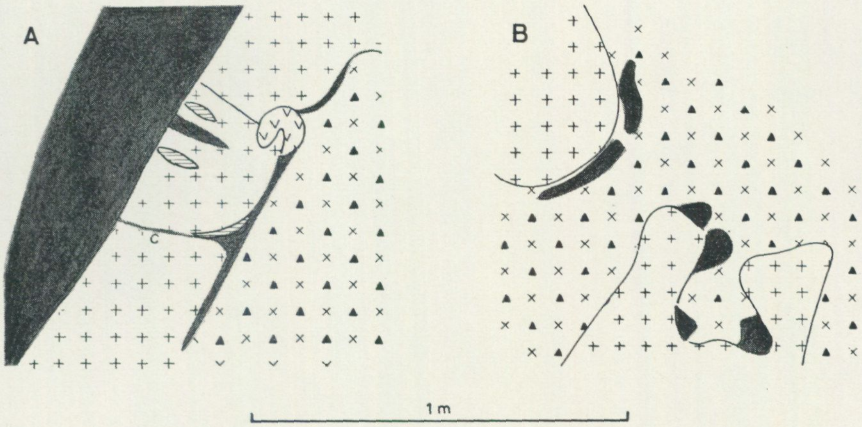


Fig. 14 A. A part of the western ore-body in contact with the gabbro dike nearest the ore consisting of older, fine-grained gabbro and further in, younger, more coarse-grained and rich sulphide-disseminated gabbro. From the ore-body apophyses containing pyrrhotite, chalcopyrite and calcite extend through the fine-grained gabbro to its contact with the coarse-grained gabbro, where the sulphides spread out along the contact plane. A granodiorite brecciating the older gabbro appears on the same contact plane and is connected by a fissure with the large ore-body. Legend see Fig. 6. About the 90 m level.
Fig. 14 B. The fine-granined gabbro of the dike is brecciated by the coarse-grained type. Along the contact there are sulphide accumulations. Location near fig. 14 A.
E. Grip 1945.

occurs together with biotite. — Another sample from the 150 m level has the same texture and composition. Needles of hornblende often penetrate the abundant pyrrhotite.

The fine-grained border type of the gabbro is often considerably poorer in pyrrhotite than the coarse-grained type.

Table IV. Col. A shows the volumetric composition of a fine-grained gabbro from the middle part of the dike on the 70 m level. The augite here is more or less strongly altered to hornblende.

Gabbro sills

The sills branching off from the gabbro dike have been especially observed between the 70 and 120 m levels. They have a thickness varying between 1 dm and 1—2 m. Most extend westwards from the gabbro dike and their appearance and connection with the dike is clearly illustrated by the sections Fig. 3 and Pl. 4.

The rock of the sills is the same as that of the border zones of the gabbro dike and like the latter it is not so rich in pyrrhotite as the coarse-grained dike type. In several places it also seems to be poorer in sulphides than the border zone. The gabbro of the sills is more amphibolitized than that of the dike and is often transformed into a real amphibolite difficult to distinguish from the amphibolitic wall rock.

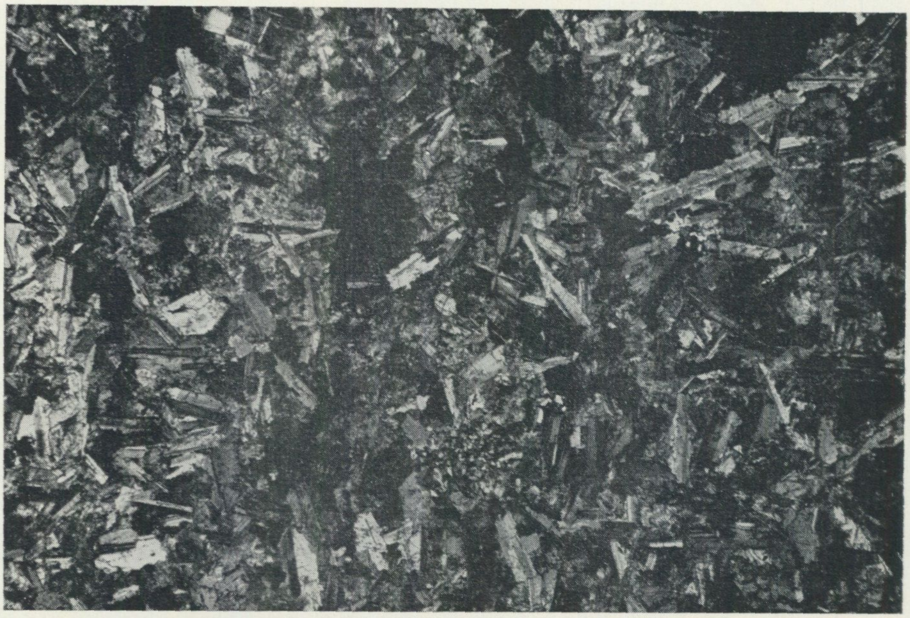


Fig. 15. Fine-grained gabbro richly sulphide-disseminated (22 %) (cf. Table IV, Col. B) from a point, where the gabbro dike spreads out to form the phacolith. Thin section. + nicols. Scale 9: 1. Stope in 62 m level.

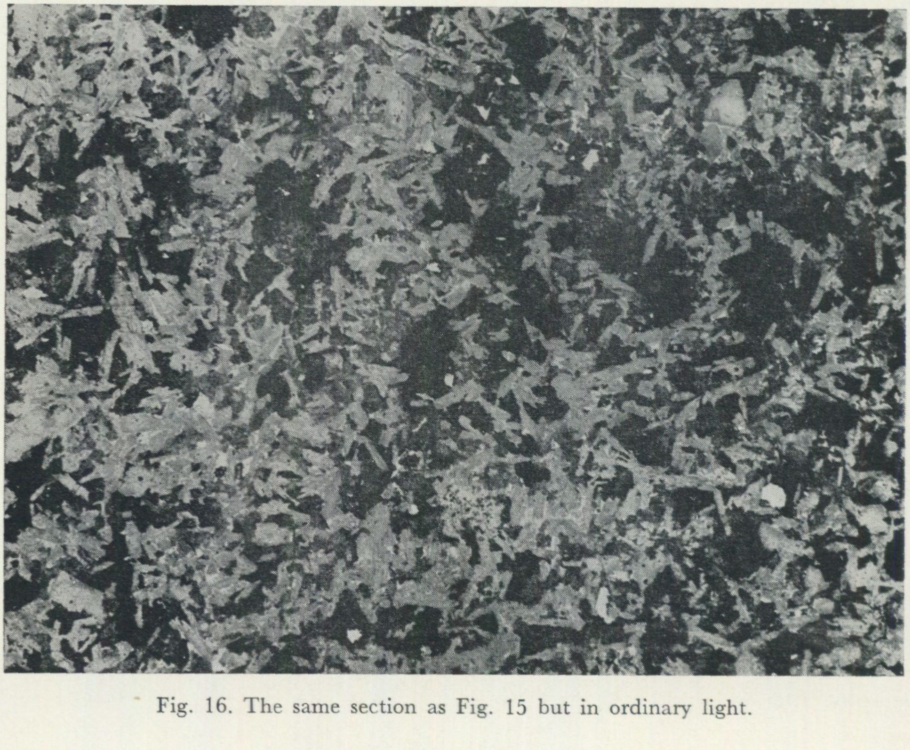


Fig. 16. The same section as Fig. 15 but in ordinary light.

Gabbro Phacolith

From the feeding channel in the synclinal trough and about 100 m outwards on both sides the gabbro is conformably intruded into the sediments. On both sides, however, the intrusion is limited by wedges and fragments of schist which are more or less strongly assimilated.

Vertically the gabbro is very variable in composition and appearance just because of the presence of these schist remnants (Fig. 3). The medium-grained olivine-gabbro here changes into fine-grained amphibolite, sometimes with relict sedimentary structures. In the upper part of the intrusion there occur several zones with a very coarse-grained gabbro while the grain-size between them may be the normal one. Towards the foot-wall the gabbro becomes more fine-grained and drop-formed accumulations of pyrrhotite appear (Fig. 17).

A pure and relatively fresh part of the gabbro lying at a depth of 11—14 m from the surface and 46—49 m above the ore horizon in dh 9 (cf. Fig. 3) has been analysed. Table III B shows the chemical composition of this gabbro

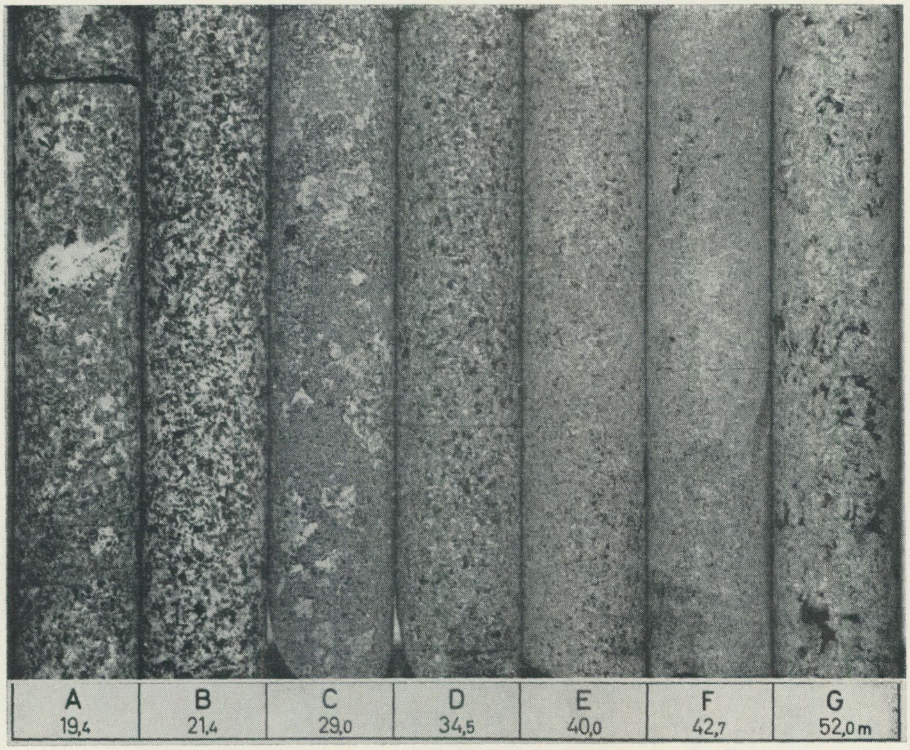


Fig. 17. Sections of 36 mm drill-cores from Lainijaur drill-hole No 30 showing varying textures. A. Coarse-grained quartz-diorite. B. Medium-grained quartz-diorite richly disseminated by nickel-pyrrhotite. C. Fine-grained quartz-diorite with plenty of inclusions of sedimentary rock fragments. D. Medium-grained diorite richly disseminated by nickel-pyrrhotite. E. Medium-grained chlorite-plagioclase schist. F. Medium-grained gabbro with amphibolite remains. G. Medium grained gabbro richly disseminated by nickel-pyrrhotite.

Table III. Chemical analyses of rocks from Lainijaur

Component	A		B		C	
	%	Mol. prop.	%	Mol. prop.	%	Mol, prop.
SiO_2	72.53	12 076	45.92	7 646	61.99	10 321
Al_2O_3	11.65	1 143	14.63	1 435	14.54	1 426
Fe_2O_3	0.38	24	6.12	383	0.72	45
FeO	4.57	636	6.74	938	7.98	1 111
MnO	0.06	9	0.16	23	0.11	16
MgO	1.79	444	11.15	2 765	1.17	290
CaO	4.17	744	7.10	1 266	4.57	815
SrO	0.009	1	0.044			
BaO	< 0.01		0.05	35	< 0.01	
Na_2O	1.02	165	2.43	392	3.86	623
K_2O	1.29	137	1.39	148	1.94	206
$H_2O < 105°$	0.10		0.12		0.04	
$H_2O > 105°$	1.02	566	2.10		0.62	
CO_2	0.41	93	0.29	66	0.36	82
TiO_2	0.90	113	0.75	94	1.29	202
ZrO_2	< 0.01					
P_2O_5	0.08	6	0.16	11	0.39	28
C	0.00					
F	0.03	16	0.00		0.08	42
Cl	0.02	6	0.00			
S	0.14	44	1.02	318	0.04	13
SO_3	0.03	4				
V			0.01			
Fe	0.18	32				
Co			0.03		< 0.001	
Ni			0.135	23	0.001	
Cu	0.003	1	0.19	30		
Zn			0.08	12		
As	< 0.002		0.14		0.02	3
Ag			0.0002			
Au			0.00002			
Pb			0.001			
Total	100.38		100.705		99.732	

Niggli values	A	B	C
Si	363	99	226
al	34.4	18.5	31
fm	34.2	58	33
c	22.4	16.5	18
alk	9.1	7	18
ti	3.4	1.2	4.4
p	0.2	0.1	0.6
mg	0.39	0.61	0.19
k	0.45	0.28	0.25

A. Slate. 70 m level. NE-wall, X 1 030, Y 1 007. Analyst: Th. Berggren.
B. Gabbro. Dh 9: 11—14 m. » B. Helger.
C. Granodiorite. Dh 47: 37.6—40,7 m. » Th. Berggren.

while Table IV, Col. D, shows its mineral composition and Fig. 18 its texture. The plagioclase forms laths up to 4 mm long which are fresh and beautifully zoned. Their composition is An_{55-67}. Except for some accessories, the plagioclases are the earliest crystallization products and between them occur large

Fig. 18. Medium-grained gabbro. Lainijaur drill-hole 9, 11—14 m. + nicols. Scale about 5 : 1. Cf. analysis Table III B.

individuals of augite partly altered to hornblende, biotite and relatively large grains of pyrrhotite. The augite only preserved in small amounts has 2 Vγ = ca 60° and c : γ = ca 60°. Its alteration product, the hornblende, forms large and small grains with c : γ = 27° and a blue-green pleochroism. The biotite is sepia coloured and has a hexagonal net work of rutile needles. In addition to hornblende and biotite occur serpentine and chlorite and fine-grained ore minerals in the substance replacing the pyroxene. The same mineral association partly also attacks the plagioclase along margins and cracks. The ore minerals in the fine-grained mass consist of irregular grains of magnetite, ilmenite, pentlandite-bearing pyrrhotite and, crystallizing last, chalcopyrite. A few idiomorphic crystals of chloantite and some sphalerite have also been observed. Pyrite is found along a fissure in pyrrhotite. The silicate minerals are disseminated with very fine-grained sulphide minerals.

Another gabbro type occurring 13.55 m down in dh 2, 22 m above the ore horizon, consists of an olivine-gabbro with plagioclase An_{40-70}. The plagioclase is fresh except for a weak sericitization along cracks. The olivine has 2 V_α = 86° corresponding to 24 % $FeSiO_4$ and 76 % $MgSiO_4$. Fine inclusions of ore minerals occur with a regular orientation along crystal faces.

Table IV. Volumetric analyses of gabbro from Lainijaur (% by vol.)

Component	A	B	C	D
Plagioclase	39	45	64	41
Augite	17	13	18	6
Olivine			8	
Ore min.	2	17	3	2
Biotite	7	3	2	1
Hornblende	31	18	1	46
Quartz		1	1	
Serpentine			3	
Chlorite	4	2		
Talc		1		4
Calcite				
Apatite		1		
Total	100	101	100	100
% An in plagioclase	32—52	25—50	40—70	55—67

A. Fine-grained gabbro from the centre part of the dike. Drift in the 70 m level. X 1 006 Y 1 103 (sample nr 72).

B. Fine-grained gabbro with a rich sulphide dessemination from a point where the gabbro dike spreads out to form the phacolith. Stope in the 62 m level. X 1 005 Y 1 105 (sample nr 74).

C. Medium-grained olivine-gabbro about 15 m up in the phacolith. Drill-hole nr 2: 13.35 m.

D. Medium-grained gabbro about 45 m up in the phacolith body. Drill-hole nr 9: 11—14 m, cf. table III.

Along cracks and margins the olivine is altered to serpentine, actinolite, quartz and calcite. The pyroxene has 2 $V\gamma = 40°—51°$ and $c:\gamma = 31°—46°$ and consequently is an augite. The augite is more or less altered to uralite

Fig. 19. Medium-grained olivine-gabbro, exceptionally fresh. + nicols. Scale 9:1. Dh 26. 61.8 m.

and biotite. Relics of orthorhombic pyroxene are found in pseudomorphs, but the main part of these consists of an actinolitic hornblende. The biotite has a pleochroism in light yellow and sepia and is corroded. Chlorite also occurs as an alteration mineral. A volumetric analysis of this rock gives the figures shown in Table IV, Col. C (cf. also Fig. 19). — Between the plagioclase laths there is often a fine-grained matrix of chlorite, serpentine and ore minerals which is at least partly of secondary formation. This substance commonly spreads out spherically from a centre and attacks plagioclase, pyroxene, olivine and biotite in the vicinity. The biotite forms an intermediate stage beween pyroxene and chlorite in the alteration process.

Quartz-Diorite and Granite

By diamond drillings from the surface to the deeper part of the ore it is established that a quartz-diorite follows above the gabbro, the contact being mainly parallel to the lower contact plane of the gabbro and to the bedding of the sediments. From Pls. 2—3 it is clear that the quartz-diorite, which in the upper parts passes into a granodiorite, is at least 90 m thick. Even examination with the naked eye shows that the grey, even-grained rock becomes a little darker downwards and the content of quartz decreases.

To a still higher degree than the gabbro the quartz-diorite is mixed up with fragments of sedimentary rocks often with diffuse contacts and assimilated in varying degrees (cf. Fig. 17). The dark fragments have sharper contacts than the lighter ones which indicate a better resistance to assimilation. Among the fragments lime-silicate skarn is often found also. The sediments here must have made a considerable contribution of material to the present quartz-diorite.

The contact with the underlying gabbro is never sharp but there is a transition zone of about one meter. It has not been possible to determine the age relation between the two rocks in the drill-cores traversing the contact zone and no other exposure of this zone exists in the mine.

The grain-size of the quartz-diorite is about 5 mm but it is very variable and locally coarse-grained types occur as in the upper part of dh 30. Among the minerals the lath-formed and zoned plagioclase dominates. Its core has a composition of An_{55} while the outer part only has An_{10-20}. The anorthite-rich core of the plagioclase appearently has been still richer in lime before as it is always saussuritized.

In its most upper parts the quartz-diorite becomes richer in quartz and here chess-board albite and microcline in small grains appear in the latest crystallized fraction together with quartz. A micropegmatitic texture formed by quartz and alkali feldspar grown together is not uncommon and such a rock may be classified as a granodiorite. (See Table III, Col. C.)

Among the dark minerals, biotite and hornblende occur in about equivalent amounts. The biotite has a pleochroism from straw-yellow to dark brown. Pleochroic halos are very well developed around small grains of zircon. To a great extent the biotite forms an alteration product of hornblende or has crystallized farther out from this mineral.

The hornblende forms irregular grains commonly with notched margins and has the pleochroism α light green, β dark green, γ blue-green. In the quartz-diorite lying nearest the gabbro the hornblende sometimes has relict pyroxene in the core.

Together with the biotite and hornblende occur small grains of ore minerals, e.g. pyrrhotite, arsenopyrite, magnetite, apatite and titanite. In a few slides epidote has been found preferably occurring together with calcite.

Table III, Col. C shows a chemical analysis of the granodiorite. The sample analysed is taken from a drill-core high up in the bed about 93 m above the gabbro contact. As emphasized before the granodiorite cannot be regarded as a real differentiation product. The structure in the drill-cores show that considerable amounts of older rocks, probably sediments have been assimilated and then they have given their chemical character to the end product. Under the microscope the continual transition from fine-grained sedimentary textures to even-grained granitic can be studied. It is convenient to compare the granodiorite with the granitization products of the sediments described on page 14. A similar mode of formation cannot be excluded. The present pyroxene, however, indicates a contribution from a basic magma.

A vertical drill-hole (dh 72) 430 m N 30° E of the outcrop of the ore body (cf. Fig. 3), that is, in the direction of plunge, has exposed a rock related to the quartz-diorite but more granitic. The exposure is calculated to lie about 200 m above the gabbro contact provided that the dip of the latter continues uniformly so far in this direction. The texture of this rock is granitic and the grain size about 3 mm. The mineral composition is 35 % plagioclase (An_{20-42}), 7 % microcline, 33 % quartz, 20 % biotite, 5 % hornblende and accessory minerals. Micropegmatitic spots are common.

This occurrence indicates that the quartz-diorite passes upwards into granite. Whether this granite is then directly connected with the Adak granite the margin zone of which is exposed in a drill-hole (dh 71) about 1 km to the NW, is still uncertain. The granite here is developed as a hybrid type with perthite eyes.

Nickel Ores

The gabbro in both the long, cross-cutting dike and in its overlying parts is disseminated with nickel-bearing pyrrhotite and in some cases the disseminations are rich enough to form ore. The *disseminated ore* is the oldest mineralization of the deposit and is therefore designated as a special ore type.

The dominating ore type in the Lainijaur deposit, however, consists of pyrrhotite containing pentlandite and minor amounts of chalcopyrite and other ore minerals. The *nickel-pyrrhotite ore* contains abundant fragments of the wall-rock and generally may be characterized as an ore-breccia.

Younger than this nickel-pyrrhotite ore is a complex type of vein ore which may be called *nickel-arsenic ore*. Quantitatively it is inferior to the former, but on account of its high nickel content has played a significant role in the nickel production. It appears in connection with the nickel-pyrrhotite ore, but is sometimes found as small veins far out from this ore type.

Disseminated Ore

As mentioned before (p. 20) the gabbro in the dike cutting the schists is partly a fine-grained older type (sometimes in two or three generations) and occurring along the walls of this dike and in the sills going out from it into the schist; partly a coarser type forming the middle part of the dike and the phacolith body. The fine-grained type has only a weak sulphide dissemination for the most part, but is a little richer in the middle parts of the sills. The coarser gabbro, on the other hand, has generally a richer dissemination. The dissemination is richest in the dike and in the central part of the phacolith. Immediately above the solid ore a considerable percentage of sulphides is sometimes found (Fig. 20). In the lower parts, the nickel-pyrrhotite is relatively

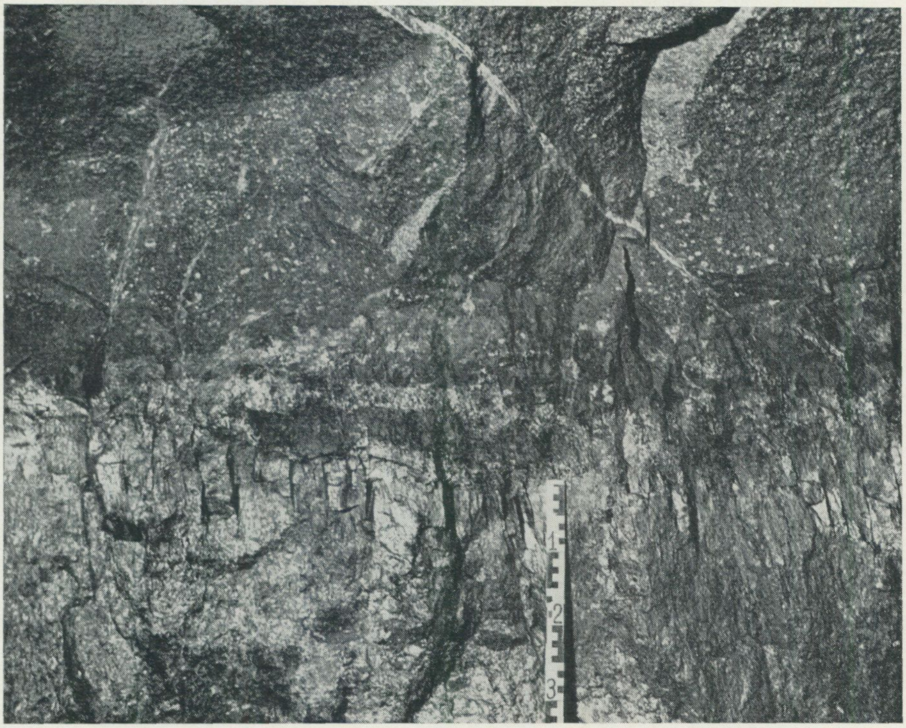


Fig. 20. The lower half of the picture consists of nickel-pyrrhotite ore lying below a hanging-wall of disseminated gabbro. The vein going through the gabbro obliquely down to the right contains nickel-arsenic minerals, chalcopyrite, quartz and carbonate. At the 150 m level, about 20 m W of the rise.

Fig. 21. Gabbro with schlieren and drops of nickel-pyrrhotite and chalcopyrite. From the phacolith.

regular and finely dispersed. Upwards, however, it passes into drop-formed and still sparser occurring accumulations while at the same time the content of sulphide in the gabbro decreases. Some meters up in the phacolith there occur scattered drop-formed accumulations of nickel-pyrrhotite reaching a size of 10 cm. (See Fig. 21.) The content of sulphides also decreases towards the margins of the gabbro phacolith, where flaps and partly assimilated remains of schist occur (cf. Fig. 3). As a matter of fact drill-hole No 9 cuts the whole gabbro phacolith. Table V shows analyses of 3-meter sections of this drill-core and also the average percentages in the intersected gabbro. The highest sulphide percentages occur towards the schist of the foot-wall. Dh 8 lying in the peripheral part of the phacolith has very low percentages of sulphides except in a bottom section where it is higher. Here, however, the percentage of nickel is remarkably low. (See Table V.) In the same table analyses of a few sections in dh 31 immediately above the solid ore are included.

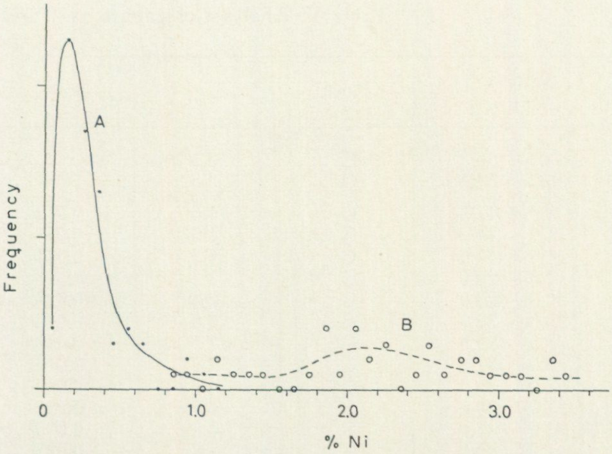


Fig. 22. Frequency distribution of nickel in the Lainijaur Deposit, A in disseminated gabbro (76 analyses) and B in massive nickel-pyrrhotite ore (38 analyses). In the frequency diagrams Figs. 22, 23, 24, 26, and 27, the points and small circles respectively represent the number of analyses of the groups marked on the horizontal axis, and they also mark the mean value within each group. The curves connect the points and circles in idealized shapes. For calculation of the tops and tendencies of the curves, groups displaced half a step have been used.

The sulphide percentage here is about the same as in the bottom section of dh 8, but the content of nickel is considerably higher. A still higher nickel percentage is shown by the gabbro lying above the solid ore in dh 40 (Table V). Higher up in this drill-hole there occurs a partly assimilated schist and the intrusion is of the sill type. Dh 20 has a still higher nickel percentage. A type sample from the middle part of the gabbro dike at the 150 m level contains about 50 % sulphide minerals. Among these pyrrhotite with enclosed strings and grains of pentlandite dominates. Chalcopyrite represents the latest crystallization. Under the microscope the gabbro is found to have a lath-shaped plagioclase with An_{48-57}, remains of pyroxene, light brown biotite and radiating hornblende with γ weak blue forming a felt-like matrix in which chlorite also appears. The hornblende needles sometimes penetrate the pyrrhotite, which often forms peculiar hexahedric skeleton net-works.

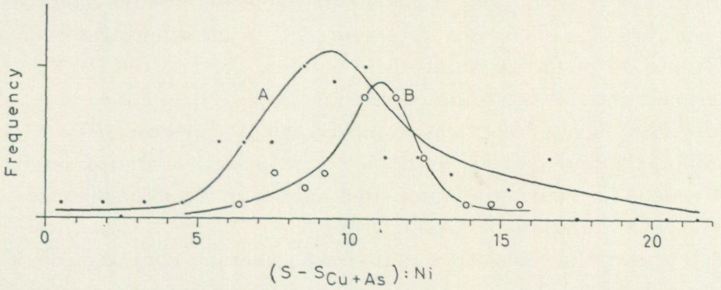


Fig. 23. Frequency distribution of $(S—S_{Cu+As})$: Ni ratios. A in disseminated gabbro (73 analyses) and B in nickel-pyrrhotite ore (32 analyses). S_{Cu+As} means sulphur combined with chalcopyrite and arsenic minerals.

Table V. Analyses of gabbro (G) and sediments (S)

Dh nr	Section m	Rock	S, %	Co, %	Ni, %
8	44.0— 56.7	G	0.3		0.02
8	56.7— 57.5	G	3.8		0.09
9	8.0— 11.0	G	1.0	0.012	0.16
9	11.0— 14.0	G	1.02	0.03	0.135
9	14.0— 17.0	G	1.9	0.021	0.14
9	17.0— 20.0	G	2.2	0.012	0.14
9	20.0— 23.0	G	2.6	0.014	0.15
9	23.0— 26.0	G	2.6	0.014	0.15
9	26.0— 29.0	G	2.1	0.012	0.13
9	29.0— 32.0	G	2.2	0.012	0.11
9	32.0— 35.0	G	1.5	0.018	0.17
9	35.0— 38.0	G	0.7	0.007	0.09
9	38.0— 41.0	G	0.8	0.008	0.05
9	41·0— 44.0	G	2.8	0.022	0.24
9	44.0— 47.0	G	2.7	0.016	0.17
9	47.0— 50.0	G	2.0	0.021	0.19
9	50.0— 53.0	G	3.1	0.021	0.26
9	53.0— 56.1	G	2.9	0.022	0.25
9	56.1— 59.2	S	1.5	0.016	0.12
9	59.2— 59.7	S	13.0	0.030	0.72
9	59.7— 60.2	S	0.3	0.001	0.00
9	60.2— 60.6	S	15.8	0.004	0.75
9	60·6— 64.1	S	0.5	0.005	0.00
9	8.0— 56.1	G	2.0	0.016	0.16
Do	Sulph. phase		38	0.3	3.0
20	51.8— 52.4	G	16.5	0.020	1.82
31	91.7— 93.5	G	2.2	0.019	0.22
31	93.5— 94.3	G	4.4	0.014	0.36
31	94.3— 95.9	G	20.3	0.080	1.83
40	135.0—138.1	G	6.0	0.33	0.66
40	138.1—139.3	G	3.0	0.013	0.37
40	139.3—141.0	G	11.4	0.031	0.98
40	141.0—142.9	G	35.7	0.087	3.31
40	145.9—146.1	G	25.6	0.062	2.25

Note. After deducting S for $CuFeS_2$ and ZnS, the remaining S has been calculated as enter-

The frequency distribution of nickel in the disseminated gabbro is shown in diagram Fig. 22. There is a pronounced concentration around a mode of 0.2 % Ni and 56 of the 76 analyses lie between 0.1 and 0.4 % Ni.

In the lower part of the sulphide-bearing gabbro magnetite lumps of varying size occur. The biggest lump was found at the 105 m level. It was more than 1 m in diameter and had an irregular shape a little flattened out parallel to the foot-wall. This magnetite lump had plenty of small inclusions of gabbro and a rich dissemination of arsenopyrite.

Table V shows that the disseminated ore generally contains cobalt percentages, in dh 9 being about 1/10 of the nickel percentages and in the other drill-holes still lower. The cobalt seems to be principally bound in cobaltite. — A certain amount of zinc is also striking. In 32 analyses of sections from four

with disseminated nickel-pyrrhotite in drill-cores from Lainijaur

Cu, %	Zn, %	As, %	$\frac{\mathrm{Ni}}{\mathrm{Cu}}$	$\frac{\mathrm{Ni}}{\mathrm{Co}}$	FeS + (NiFe)S	$\frac{100\ \mathrm{Ni}}{\mathrm{FeS} + \mathrm{FeNiS}}$
0.14	0.002		1.1	13	2.3	7.0
0.19	0.08	0.14	0.7	5	2.0	6.6
0.21	0.018		0.7	7	4.4	3.2
0.26	0.18		0.5	12	4.9	2.9
0.32	0.008		0.5	11	6.0	2.5
0.28	0.005		0.5	11	6.1	2.5
0.21	0.006		0.6	11	5.0	2.6
0.16	0.002		0.7	9	5.4	2.0
0.09	0.014		1.9	9	3.7	4.6
0.05	0.006		1.8	13	1.7	5.3
0.05	0.006		1.0	6	1.9	2.6
0.23	0.002		1.0	11	6.8	3.5
0.23	0.018		0.7	11	6.5	2.6
0.10	0.051		1.9	9	4.9	3.9
0.20	0.39		1.3	12	7.1	3.7
0.21	0.087		1.2	11	7.0	3.6
0.11	0.018		1.1	8	3.6	3.3
0.74	0.014		1.0	24	32.3	2.2
0.03	0.015				0.7	0
0.30	0.010		2.5	188	40.9	1.8
0.07	0.053				1.0	0
0.18	0.05		0.9	10	4.7	3.4
3.4	0.95		0.9	10	9.0	3.4
0.33	0.05		5.5	91	42.3	4.3
0.02	0.19		11.0	12	5.5	4.0
0.34	0.013		1.0	26	10.6	3.4
0.60	0.15		3.1	23	51.6	3.5
0.53	0.007	0.01	1.3	20	14.4	4.6
0.24	0.085	0.01	1.5	28	7.1	5.2
1.12	0.050	0.02	0.9	32	27.0	3.6
0.52	0.041	0.00	6.2	38	92.5	3.6
0.24	0.14	0.00	9.4	36	66.7	3.4

ing into nickel-pyrrhotite with 38 % S.

drill-holes the zink grade is 0.002—0.39 % averaging 0.064 % Zn (cf. Table V).

In order to be able to study and review the large item of chemical analyses I have compiled some diagrams showing the frequency distribution of the ratios between different elements in the disseminated gabbro and in the massive ore (Figs. 23—27). Practically all the analyses cited are made on drill-core samples, taken from 20 drill-holes through the phacolith (these holes are all indicated on the map Fig. 3). The lengths of the drill-core samples vary, but most are of 2—3 m. As the samples are well spread through the phacolith the analyses give a good picture of the distribution of certain elements in the disseminated gabbro and of the variations of their percentages.

The frequency distribution of the sulphur : nickel ratios is shown in Fig.

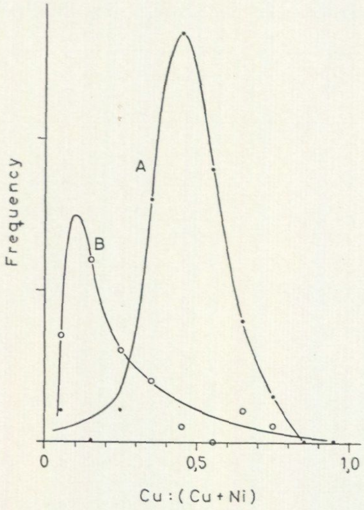


Fig. 24. Frequency distribution of copper : nickel ratios, A in disseminated gabbro (77 analyses) and B in nickel-pyrrhotite ore (33 analyses).

23. To get the right relations between sulphur and nickel entering into pyrrhotite and pentlandite the sulphur bound to chalcopyrite and arsenopyrite has been subtracted from the sulphur given in the analyses. The distribution is

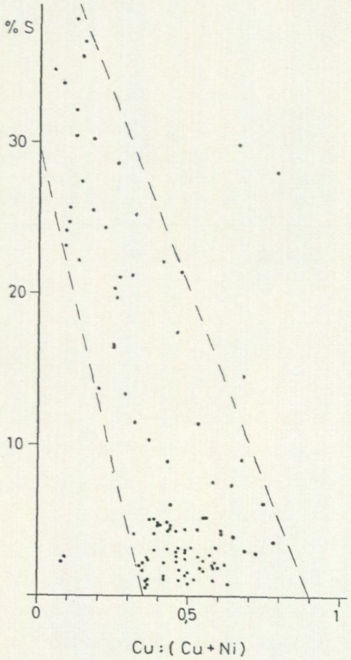


Fig. 25. Relation between sulphur and the ratios Cu : (Cu + Ni) in disseminated gabbro and nickel-pyrrhotite ore (106 analyses).

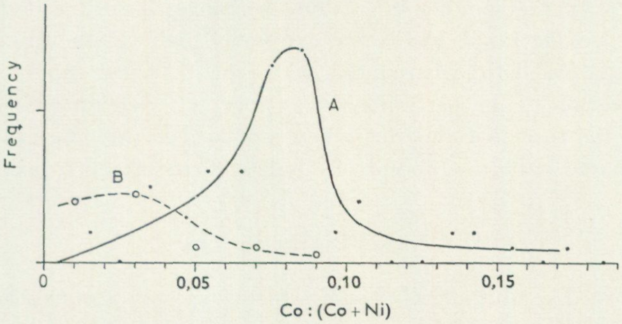


Fig. 26. Frequency distribution of Co : (Co + Ni) ratios, A in disseminated gabbro (61 analyses) and B in massive nickel-pyrrhotite ore (23 analyses).

rather widespread between 5 and 20 but clearly concentrated around a mode of 9.3.

The frequency curve for the copper : nickel ratios forms a very nice and regular picture shown in Fig. 24. The distribution is concentrated between narrow limits about a mode of 4.5.

Fig. 25 shows the influence of the sulphur percentage on the ratio Cu : (Cu + Ni). Here also analyses of massive ore have been plotted in the diagram. Practically all the analyses are distributed along a narrow belt and the diagram clearly shows the increasing copper : nickel ratio with decreasing percentage of sulphur. Thus the massive nickel-pyrrhotite ore has a copper : nickel ratio only half that of the disseminated ore. In the latter it is most usual with 1—5 % sulphur and equal amounts of copper and nickel.

The cobalt : nickel ratio is given in Fig. 26. In the disseminated gabbro the distribution is concentrated around a mode of 0.08 Co : (Ni + Co) but is not so sharply limited.

The distribution of zinc in the disseminated gabbro is illustrated by the diagram Fig. 27, where there is a high concentration around a mode of 40

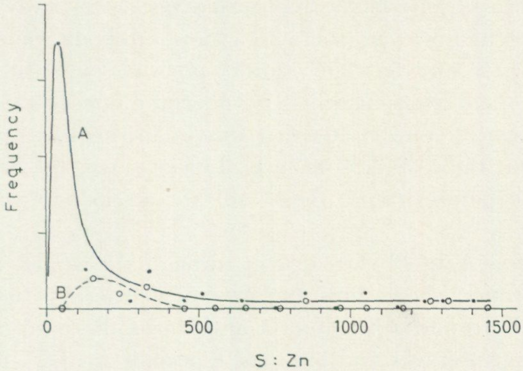


Fig. 27. Frequency distribution of S : Zn ratios, A in disseminated gabbro (58 analyses) and B in massive nickel-pyrrhotite ore (15 analyses).

S : Zn. 48 % of the samples lie within the range 0—100 and the others are spread over a wide range with some extremely high values. In other sulphide deposits in the Skellefte District the percentage of zinc usually occurs in reversed proportion to the percentage of copper (cf. Gavelin 1943). This, however, is not the case in Lainijaur, where on the contrary the grade of zinc in the disseminated gabbro is completely independent of the copper grade.

Nickel-Pyrrhotite Ore

The gabbro dike cuts the foot-wall schists, expands upwards and forms the hanging-wall of the ore-bodies running like a backbone through the whole ore deposit (see Fig. 3 and Pl. 1). On both sides of this gabbro dike, in the contact zone between gabbro and underlying sedimentary rocks, there are two linear shaped ore-bodies consisting of nearly compact nickeliferous pyrrhotite. The contacts of the two ore-bodies are sharp against the gabbro dike and this is emphasized by slicken-sides along fault-lines. On the other hand, the contacts with the hanging-walls and foot-walls are very irregular because of strong brecciation there, about which more below.

The *eastern ore-body* is in its most upper or southern part spread out like a thin sheet (cf. Pls. 1 and 4). Even at about the 30 m level it is compressed to half its breadth and downwards becomes still narrower. Eastwards the ore-body becomes gradually thinner and tapers out into a breccia ore with a sulphide content decreasing outwards.

In the direction of plunge the ore-body gently undulates (see Pl. 3) and generally follows the bedding plane of the sediments, even when these are wavy as on the 20—30 m level. In some places, however, there are divergences. From the 70 m level and down to the 150 m level the sediments show structures caused by compression in the direction of plunge and resulting in an imbrication structure. The ore-body follows these flatter structures and is e.g. on the 70 m level, split up into a couple of branches which follow the bedding planes. At the 100 m level the ore-body flattens out and terminates at the same time as a part of the foot-wall schist fades away into the gabbro. 10 m deeper down, however, there is a new ore-body en echelon, but this only forms a narrow and flat lens rapidly tapering out. Still 10 m down, on the 125 m level, there is ore again. It is wider and concentrated in the general direction of plunge in spite of its lying discordant against the bedding of the sediments at about the 140—150 m level. Lower down, the ore is incompletely known, but the exposures found there indicate an unchanged style at least to the 185 m level.

The cross-section A in Pl. 4 is drawn through the upper, wide part of the ore-body. The section shows how the ore-body generally follows the contact zone between gabbro and schist, but it also shows the tendency of the ore to appear as a filling in cracks and breccias, especially in the schist, and how the ore contacts cut the bedding.

Section B in Pl. 4, a cross-section 10 m north of the former, shows quite another shape to the ore-body, which here is compressed from a wide sheet to a narrow body of irregular cross-section. Here we see the sharp contact lines of the schist and the ore against the gabbro dike. From the ore-body a long apophysis goes out into the gabbro roof which is here richly disseminated with nickel-pyrrhotite. In the schist a couple of separate small ore-bodies appear, one of them along a fault plane.

Section C, Pl. 4, 30 m farther to the north, shows the ore-body to be still smaller than in the previous section and very irregular.

Section D, Pl. 4, is from the 95 m level, 30 m from the end of the upper part of the linear shaped ore-body. The ore-body here has quite a simple shape. It is noteworthy that the ore is only connected with the gabbro dike by a narrow apophysis.

In the section E, Pl. 4, drawn through a swell of the lower elongated ore-body the shape is irregular. The ore borders the gabbro dike and has gabbro in the hanging-wall. Here inclusions of gabbro occur in the ore and the foot-wall schist comes in as a long tongue.

The *western ore-body* is more narrow, but at several places is thicker than the eastern ore (cf. Pl. 1). Like the eastern ore-body it is also sharply limited by the gabbro dike while in the opposite direction it successively tapers out.

A comparison between the longitudinal sections through both these elongated ore-bodies, Pls. 2 and 3, shows their similarity in the direction of plunge. Both also have interruptions caused by disturbance of the sediments around the 100 m level.

The upper part of the western ore-body is very flat as section A in Pl. 4 shows. As usual the schist forms the foot-wall, but from the gabbro dike a couple of gabbro sills go out and a tongue of the ore-body lies between these sills.

In section B in Pl. 4, 10 m farther to the north, the ore-body is more concentrated and has a simple and regular contour to the east limited by the gabbro dike.

In contrast to this ore section the next one, C in Pl. 4, shows the ore to be separated into several units. The western part of the ore-body is well exposed in Shaft II and there it is steeply inclined. Broadly speaking it lies in its usual position between gabbro and sediments, but is partly controlled by tectonic structures of the schist. In the normal position and separated from the first ore only by a band of schist about one meter thick, follows a continuation of the ore-body to the east out into the gabbro dike. Below this part of the ore-body and totally surrounded by sedimentary rocks is one more ore unit.

In section D, Pl. 4, 60 m farther to the north, the ore is once more concentrated and lies in a normal position.

The ore section 90 m farther to the north, E in Pl. 4, has a different look. It is here 5 m thick and has a sharp contact against the gabbro-dike and against the underlying sedimentary rocks. To the west it tapers out into the gabbro, which is an unusual feature.

In connection with both the elongated ore-bodies there occur veins and secretions containing nickel-arsenic minerals and chalcopyrite. They are most abundant in the lower part of the ore-body and in adjacent schists. Sometimes veins are also found cutting the solid ore and in some rare cases narrow nickel-arsenic ore-veins occur high up in the gabbro. These ore-veins have not been plotted on the sections in Pl. 4, as they are of too small dimensions to be clearly presented in the scale of the figures. The figures mentioned below (Figs. 28 and 29), however, may give a clear picture of the mode of occurrence of the veins.

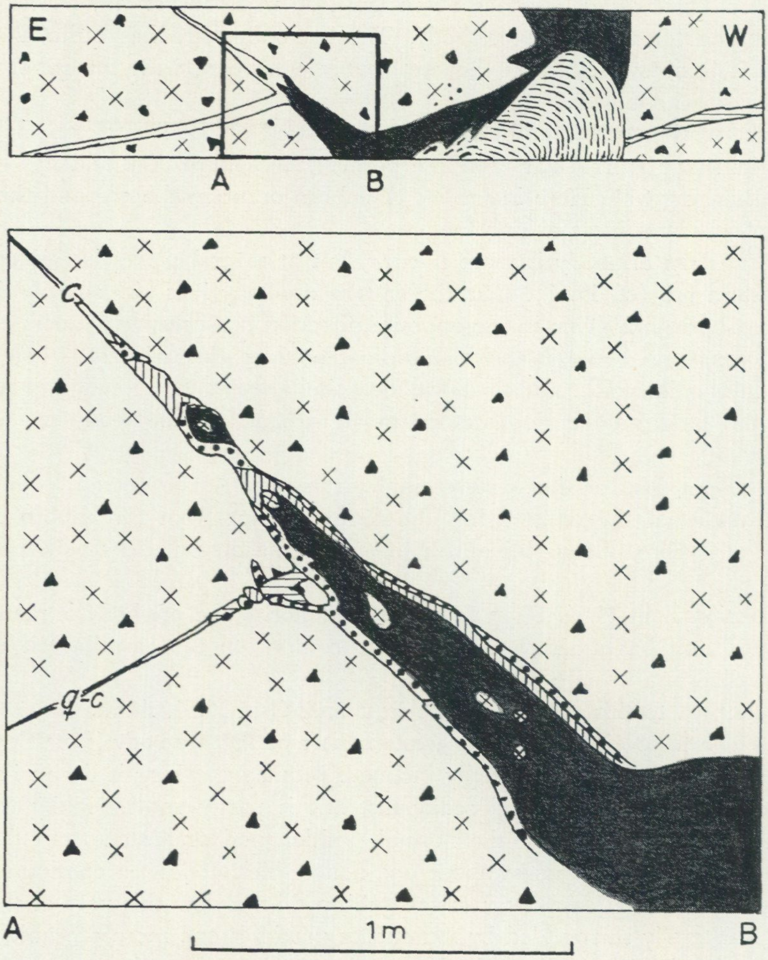


Fig. 28. Vertical section in the scale 1: 100; below, a detail in the scale 1: 20. In the western part the sulphide-disseminated gabbro dike is cut by a chalcopyrite vein. The massive ore extends from the dike eastwards between a folded schist in the foot-wall and a sulphide-disseminated gabbro in the hanging-wall. Its eastern termination follows a fissure plane in the gabbro phacolith. The ore includes fragments of gabbro. The vein of the nickel-pyrrhotite ore is surrounded by a crust of nickel-arsenic minerals and chalcopyrite, and these continue outwards as apophyses successively going over to quartz and carbonate veins. Legend see Fig. 6. Wall of an adit on the 40 m level nearby coincident with section B in Pl. 4. E. Grip 1943.

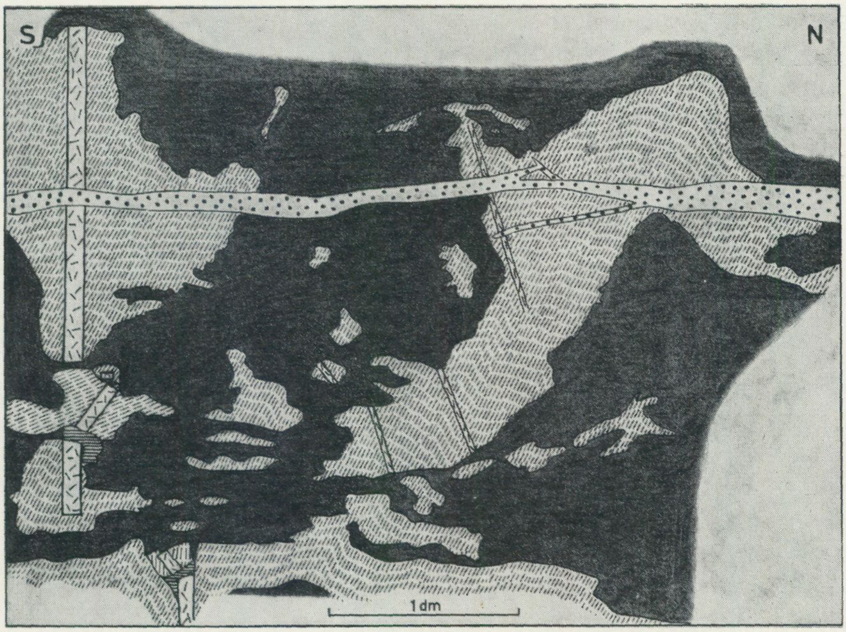


Fig. 29. Nickel-pyrrhotite ore replacing a brecciated schist with quartz veins. A vein containing nickel-arsenic ore cuts the whole. Legend see Fig. 6. The western ore-body at about the 130 m level. E. Grip 1945.

Fig. 30. Nickel-pyrrhotite ore with swimming fragments of schist and below the brecciated foot-wall of banded schists. About the 130 m level.

Fig. 31. Nickel-pyrrhotite ore brecciating and replacing quartzitic sediments.

The following figures show in more detail the behaviour of the nickel-pyrrhotite ore against its wall-rock. Fig. 28 nearly coincident with section B (980 Y) in Pl. 4, shows how the sulphide ore sends out an apophysis into the sulphide disseminated gabbro. It follows a pronounced fissure and it is obvious how it has only been able to fill the wider part of the fissure while other ore minerals have gone farther outwards (see below).

Fig. 32. Nickel-pyrrhotite ore, fine-grained and rich in chalcopyrite in the upper part, coarse-grained lower down, has partly replaced schist fragments. Chalcopyrite has segregated along the contacts. Legend see Fig. 6. At the 126 m level. E. Grip 1945.

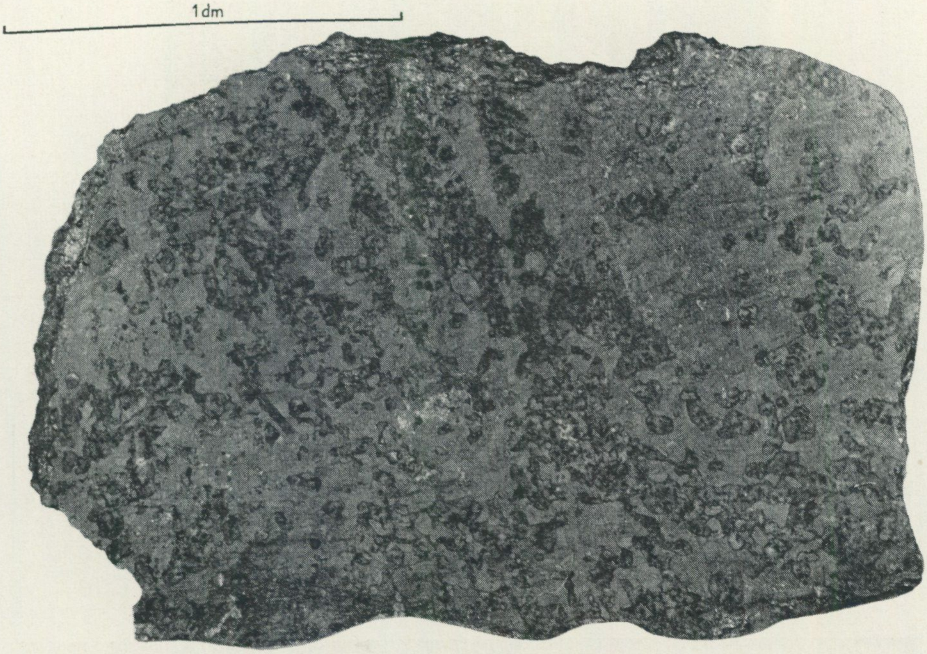


Fig. 33. Nickel-pyrrhotite ore replacing gabbro. Photo of polished sample.

Fig. 29 shows the nickel-pyrrhotite replacing a brecciated schist and the same is shown in Figs. 30—31. In such cases chalcopyrite in varying amounts has crystallized along the contacts against the schist as shown in detail in Fig. 32.

In Fig. 13 the sulphide ore replaces both fine-grained and coarse-grained gabbro at the gabbro dike. Fig. 33 shows a photo of sulphide ore replacing gabbro. The small rounded gabbro fragments consist of plagioclase, pyroxene and hornblende.

Fig. 6 shows an ore finger lying between schist in the foot-wall and gabbro in the hanging-wall. The finger has left the contact plane and lies entirely in schist.

Fig. 34 shows a fragment of gabbro in contact with schist. The whole fragment is well rounded and surrounded by the replacing nickel-pyrrhotite. Such rounded fragments are very common in the ore, which in many places may be called a pellet ore. They are not very much altered and their pyroxene is still partly preserved. The gabbro fragments have a tendency to become more completely rounded (Fig. 35) than the fragments of schist which mostly keep their angular shapes even when replacement has gone as far as in Figs. 29, 31, and 32.

Among the gabbro fragments in the ore there are also some with drop-formed accumulations of sulphides (disseminated ore) indicating that this type

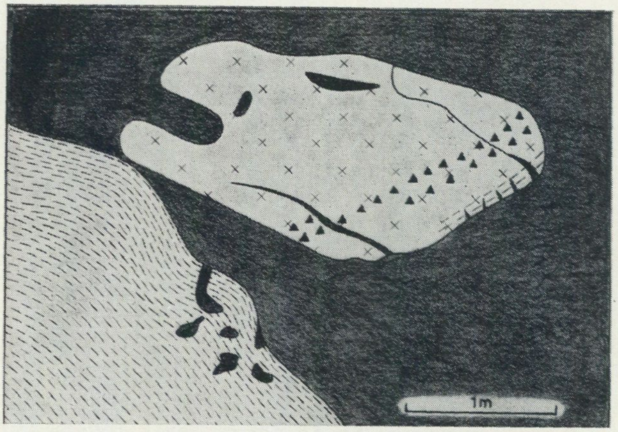


Fig. 34. A big rock fragment swimming in nickel-pyrrhotite ore. The main part of the fragment is gabbro, but its lower right part consists of schist. Within the gabbro there are zones of an old sulphide dissemination. Nickel-pyrrhotite veins run through the fragment and are also found in the foot-wall schist. Stope on the 150 m level. Å. Wirstam 1945.

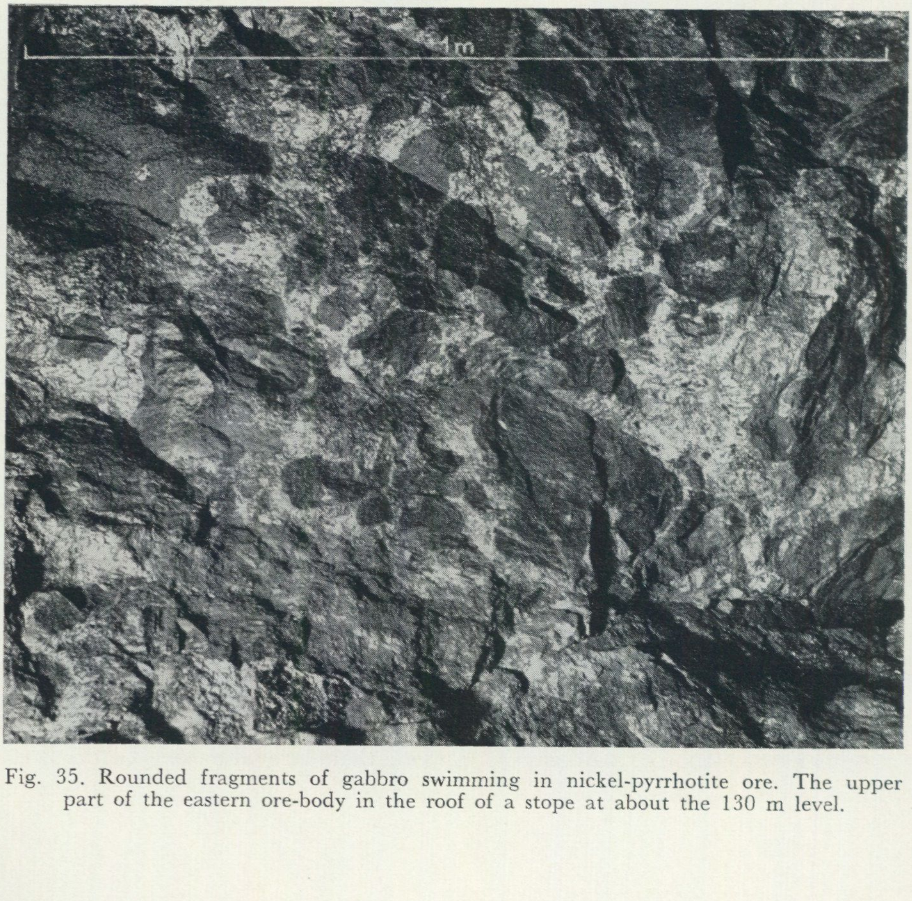


Fig. 35. Rounded fragments of gabbro swimming in nickel-pyrrhotite ore. The upper part of the eastern ore-body in the roof of a stope at about the 130 m level.

of ore was formed at the crystallization of the gabbro before the crystallization of the nickel-pyrrhotite ore.

The nickel-pyrrhotite ore is sometimes completely solid, but it mostly contains varying amounts of fragments from the wall-rock. The grain-size varies within wide limits. Generally the ore is most fine-grained in the apophyses and in the contact zones, and coarse-grained in the inner parts, where the grain-size can be more than 1 cm.

At the 150 m level big fragments of a gabbro sill cut into pieces swim in a coarse-grained, solid nickel-pyrrhotite ore. In a middle zone the fragments of the gabbro sill are richly disseminated with nickel-pyrrhotite but not at the borders. The dissemination of nickel-pyrrhotite gives a clear impression of being of primary origin in the centre part of the sill.

The mode of appearance of the nickel-pyrrhotite ore in the apophyses and the plentiful occurrence of swimming fragments of wall-rock in the solid sulphide ore indicate that the melt has been rather viscous.

As a rule the nickel-pyrrhotite ore is massive without any parallel structures other than zoning along the contacts. Occasionally, however, it is tectonically controlled as, e.g. at the 150 m level, 10 m W of the rise (see Pl. 4, E), where it has a pronounced vertical linearity.

The essential ore minerals in the nickel-pyrrhotite ore are pyrrhotite, pentlandite, chalcopyrite and magnetite. To these comes a series of accessory minerals such as arsenopyrite, cobaltite and other Ni-Co-arsenides. As we shall see below (p. 47), the transition from the nickel-pyrrhotite ore to nickel-arsenic ore is to a certain degree diffuse and any sharp boundary between the two parageneses cannot generally be drawn. The minor minerals therefore will only be described under the heading "nickel-arsenic ores".

Magnetite is the first ore mineral crystallized in the nickel-pyrrhotite ore where it is found as scattered, small, rounded grains up to 0.5 mm in size. Sometimes it has traces of crystal form but is corroded and often strongly replaced by pyrrhotite. Magnetite also occurs in connection with silicate minerals emanating from the wall-rock, but this variety strictly speaking does not belong to the ore paragenesis.

Cobaltite occurs sporadically in sharp idiomorphic crystals up to 0.5 mm in size. Sometimes it has a core of a silicate mineral (cf. Ödman 1932). Magnetite and pyrrhotite are also found as inclusions.

Pyrrhotite is the predominant mineral in the nickel-pyrrhotite ore. The grain-size varies from very fine-grained up to about 20 mm. Occasionally it has very nice twin lamellae, through the strong anisotropy of the mineral which is apparent even in normal light and extremely clear under crossed nicols. The pyrrhotite is relatively strongly magnetic, but the magnetism has only been proved with a simple horse-shoe magnet and no determinations of the permeability have been carried out. Pehrman (1954) has shown how the magnetism of the pyrrhotite built up by a monoclinic and a hexagonal phase increases with increasing percentage of the former. This phase has a higher content of sulphur than the hexagonal one. In our case the monoclinic phase should be the dominating one and consequently the percentage of sulphur should also be relatively high. This seems to be in contradiction to the results of Lindroth 1946, who investigated a hand sample of nickel-pyrrhotite ore from Lainijaur. He found the pyrrhotite to be ferromagnetic but in spite of this fact it had a hexagonal lattice. As shown by Pehrman the hexagonal and the monoclinic phase and a mixture of both may form pyrrhotite in one and the same deposit and this also may be the case here. — The pyrrhotite in a portion of the uppermost part of the ore-body has, through tectonic influence, got a fine ripple structure.

Pentlandite is the most important of the nickel-bearing minerals in the ore and it always appears nearly connected with the pyrrhotite. The pentlandite partly forms scattered accumulations or strings of panidiomorphic crystals up to 1.5 mm in size lying within the pyrrhotite and partly occurs as gashes forming unmixing textures in this mineral. It is common that the pentlandite occurs as strings of fine-grained crystals through the pyrrhotite and in the coarse-grained type this can be seen with the naked eye (see Fig. 36, where the pentlandite grains are up to 1.5 mm). Feather-formed replacement figures are also common. From small cracks in the pyrrhotite rays of pentlandite often go inwards and fissures may also be filled with pentlandite (cf. Ramdohr 1950, Fig. 281). Sometimes it occurs like a secretion and then it may lie around earlier crystallized magnetite and cobaltite.

Chalcopyrite always occurs in the nickel-pyrrhotite ore. The chalcopyrite is later crystallized than the pyrrhotite and the pentlandite and it frequently ap-

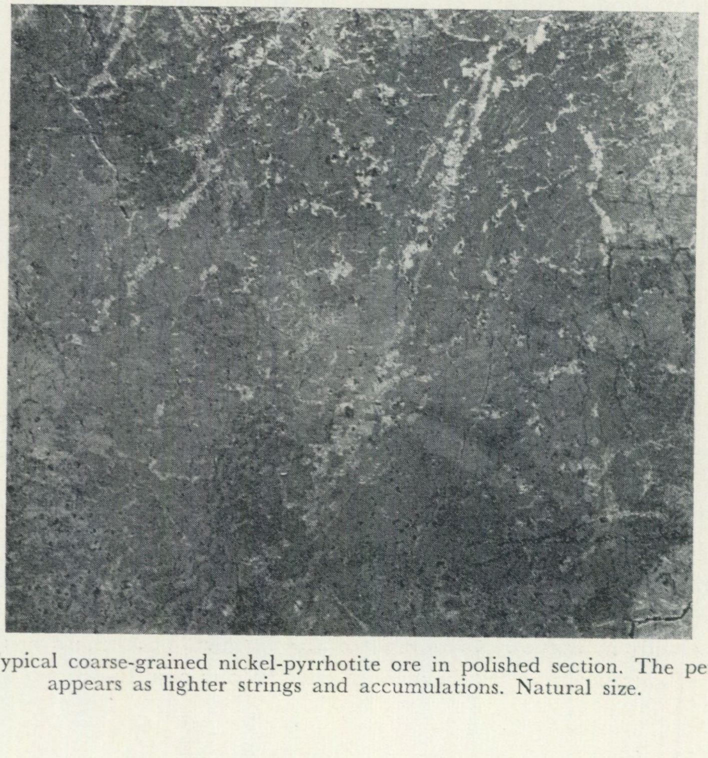


Fig. 36. Typical coarse-grained nickel-pyrrhotite ore in polished section. The pentlandite appears as lighter strings and accumulations. Natural size.

pears together with the coarse-grained type of pentlandite and then forms a cement between the grains or along fissures. Chalcopyrite often occurs also along grain borders in the pyrrhotite.

Bravoite is found in the most upper part of the ore-bodies. It occurs along fissures and cleavage faces in the pentlandite and constitutes an alteration product of this mineral.

As mentioned before there are plenty of fragments of the wall-rock in the nickel-pyrrhotite ore. The gabbro fragments are especially well rounded (Fig. 37) and may be only a few mm in diameter. Apparently they are only very weakly altered and have about the same mineral composition as the gabbro far away from the ore contact. Even pyroxene is present as remnants, but quartz and microcline are added.

Table VI, Cols. A and B shows the chemical composition of two average samples of the nickel-pyrrhotite ore. The principal elements in this ore-type are Fe, S, Ni, and to a lesser degree Cu. Table VII shows the composition of a sample of coarsely crystalline nickel-pyrrhotite. The proportions between the elements here are about the same as in the big samples of Table VI.

The frequency distribution of certain elements in the nickel-pyrrhotite ore is shown in the diagrams Figs. 22—27, which also give comparisons with the disseminated ore. The frequency distribution of nickel in the ore is shown in the diagram Fig. 22. Most of the 38 analyses lie between 1.8 and 2.8 % Ni, but there is no pronounced peak to the curve. The ratios sulphur : nickel, Fig. 23, are concentrated around the mode 11, thus being higher than in the disseminated ore. The frequency distribution of the copper : nickel ratios lies around a mode of 0.1 Cu : (Cu + Ni) being considerably lower than in the

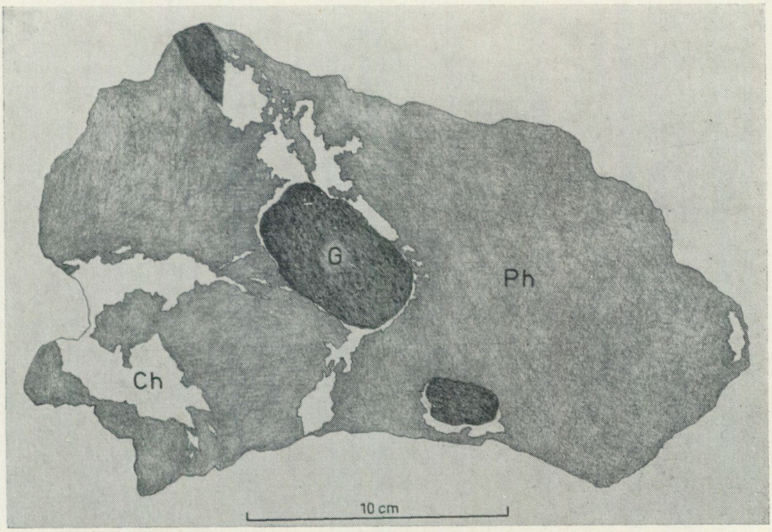


Fig. 37. Pellet ore. Well rounded pellets of gabbro (G) swimming in nickel-pyrrhotite ore (Ph). Segregations of chalcopyrite (Ch) are lying around the pellets in shrinkage fractures.

Table VI. Nickel ore from the 32 m level in Lainijaur

Component	A. Picked out Ni-pyrrhotite ore	B. Ni-pyrrhotite ore	C. Ni-As ore
SiO_2	4.92	7.90	19.55
Al_2O_3	1.9	3.10	6.70
TiO_2		0.11	0.18
CaO	0.58	0.95	2.84
BaO		0.03	0.08
SrO		0.0025	0.0081
MgO	0.43	0.52	1.61
Na_2O		0.57	1.43
K_2O		0.82	0.67
$H_2O < 105°$		0.03	0.08
$H_2O > 105°$		0.29	0.78
Cl		< 0.01	< 0.01
F		< 0.01	< 0.01
P_2O_5		0.018	0.028
CO_2		< 0.02	0.98
S total	34.7	32.14	15.48
V		0.001	0.01
Cr		0.008	0.011
Mn	0.02	0.01	0.05
Fe total	53.5	50.20	17.99
Co	0.01	0.03	1.13
Ni	2.73	2.55	10.05
Cu	0.16	0.36	1.89
Zn	0.0	0.001	0.001
As	0.04	0.08	18.45
Se		0.01	0.01
Mo		< 0.0001	0.0007
Ag	< 0.00018	0.0004	0.0018
Cd		0.001	0.001
Sn		0.005	0.001
Sb		0.03	0.06
WO_3		0.01	0.01
Pt	< 0.00001	< 0.00001	< 0.00001
Au	< 0.00001	0.00002	0.00043
Hg		< 0.0003	< 0.0003
Pb	< 0.01	< 0.0001	< 0.02
Bi	0.00		
S : Ni	12.6	12.6	15.4
Ni : Cu	17	7	5.3
Ni : Co	273	85	8.9
FeS + (Fe, Ni) S	91	85	
100 Ni : [FeS + (Fe, Ni) S]	3.0	3.0	

Calculation, see Table V. Analysts: I. HEYMAN and A. G. HYBBINETTE.

Table VII. Coarse crystalline nickel-pyrrhotite ore. 32 m level in Lainijaur

Component	%	Calculated mineral composition	
S	38.0	NiS	4.7
Co	0.08	$CuFeS_2$	1.2
Ni	3.07	CoSAs	0.2
Cu	0.41	FeS	93.9
Ni : Cu	7.5		
Ni : Co	38		

disseminated ore. The same thing is illustrated by Fig. 25. The frequency distribution of the ratio Co : (Ni + Co) is concentrated around the mode 0.03 and this is also lower than in the disseminated ore. Finally the ratio S : Zn can be studied in Fig. 27. Even if the curve here is founded only on 15 analyses it gives the tendency of a concentration around 200 which is higher than in the disseminated ore.

Nickel-Arsenic Ore

The nickel-arsenic ore forms the third and latest ore-formation stage, but it is closely connected with the preceding one. Mostly the ore of this type occurs as fissure fillings and these ore-veins cross both the older ore as well as its wall-rock. The nickel-arsenic ore is mainly found in fissures in the sedimentary rocks immediately below the nickel-pyrrhotite ore and especially around the terminations of the ore-bodies. Downwards the veins rapidly taper out, but they occur several tens of meters below the solid ore and also far above this ore both in the gabbro and quartz-diorite.

Nickel-arsenic minerals also appear as disseminations and aggregations both in the compact nickel-pyrrhotite ore and in the gabbro and the sedimentary rocks, but then they generally originate from veins nearby (Fig. 38).

In the profile series shown in Pl. 4 it has not been possible to plot the nickel-arsenic veins as the scale is too small, but nevertheless the profiles may be used for orientation purposes. In section A nickel-arsenic ore is found as a vein along a part of the contact between the solid nickel-pyrrhotite ore-body and the gabbro in its hanging-wall and also as veins within the solid ore.

In section B the nickel-arsenic paragenesis occurs in a steep dipping vein in the gabbro dike and in adjacent schist and in irregular veins in the solid ore.

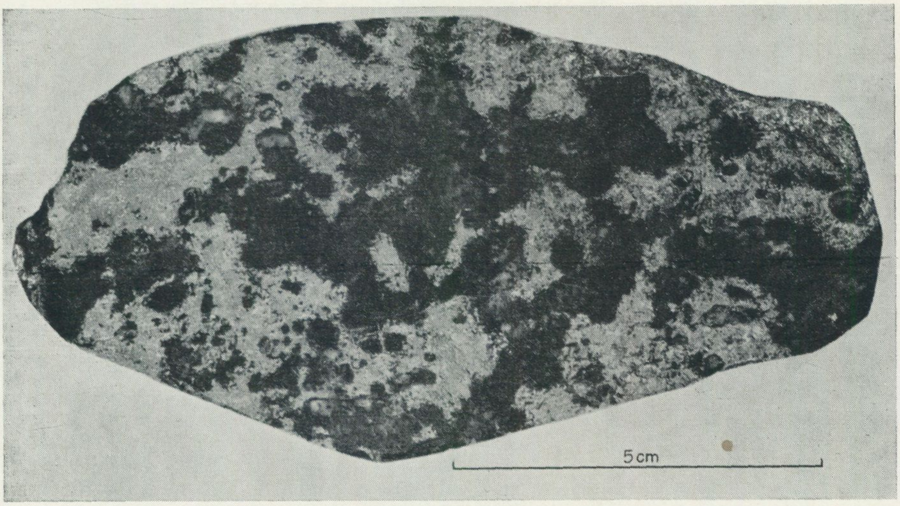


Fig. 38. Nickel-arsenic ore replacing gabbro. Polished section.

In section C numerous minor veins with nickel-arsenic ore occur within and around the gabbro dike. One of these veins contains plenty of niccolite. Around the most eastern ore shoot there are also plenty of veins of nickel-arsenic minerals, especially in the contact to the wall-rock, and also in the solid ore. Below the ore-body, in the inclined shaft, occur some veins rich in chalcopyrite traversing the bedding.

In section D as in section C there are plenty of nickel-arsenic veins around the eastern tip of the eastern ore-body. The nickel-pyrrhotite ore-body extends as small sills in the schist and the nickel-arsenic paragenesis follows these.

Finally, in section E nickel-arsenic ore occurs especially around the western end of the eastern ore-body at the contact between the schist and the gabbro dike and 1—2 m outwards into both rocks.

Fig. 6 shows how the nickel-arsenic paragenesis appears around a finger of solid nickel-pyrrhotite ore. Here plenty of chalcopyrite occurs and is younger than the white nickel-arsenic minerals.

Fig. 28, nearly coincident with the central part of section B in Pl. 4, shows an apophysis from the nickel-pyrrhotite ore-body. The nickel-pyrrhotite ore extends obliquely upwards along a fissure in the gabbro and small fragments of the gabbro are floating in the ore. Niccolite and white nickel-arsenic minerals are located along the contacts. Outwards, as the vein grows thinner and thinner calcite takes over the role of the ore minerals as a vein filling. From the large apophysis a veinlet goes obliquely downwards. Close to the main apophysis it is filled with chalcopyrite, white nickel-arsenic minerals and niccolite. 30 cm from the apophysis the ore minerals stop and further downwards the fissure is filled with quartz and carbonate.

Fig. 29 shows how a vein, one cm thick with white nickel-arsenic minerals, sharply cuts nickel-pyrrhotite ore with partly replaced schist. Some small agglomerations of chalcopyrite beneath a broken older quartz vein may belong to the nickel-pyrrhotite stage.

On Fig. 20 there is a vein with nickel-arsenic minerals, chalcopyrite and quartz and carbonate running obliquely upwards through the gabbro from the underlying solid nickel-pyrrhotite ore. Below this ore there are schists richly traversed by veins containing quartz and carbonate, pyrrhotite, chalcopyrite and nickel-arsenic minerals.

Fig. 39 shows the schist in contact with the overlying gabbro being strongly brecciated and cemented by pyrrhotite. Small veins with nickel-arsenic minerals, chalcopyrite, quartz and carbonate cut the whole.

A summary of the paragenesis of the nickel-arsenic ore is given in Table VIII. The proportion between the minerals varies strongly in different zones as appears from what is said above. Below, the minerals will generally be described in their order of crystallization.

Ilmenite is found in connection with magnetite, but scattered grains of ilmenite have also been found in the nickel-arsenic ore.

Magnetite in small amounts is common in the nickel-arsenic ore. It appears

Fig. 39. Section showing the bottom of the gabbro phacolith with brecciated schist in the foot-wall. The contact line is marked with a broken chalk-line and runs from the middle part of the left side upwards towards the upper right corner. The schist is brecciated by fine-grained nickel-pyrrhotite ore. The veins going in several directions contain chalcopyrite, nickel-arsenic minerals, carbonate and quartz. Stope-wall at about the 120 m level.

in small grains with or without an idiomorphic shape. Sharp idiomorphic crystals of magnetite have been found in the löllingite in the analysed sample Table IX. The content of magnetite in this sample is about 1 %.

In a magnetite crystal a core of another mineral has been observed which is possibly *spinel* (cf. Ödman 1932).

Cobaltite is common as scattered idiomorphic crystals among the other Ni-Co-As-minerals. It is also found as the sole mineral on fissure planes. The cobaltite is early crystallized and is replaced by pyrrhotite, pentlandite and chalcopyrite. Sometimes it forms crystal skeletons.

Skutterudite (the smaltite-chloantite series) occurs as more or less sharp idiomorphic crystals especially in chalcopyrite and in niccolite. It is replaced by chalcopyrite. By etching with HNO_3 a beautiful zoning appears in the skutterudite. According to Ramdohr (1950), typical skutterudite is only little zoned while the smaltite is strongly zoned. The zoning texture in the Lainijaur mineral then should indicate a considerable content of cobalt. According to

Table VIII A. List of non-ore minerals in the Lainijaur ores

Mineral	Disseminated ore	Ni-pyrrhotite ore	Ni-arsenic ore
Apatite	×		
Augite	××		
Biotite	××		
Calcite	×		×××
Chlorite	××		
Clinozoisite	××		
Dolomite	×		××
Epidote	×		
Garnet	×		
Hornblende	×××		
Microcline	(×)		×
Olivine	×		
Orthorhomb. pyroxene	××		
Phlogopite			×
Plagioclase	×××		×
Quartz	(×)	×	×××
Rutile	×		
Sericite	×		
Serpentine	××		
Talc	××		
Titanite	×		
Tourmaline		×	×
Zircon	×		
Zoisite	××		

the mineral calculation in Table IX chloantite should occur there but in a polished section of the analysed sample this mineral has not been proved for certain.

Rammelsbergite-löllingite. In Shaft II a part of the ore occurs which was found to be extremely rich in arsenic (see Table IX). Its mineral composition has been calculated from the analysis and the paragenesis checked under the microscope. $NiAs_2$ and $FeAs_2$, together forming 73 % of the ore, occur in the proportion 2: 1. The corresponding mineral, the rammelsbergite (or pararammelsbergite?) and the löllingite form a fine crystalline blue-white mass, where it is very difficult to distinguish the two components from one another. There can here be an isomorphic mixture.

Arsenopyrite forms an essential part of the nickel-arsenic ore. It appears in fine crystalline shapes together with other white arsenic minerals.

In a sample from Shaft II the composition of which is shown in Table IX, there are irregular grains of arsenopyrite in a mass of rammelsbergite-löllingite. The percentage of arsenopyrite in this sample is about 16 %.

Tourmaline. Fine needles of dark tourmaline occasionally occur together with the nickel-arsenic ore, as for example, beneath the hanging-wall of the ore-body at the 190 m level (where also chalcopyrite occurs).

Niccolite is fairly abundant and veins nearly completely filled with this mineral are not uncommon (Fig. 28). Twin lamellae occur in one or two

Table VIII B. Ore minerals in the Lainijaur ores approximately listed in order of crystallization

Mineral		Disseminated ore	Ni-pyrrhotite ore	Ni-arsenic ore
Ilmenite	$FeTiO_3$	×		×
Magnetite	Fe_3O_4		×	×
Spinel?	$MgAl_2O_4$			×
Cobaltite	$CoSAs$		×	×××
Smaltite	$CoAs_{2-3}$			×
Chloantite	$NiAs_{2-3}$			×
Rammelsbergite	$NiAs_2$			×
Safflorite	$CoAs_2$			×?
Löllingite	$FeAs_2$			×
Arsenopyrite	$FeSAs$			××
Niccolite	$NiAs$	×?		××
Maucherite	Ni_4As_3	×?		××
Pyrrhotite	FeS	×××	×××	××
Pentlandite	$(Fe, Ni)S$	××	××	×
Bornite	Cu_5FeS_4			×
Valleriite	$Cu_3Fe\ S_7$			×
Chalcopyrite	$CuFeS_2$	××	××	×××
Scheelite	$CaWO_3$			×
Molybdenite	MoS_2			×
Sphalerite	ZnS			××
Galena	PbS			×
Bravoite	$(Ni, Co, Fe)S_2$		×	×
Pyrite	FeS_2			(×)

(×) very rare ×× common ? identity of mineral not quite certain
× rare ××× abundant

directions. In some individuals there are lamella-formed and spear-like *maucherite* crystals. The niccolite has a reflexion pleochroism of yellow-red and rose while the maucherite is a little darker and rose-grey.

Pyrrhotite occurs in varying amounts. The compact nickel-pyrrhotite ore often tapers out in veins which become more and more rich in arsenic-nickel minerals. Real transition forms thus exist between the two ore-types and the pyrrhotite with its *pentlandite* is of the same character in both.

Bornite has only been found in two polished sections. In one from the 32 m level it forms small grains in a fissure filled mainly with calcite and lesser amounts of sphalerite, galena, chalcopyrite, pyrrhotite and pentlandite. In the other section from the 100 m level bornite forms a dissemination in large chalcopyrite grains.

Chalcopyrite is one of the most common minerals in the nickel-arsenic ore paragenesis and is often found in veins completely filled up with this mineral. The chalcopyrite, however, is not strictly bound to veins, but also occurs disseminated in amphibolitic wall-rock, where together with the pyrrhotite it replaces the silicate minerals, i.e. generally hornblende. The chalcopyrite is often replaced by galena and sphalerite. It always appears in near connection with pyrrhotite and pentlandite. — In a secretion of calcite and microcline-perthite (100 m level) the chalcopyrite partly forms a fine-grained dissemination and partly bigger grains with small inclusions of bornite.

Table IX. Nickel-arsenic ore. Shaft II Lainijaur

Component	%	Mol. prop.	Calculated mineral composition	
SiO_2	1.5	250	CoSAs	1
TiO_2	0.02	3	FeSAs	16
S	3.3	1,029	$FeAs_2$	25
Cr	0.03	6	$NiAs_2$	48
Fe	13.5	2,418	$NiAs_3$	5
Co	0.24	41	Magnetite	
Ni	14.6	2,488	Pyrrhotite	
Cu	0.01	2	Titanite	5
As	63.8	8,520	Silicates	
Sb	0.00		Carbonates	
$H_2O < 105°$	0.03			
Total	97.03			100
Ni : Cu	146			
Ni : Co	61			

Valleriite occurs abundantly as small grains in chalcopyrite.

Scheelite for the first time was found when some samples from the mine were investigated in ultra-violet light. By systematic examination of the walls in the mine by ultra-violet light the mode of occurrence of the scheelite could be studied in detail (Grip 1951).

The scheelite appears in swarms of small grains up to a few mm in size. They occur especially in carbonate veins and also in their near vicinity, and as disseminations in both compact pyrrhotite ore and in schist brecciated by ore. Lime-rich parts of the schist contained more scheelite than those poor in lime.

The scheelite forms more or less idiomorphic crystals with an octahedral form lying in the nickel-arsenic ore, but sometimes also in the nickel-pyrrhotite ore. The scheelite crystals sometimes form twins.

Molybdenite is very rare. It has been found in the margin of a niccolite vein, in a segregation of nickel-arsenic ore in gabbro and relatively abundantly in the most eastern part of the eastern ore-body on the 105 m level.

During an investigation of a number of molybdenites Aminoff 1943 also made an X-ray spectrographic analysis of a sample from Lainijaur. He found it to have a content of rhenium higher than any previously known being 0.25—0.05 weight % Rh. This means that the Lainijaur mineral had a content of Rh 25 times higher than the highest known before. Some years later Aminoff (1947) found a still higher content of rhenium in a molybdenite from the Kuorbevare (Adak) district not far from Lainijaur in which the content of rhenium was $0.2\ \% \leqslant \mathrm{Rh} < 0.5\ \%$.

Recently Neumann (1956) has investigated the rhenium content in some Norwegian molybdenites and found percentages nearly as high as in the Lainijaur mineral.

Sphalerite has often been found in the nickel-arsenic veins. It is mostly found in the extremities of the veins and together with galena forms the latest crystallization. In fissures through nickel-pyrrhotite ore the sphalerite replaces both pyrrhotite and pentlandite. The sphalerite is always dark in colour.

In exhausted ore from the upper part of the mine some coarse-crystalline sphalerite was found. This sphalerite was peppered by fine-grained pyrrhotite and pentlandite formed irregular segregations, as well as more regular grains. Together with the pyrrhotite there was plenty of small round quartz-grains and sometimes some chalcopyrite.

Galena often occurs towards the terminations of nickel-arsenic ore veins but in small quantities. Together with the sphalerite it is one of the latest crystallized minerals. The galena replaces pyrrhotite and pentlandite.

Bravoite as in the nickel-pyrrhotite ore occurs together with pentlandite.

Pyrite is only found as a rarity. It occurs as a filling in a fissure just below the ore-body at about the 100 m level.

Quartz is common in the nickel-arsenic paragenesis, but it never occurs in large quantities. Sharp idiomorphic quartz crystals are found as inclusions in chalcopyrite. Together with calcite, quartz forms fissure fillings at vein terminations.

Carbonate minerals are also common in the veins. In ultra-violet light a part of them fluoresces with a red-yellow colour and is proved to be calcite while the non-fluorescent part is dolomite. Both minerals may occur in the same vein. The calcite often appears in the margins of small quartz veins as on the 20 m level where scheelite also occurs.

The determination of the two minerals has been carried out partly chemically partly spectrochemically and partly by X-ray study. Table X shows the chemical composition of the non-fluorescent dolomite.

The nickel-arsenic ore varies very much both in composition and in character. In order to get an idea of its chemical composition a sample has been taken out from hand-picked nickel-arsenic ore exhausted from about the 30 m level in the mine. The analysis is shown in Table VI, Col. C.

Another portion of the nickel-arsenic ore from a vein in Shaft II has also been analysed (Table IX). Here the arsenic is dominant while the percentage of sulphur is low. The mineral composition calculated from the analysis is shown in the same table. Under the microscope cobaltite, arsenopyrite, löllingite, rammelsbergite, pyrrhotite, magnetite and titanite have been determined.

Table X. Carbonate vein. 32 m level in the Lainijaur Mine

Component	%	Calculated composition of the carbonate	
CaO	18.4	$CaCO_3$	57.4
MgO	9.06	$MgCO_3$	33.3
CO_2	27.6	$(Fe, Mn)CO_3$	9.3
		Total	100.0

Comparisons between Ore Types

The three ore types — the disseminated ore, the nickel-pyrrhotite ore and the nickel-arsenic ore — form three stages of mineralization. Each has its own character both in appearance and chemical composition.

The disseminated ore occurs in all grades of concentration from about 50 % sulphide and downwards. At which percentage the ore boundary shall be drawn is a technical and economic question of no particular importance for a comparison between the three ore types. Most of the analysed parts of the disseminated sulphide gabbro lie far below the workability limit, but they are mentioned here since they illustrate the ore type and its distribution of elements. In the lower parts of the gabbro there are drop-formed segregations constituting a transition to the next ore stage, namely, the nickel-pyrrhotite ore. In the gabbro, scattered grains of nickel-arsenic minerals are common especially in connection with magnetite lumps.

The nickel-pyrrhotite ore occurs in compact portions brecciating both the schist and the gabbro and also the disseminated ore. It keeps relatively well collected in fracture zones along the contact between the sedimentary rocks and the overlying gabbro. Its mineral composition is simple. Pyrrhotite with pentlandite is extremely dominant, but there are also some scattered grains of nickel-arsenic minerals. The nickel-pyrrhotite ore-bodies sometimes go out in fissures but generally do not form any long veins. The nickel-pyrrhotite ends in blunt terminations and then follows nickel-arsenic ore. Consequently there is a very sharp boundary between the two ore types.

The nickel-arsenic ore is the richest in minerals of the three ore types. It has the character of an ore-pegmatite grading over into a low hydrothermal paragenesis. Quartz and microcline and also mobilized quartz-diorite belong to the paragenesis in portions close to the nickel-pyrrhotite ore-bodies while carbonates take over its role further out in the veins.

The three ore types thus form a suite from the magmatic stage with the liquid unmixing of the disseminated ore and the intrusive ore injections of the nickel-pyrrhotite to the pegmatitic-pneumatolytic stage of the nickel-arsenic ore which passes into a hydrothermal stage.

Some characteristic features in the composition of the disseminated ore and the nickel-pyrrhotite ore are compiled in the diagrams Figs. 22—27. From these it can be seen how the frequency distribution of the ratios S : Ni are concentrated around a mode of 9.3 for disseminated ore but 11.0 for nickel-pyrrhotite ore. The ratios Cu : (Cu + Ni) lie around 0.43 resp. 0.10 and in Fig. 25 it is shown how the copper grade decreases with percentage of sulphur and how the disseminated ore has equal portions of copper and nickel, but the nickel-pyrrhotite ore is dominated by nickel. The frequency distribution of the ratios Co : (Ni + Co) appears from Fig. 26, where the disseminated ore has a concentration of the ratios around a mode of 0.08 while the figure for the nickel-pyrrhotite ore is about 0.03. Even for zinc the values are higher in the disseminated ore than for the nickel-pyrrhotite ore, the modes of the ratios S : Zn being 40 and 150 respectively.

In Table XI an attempt has been made to calculate the composition of the sulphide-arsenic phase of the three ore types I, II and III. Column I a is based on one single analysis with low sulphide percentage and is therefore uncertain. It is nevertheless referred to because of its As-determination. It is found that the disseminated ore I and the nickel-pyrrhotite ore II constantly contain 3.0 % Ni apart from I a, while the nickel-arsenic ore contains 16 % Ni. The percentage of Co is 0.3 % in type I, insignificant in type II and 1.8 % in type III. The percentage of Cu is highest in type I with 3.4 %, a little lower in type III with 3.1 % and lowest in type II with 0.2—0.4 %. The percentage of As is only determined for one sample and amounts to 5.2 %. A certain content of As, however, is general in type I according to observations of scattered arsenic minerals. Type II is very poor in As while type III is extremely rich with 29.5 % As. Type I has 1 % Zn while in the other types this metal is extremely low. However, it is worthy of note that in type III pure sphalerite veins sometimes occur, but certainly no such one has gone into the analysed sample.

Table VI gives analysis figures for a series of elements in the ore types II and III and from these some facts can be stated. Thus the percentages of the following elements are higher in type III than in type II: V, Cr, Mn, Co, Ni, Cu, Zn (according to general observations), As, Mo, Ag, Sb, W, Au, Pb. Only S, Fe and Sn are higher in type II than in type III, while Se and Cd are found in equal percentages in these two ore types. The content of mercury is less than 3 ppm in both types and thus among the lowest Hg-percentages in all the sulphide ores of the Skellefte District (cf. Grip 1948).

The average analyses of the production from Lainijaur in 1943 and 1945 are given in Table XII. These samples include ore from all three ore types,

Table XI. Calculated composition of the sulphide-arsenides in the three ore types at Lainijaur

Component	I		II		III
	a	b	a	b	
S	38	38	38.2	37.5	24.8
Fe			58.6	59.0	24.9
Co	1.1	0.3	0.0	0.0	1.8
Ni	5.0	3.0	3.0	3.0	16.0
Cu	7.1	3.4	0.2	0.4	3·1
Zn	3.0	1.0	0.0	0.0	0.0
As	5.2		0.0	0.1	29.5
Total			100.0	100.1	100.1

I. The sulphide-arsenide phase of disseminated gabbro calculated with 38 % S. a) Dh 9: 11—14 m. Cf Table III. — b) Dh 9: 8—56.13 m. Average of 16 analyses. Cf Table V.

II. a—b. Nickel-pyrrhotite ore of Table VI, Cols. A and B resp. Sulphide phase calculated to 100 %

III. Nickel-arsenic ore of Table VI, Col. C. Sulphide-arsenide phase calculated to 100 %.

Table XII. Samples of 30 tons representative for the Lainijaur production of nickel ore during the years 1943 and 1945

Component	1943	1945
SiO_2	20.5	18.8
Al_2O_3	4.56	6.18
CaO	2.50	2.22
MgO	1.93	1.56
S	23.0	23.1
Fe	35.5	37.1
Co	0.14	0.12
Ni	2.36	2.03
Cu	1.00	1.04
Zn	0.15	0.08
As	0.36	0.34
Se	0.09	0.004
Ag	0.0006	0.0005
Sn	0.028	0.001
Sb	0.029	0.09
Au	0.00003	0.00003
Pb	0.0	0.09
Bi	0.005	0.001
S : Ni	9.8	11.3
Ni : Cu	2.4	2.0
Ni : Co	17	17
FeS + (Fe, Ni) S	61	61
100 Ni : [FeS + (Fe, Ni) S]	3.9	3.3

but type II is extremely dominant. A comparison with the type samples dealt with above and a calculation of the contents of Ni, Co, and As in these and in the annular samples shows that the ore taken out contained about 15 % nickel-arsenic ore. According to the analyses about 30 % of the exhausted ore was made up of silicate rocks. These occurred partly as inclusions in the nickel-pyrrhotite ore, partly as wall-rock in the hanging-wall and foot-wall. As the solid ore is situated in the contact zone between gabbro and schist both these rock components can be assumed to have entered the exhausted ore and in about similar amounts. The gabbro beneath the compact ore is generally richly disseminated and it may be reckoned as dissemination ore even if it is sometimes poor. The proportion betwen the three ore types forming the deposit should then be 15 % disseminated ore, 70 % nickel-pyrrhotite ore and 15 % nickel-arsenic ore.

As to the content of the annular sample attention may be especially called to the high percentage of Zn which is from 0.08 to 0.15 %. This can originate to a large extent from disseminated ore which is able to bear considerable amounts of zinc as shown in Table V.

In drill-hole 9 the gabbro has an average content of nickel-pyrrhotite of 4.7 % and of chalcopyrite of 0.5 %, that is to say 5.2 % sulphides. The gabbro is about 48 m thick and its content of sulphides then corresponds to about 1.7 m of solid ore. Thus the sulphide content of the gabbro, though not so high as that of the solid ore, is considerable.

Tectonic and Intrusive Structures

The tectonics in that part of the Skellefte District, where the Lainijaur deposit is situated have already been dealt with in the geological summary p. 7. The supracrustal series is gently folded along flat fold-axes. From the neighbourhood of Rakkejaur lying 14 km SE of Lainijaur the fold-axes radiate within W and NNW. The supracrustal series, for the most part consisting of sedimentary rocks just west of Lainijaur, is cut off by the large Adak granite massif.

The Lainijaur deposit is situated in a small syncline with a fold-axis dipping 25° N 35° E. The granite contact about 1 km northwest of the mine strikes N 45° E as far as is known from the sparse outcrops.

In the bottom of the syncline of sediments there is a fracture striking N 45° E, 55° NW, parallel to the granite contact. This fracture is filled with gabbro and the tectonics in the mine are all intimately related to the intrusion mechanism.

Fig. 3 shows the general outline of the intrusive and its relation to the sedimentary rocks. Details may be studied in the section series, Pl. 4.

Section A shows the gabbro spreading out on both sides of the feeding channel which is not, however, here exposed. The schist is wavy folded, and the gabbro, the largest part separated from the schist by solid ore, follows its wavy bedding conformably. In the hanging-wall of the eastern ore-body there is a fault-plane parallel to the ore contact.

Section B, only 10 m from A, completes the central part of this section. East of the gabbro dike the schist is strongly folded. The gabbro closely follows the deformation of the schist, and shows the latter to have occurred in connection with the gabbro intrusion. Here too ore lies along the irregular contact plane. A fault plane dipping 45° E runs nearly parallel to the bedding plane through the schist in the eastern part of the section and the eastern portion is sunk about 1 m compared with the western one. Along a part of the fault runs a thin ore vein. A sill of ore lies in the schist east of the gabbro dike and an apophysis goes out nearly horizontally to the east. — The western ore-body is separated from the gabbro dike by a fault plane.

Section C shows the gabbro dike cutting the sediments. A bed of lime-silicates is found on both sides of the dike and it indicates the western portion to be only insignificantly depressed compared with the eastern one. A vertical fissure in the gabbro dike is filled with nickel-arsenic minerals. Generally the gabbro on both sides of the dike is conformable to the bedding of the sediments, but in detail the ore-bodies are somewhat irregular, especially against the sediments. In Shaft II there is a vertical fault plane striking parallel to the gabbro dike and downwards fading out into a feather-fissure system. Along this plane there is a small depression of the eastern portion and the forms and situations of the ore-bodies indicate that it is this very movement that has given space for the intruding sulphide smelt. On the 70 m level, a little below section

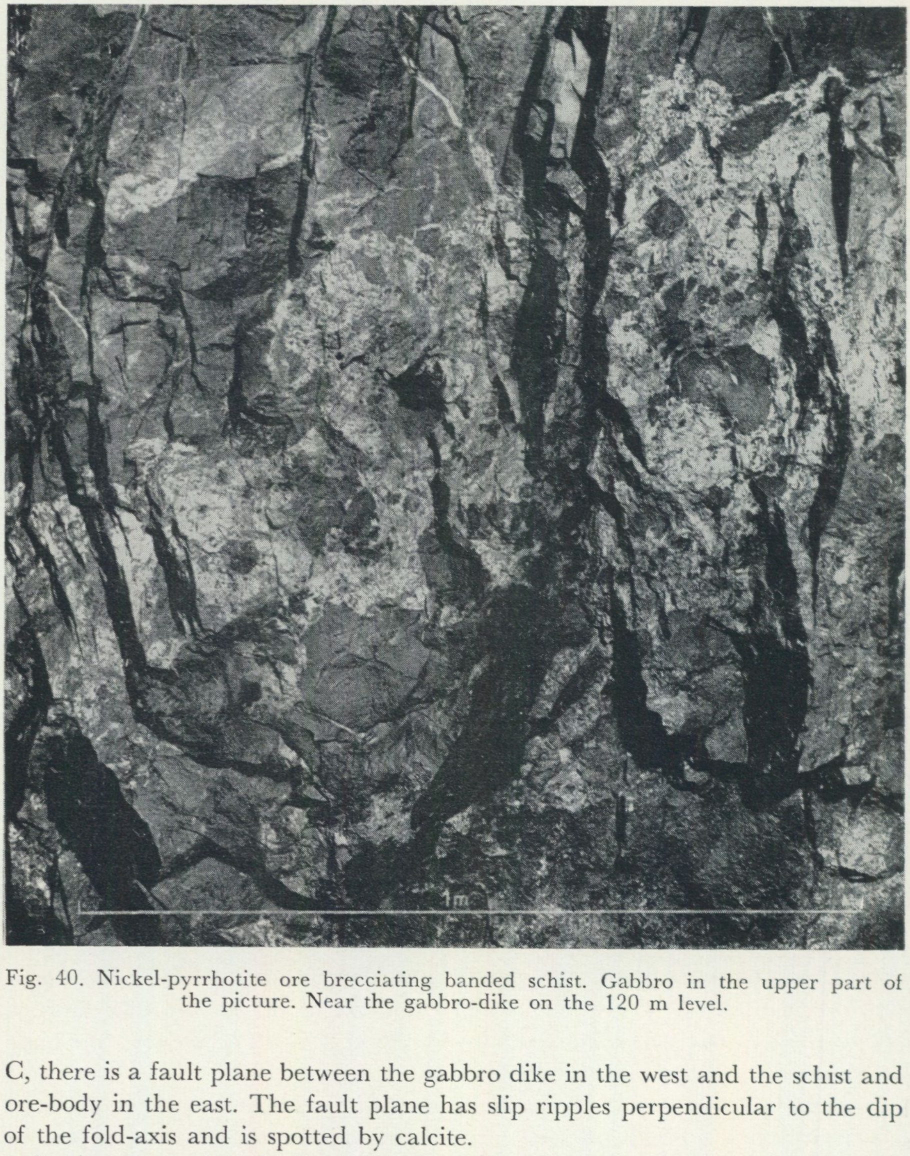


Fig. 40. Nickel-pyrrhotite ore brecciating banded schist. Gabbro in the upper part of the picture. Near the gabbro-dike on the 120 m level.

C, there is a fault plane between the gabbro dike in the west and the schist and ore-body in the east. The fault plane has slip ripples perpendicular to the dip of the fold-axis and is spotted by calcite.

Section D nearly coincides with the section given in Fig. 3 and therefore I will describe them both together. Fig. 3 shows the gabbro cutting the bottom of the syncline and sending out sills into the bedded sediments. East of the dike the upper lip of the schist, 10 m above the ore-body, lies in the right position compared with the sediment beds west of the dike, while the sediment pack below the big gabbro-wing going out to the east has sunken at least five meters. The cross-cutting contacts of the gabbro dike against the sediments are remarkably sharp, especially in the lower part of the dike. As usual the ore-bodies lie on both sides of the gabbro dike with sediments in the foot-wall and gabbro completely or partly in the hanging-wall (cf. Fig. 40). The structures indicate that the movement, which has given space for the ore-bodies, has been directed downwards in the schist portions on both sides of the gabbro-dike.

The upper parts in the section, Fig. 3, are known only by drill-holes and therefore they are not so rich in details. However, it is evident that the sediments are here generally conformable to the sediments below the gabbro intrusion proper. As pointed out before the sediments around drill-hole 31 are replaced by quartz-diorite and the fracture forming the feeding channel seems to have its continuation here. The assimilation and replacement of the sediments have also been described above.

Section E shows one more picture of the gabbro dike and its surroundings. The western ore-body is sharply delimited by a fault plane against the gabbro dike. A similar fault plane follows the eastern wall of the dike and here nickel-arsenic ore is found. The eastern ore-body is conformable to the sediments in the foot-wall except in the east and where the sediments are dipping about 45° eastwards. The hanging-wall consists of gabbro and nearest the gabbro dike, of a gabbro sill brecciated inwards by the ore.

The longitudinal sections, Pls. 2—3, lie on each side of the gabbro dike. They too show how the gabbro is principally intruded parallel to the bedding of the sediments and how the ore lies along the contact. In the middle part of the sections, however, there is an important dislocation. The sediments flatten out and form an imbricate structure. Between the sediment packs there are several gabbro sills intruded from the gabbro dike (see Pl. 4 D). The structures indicate a compression in the direction of the fold-axis and the close adaptation of the gabbro to the structures shows that the compression has taken place in connection with the gabbro intrusion. In conjunction with the overthrusting an infiltration of solutions rich in nickel-arsenic has taken place contributing both disseminations and fissure fillings of nickel-arsenic minerals.

In the petrographic description of the gabbro dike it has already been mentioned (p. 20) that the gabbro has demonstrably been intruded in at least three different stages between which the magma was consolidated and then broken up again to give space for a new intrusion. In the big phacolith the gabbro varies both in grain-size and composition and these features can be shown to depend directly on assimilation of sedimentary material. The existence of gabbros of different ages on the contrary has not been proved. This fact, however, does not exclude the possibility that they may have occurred, but the drill-hole sections do not give any real information about it.

The youngest tectonic features found in the mine area are small fissures traversing the ore-bodies in different directions. Small faults have also occurred along some but they are without any mineralization.

Metamorphism

In the area surrounding the Lainijaur deposit and its intrusive the metamorphism is of low grade being in the chlorite-sericite stage. The carbonates are unaltered and no formation of lime-silicate skarn has occurred.

From the petrographic description it can be seen which metamorphic products are found in the mine. All can be related to the intrusion of basic magma or with the ore formation associated with it. By assimilation of the wall-rock in the basic magma contaminated rocks of different acidity have been formed. The acid beds in the sedimentary rocks have been most easily assimilated while more basic layers and especially the beds rich in lime have been more resistent. Thus bands and elongated fragments of lime-silicate skarn are found in the gabbro and without doubt originally have been beds in the sediments. In these fragments there occurs a zonal structure more or less well developed, with light coloured lime-silicate as clinozoisite and sometimes wollastonite in the centre. Then follows a zone rich in grossularite and then outermost a crust rich in light-green diopside. Also in the sediments outside the intrusive this alteration in lime-silicate skarn occurs, but it decreases very rapidly outwards.

An extensive amphibolitization of the sediments and especially of dacitic tuffs has also occurred in connection with the gabbro intrusion. The amphibolitization, too, decreases outwards from the intrusive. The drill-hole sections show how the sedimentary rocks wedge in from the sides into the gabbro phacolith. The pure amphibolites reach farthest and also occur as swimming fragments in the gabbro. In the inner parts of the gabbro "wings" there is a diffuse transition from gabbro into amphibolite and an exchange between the sediments and the intruding magma seems to have occurred.

Psammitic portions of dacitic composition (tuffs) have been affected very little by the gabbro while on the contrary they have been strongly metamorphosed by late solutions emanating from the ore. Thus granitization phenomena of all stages are found in such psammites where it lies around vein terminations. Here quartz-diorite has been mobilized and migrated into veins and secretions. The close relationship between ore formation and granitization appears from the fact that these veins and secretions commonly contain plenty of sulphide and arsenic minerals and that the fissures containing the quartz-diorite can be followed to some ore termination.

In the gabbro proper there has occurred a deuteric alteration resulting especially in a new formation of amphibole.

Summary of Geological Events in Lainijaur

The sedimentary rocks at Lainijaur referable to the phyllite series of the Skellefte District, or the Elvaberg series as it is called by G. Kautsky (1957), were affected by folding. In the bottom of a syncline a fracture was formed with the direction N 45° E, 55° W, and this was intruded by a basic magma. The magma was injected in several stages, crystallized and broken up again. It not only followed the fracture through the sediment beds but also extended laterally as sills. A little higher up the magma expanded to an intrusive body of phacolith shape, the sediments being to a large extent assimilated by the magma.

The gabbro intrusion took place in connection with movements in the sediment beds not only perpendicular to the direction of the fracture but also parallel to it. Thus at about the 100 m level there are structures indicating a considerable compression in the direction of the fracture during the time of gabbro intrusion.

In spite of the fact that the magma has intruded the fracture in the bottom and then spread along several horizons the stratigraphical sequence of the sediments has remained undisturbed. The magma had the power partly to replace the sediments and partly to rise by magmatic stoping.

An idea that the whole of the gabbro phacolith could be a metasomatic product can be disregarded inter alia on account of the fact that the present beautiful drops of sulphide could hardly have been formed in that case.

The assimilation of the sedimentary rocks gave the intruding magma a very varying composition generally growing more and more acid upwards. Assimilation was not, however, complete. Undigested fragments and flips of wall-rock were swimming in the magma. In the upper portions recrystallization with the formation of quartz-diorite and micropegmatite seems to have taken place during substance exchange, at least partly in the solid state. Similar conditions prevailed in deeper lying relict fragments, where the sedimentary structures still remain. The wall-rock along the dike has been very little affected by the intruding magma owing to the protective covering formed by the first and rapidly crystallized gabbro.

The rising basic magma brought considerable amounts of sulphide concentrated in the magma at a deeper level. The section through the gabbro phacolith shown in dh 9 (Table V) has an average of 2 % S and the frequency distribution of all the sulphur analyses made on samples from the gabbro phacolith is concentrated around a mode value of about 2.5 % S. According to Wager (1957) the solubility of sulphides in a basic magma corresponds to 0.01—0.05 % S. The gabbro of the Lainijaur phacolith thus contains about 100 times as much sulphide as its magma ever was able to keep dissolved, and the gabbro of the dike contains still more. The concentration of the sulphides thus has taken place in the magma before the intrusion into the portions now exposed to us and then they have been transported with the magma as drops of varying size. Such drops are fixed in the intrusive rocks of both the dike and the sills as well as in the phacolith. It is difficult to say how the concentration of the sulphides at deeper levels took place, but decreasing temperature and pressure of the ascending magma caused liquid unmixing of dissolved sulphides. Whilst ascending and to a certain degree by pulsating movements of the magma, sulphide drops have then merged and become enlarged. Fractures in the wall-rock have been intruded by the sulphide liquid and especially cavities formed in the fracture zone around the foot-wall of the phacolith have provided a site for deposition of the sulphide liquid. Here also the main part of the ore is found. During continued cooling pyrrhotite, pentlandite, chalcopyrite and a lot of accessories crystallized from the sulphide liquid. Intrusion of the gabbro occurred in several different stages between which the magma was able to crystallize. The first crystallized gabbroic portions in the dike show the magma to have been poor in sulphides then growing richer and richer in successive intrusion stages. In addition to the depression of temperature and pressure, assimilation of more acid material also accelerated unmixing of the dissolved sulphides. Magnetite, sometimes collected in large lumps, is also an early crystallization product of the magma. A gravitative differentiation also in the phacolith may have contributed to the fact that the sulphide minerals richly occurring as disseminations and drop-formed portions in the gabbro are especially concentrated in its lower parts.

In the latest stage of the crystallization of the gabbro a very intense deuteric alteration has taken place. Hornblende especially but also biotite, chlorite, serpentine and talc have then been formed.

In connection with crystallization and shrinking of the gabbro phacolith the sediments and the overlying gabbro were brecciated around the contact zone. Movements both upwards and downwards have also been registered in fault planes coincident with the contacts of the big gabbro dike against the wall-rock. The play between gabbro and sediment has been filled up by sulphide liquid of the same type as in the drops swimming in the gabbro. A pulsating movement apparently has occurred and the sulphide liquid seems to have been squeezed out of the crystallizing gabbro and accumulated in the cavities and zones of weakness. In favour of this idea is the fact that no feeding channels for the sulphide liquid have been found in spite of excellent exposures.

The sulphide phase in the disseminated ore has such a composition that divided into two fractions it may have given birth to nickel-pyrrhotite ore and nickel-arsenic ore. Apparently such a differentiation, probably by immiscibility, has occurred in connection with injection and deposition of the compact ore. During the crystallization of this nickel-pyrrhotite ore with a very simple composition the solutions rich in arsenic and metals were driven out peripherally and from these the minerals then crystallized, forming nickel-arsenic ore and ore pegmatites in the periphery of the nickel-pyrrhotite ore-bodies. Formed during the pneumatolytic-hydrothermal stage, here occur all transitional forms from nickel-pyrrhotite ore to low temperature hydrothermal formations with sphalerite, galena, quartz and calcite. A surplus of volatiles has gone out from the distal extremities of the ore-bodies and migrated along fissures causing granitization and other alterations in convenient parts of the sedimentary series.

The zinc grade of the gabbro and disseminated ore is remarkably high being on an average 0.05 % (Table V). The solid nickel-pyrrhotite ore has a zinc grade being only a little higher, 0.12 %. (See Table XII.) The zinc, at least partly, goes into the sphalerite, which sometimes can be recognized with the naked eye. The frequency distribution of the ratios S : Zn (Fig. 27) is concentrated around a mode of 40 in the disseminated ore and 150 in the nickel-pyrrhotite ore. Thus at the differentiation of the primary sulphide phase, which is equivalent to the sulphide phase of the disseminated ore, the zinc only stayed in the nickel-pyrrhotite ore to a small extent, the main part going further into the nickel-arsenic ore stage.

Along with the zinc went also several other elements like copper, cobalt, arsenic and a great many of the trace elements recognized in the nickel-arsenic ore.

Within the third ore formation stage, the nickel-arsenic ore, a complicated crystallization differentiation took place resulting in several groups of ore minerals. Principally the first was the formation of arsenic minerals followed by the copper minerals and then scheelite, molybdenite, sphalerite and galena. Feldspars, quartz, carbonates and some phlogopite and tourmaline also belong to this pegmatitic-pneumatolytic stage ending in a low-hydrothermal stage. Fig. 41 gives a simple review of the progress of the ore differentiation at Lainijaur.

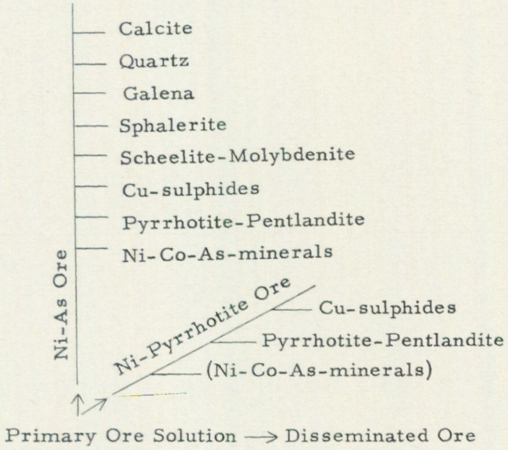


Fig. 41. A simple review of the progress of ore differentiation at Lainijaur.

Brief Outline of other Nickel Deposits in Sweden

For comparison with Lainijaur I here give an account of other nickel deposits in Sweden as found by an extensive nickel prospecting campaign carried out by the Boliden Mining Co over the whole of the country in the years 1941—1944. Principally the nickel prospecting was an examination of greenstone areas known from published geological maps or from geological surveys by the Company. As nickel ores are mostly bound to basic intrusives and com-

Table XIII. The relations between S, Cu, Co and precious metals in the principal nickel deposits and prospects in Sweden and in some well-known nickel deposits in other countries

Country Mine or prospect	Reference	Ore type	Associated rock	$\frac{S-S_{Cu}}{Ni'}$	$\frac{Ni}{Cu}$	$\frac{Ni}{Co}$	Ag, ppm	Au, ppm	Pt metals, ppm
Sweden									
Nilsliden	p. 69	dissem.	Serpentinite	4					
Åvike	p. 70	»	Gabbro-diabase	4; 9	1.2; 1.1				
Routevare B; A	p. 68	»	Olivine-yamaskite, diorite	9; 14	0.4; 1.5				
Storbodsund B	p. 69	massive	Gabbro	9.1	4.8				
» C	p. »	»	»	9.2	15.4	37	3	tr.	
» A	p. »	dissem.	»	10.2	1.1				
Ruda	p. 73	massive + dissem.	Norite	ca 10	2	22			
Lainijaur A Total	Tab. XII	» + »	Olivine-gabbro	9.2; 10.8	2.4; 2.0	17; 17	6; 5	tr.	
» I	» V	dissem.	» - »	11.3	0.9	10	2	0.2	
» II	» VI	Ni-pyrrh.	» - »	12.6; 12.4	17; 7	273; 85	<2; 4	tr; 0.2	< 0.1
» III	» VI	Ni-As	» - »		5.3	8.9	18	4.3	< 0.1
Appojokk	p. 68	dissem.	Melagabbro; diorite	11	1.9				
Kleva I	Tab. XIV	massive + dissem.	Gabbro, bronzite-norite	12.6	4.8	7.5	6	0.4	
» II	» XIV	» + »	» »	13.3	1.8	8.2	6	0.3	
Kuså	p. 71	» + »	Melagabbro	13	0.9				
Ekedal	p. 73	» + »	Melanorite-gabbro	16.4	5.8	7			
Notträsk B; A	p. 68	dissem.	Gabbro	16; 22	–; 0.8				
Bastuträsk	p. 69	»	»	19	1.2				
Ö. Skogträsk	p. 67	»	Gabbro, quartz-diorite	20.5	1.3				
Frustuna	p. 73	massive + dissem.	Gabbro	21	1.1; 3.0	11; 19			
Gaddbo	p. 73	» + »	Melaquartz-gabbro	23	2.5	22			
Rossvik	p. 69	dissem.	Gabbro	23; 29	0.4; 2.7				
Påläng	p. 68	»	Quartz-diorite	27					
Förnätra, hand sample	p. 69	massive	Diorite	31	0.3	9			
Förnätra, 15 m leval	p. »	»	»	35	0.6				tr.
» , Surface	p. »	»	»	36	0.5				»
Rian A; B	p. 68	dissem.	Diorite, quartz-diorite	36; 40	2; 4.4				
Loos	p. 70	veins		74	0.04	0.9			
U.S.S.R.									
Petsamo, average	Tab. XIV	dissem. + breccia	Peridotite	2.0	[1]1.9		25	0.2	

Finland									
Makola	a	dissem.	Norite		2—3				
Norway									
Hosanger, Litland.	b	dissem. + massive	Norite	5.7; 1.8	7.7; 1.8	[2]18—24	1	0.045	0.18
» , Lien	b	» + »	»	6.3; 7.6	2.5; 2.0			0.030	0.11
Flåt, total	c	massive + dissem.	Diorite		1.7	8		0.11	0.07
»	c	rich ore	»	8.9	1.8				
»	c	usual ore	»	7.1	1.4				
»	c	poor ore	»	19.1	1.3				
Canada									
Sudbury, Creighton	d, e	massive	Norite	5	2				0.3—0.8
» , Garson	d	»	»	6	1				
» , Frood-Stobie. .	d	»	»	< 7	0.2				
» , » - » . .	d, e	dissem.	»	7	1—1.4				2—4
» , Levack	d	breccia	»	7	2				
» , Murray	d, e	»	»	8	2				0.3—0.8
» , Year average .	f				1.6		6	0.005	0.2
Falconbridge, Hardy . .	g		»	7	[3]2	24			
Mystery Lake	g		Peridotite		142	36			
» »		veins			16—45				

For references see the bibliography p. 78 ff. a) Aurola 1954, b) Björlykke 1949, c) Björlykke 1947, d) Int. Nickel 1946, e) Foslie-Höst 1932, f) Schneiderhöhn 1941 p. 94, g) Wilson-Anderson 1959.

[1] Väyrynen 1938 considers 1.5 to be a good average ratio for all the Petsamo deposits.

[2] Björlykke 1949 regards Co as being combined with pyrite and pentlandite while the pyrrhotite has a low grade of Co.

[3] Constant with the depth.

monly appear as marginal deposits the marginal zones of greenstone massifs were especially carefully examined. At the same time as we looked for sulphide disseminations in greenstone outcrops we also hunted for ore boulders in the neighbourhood (cf. Grip 1953). Our prospecting methods were very effective. Thus the small Storbodsund deposit was found at the end of a string of glacial boulders, which we had followed 60 km from the first boulder of disseminated gabbro.

Nickel deposits are commonly surrounded by a comparatively large area with disseminated nickeliferous pyrrhotite and some chalcopyrite. The solid pyrrhotite ore weathers very easily and therefore it is not expected to be found either in outcrops or in boulders. Greenstone richly disseminated with sulphides on the contrary does not weather very easily. Therefore in the prospecting we tried to localize and limit areas with the richest disseminations and then select the richest sulphide parts by geophysical methods.

There are several types of sulphide dissemination in greenstones, but the presence or absence of nickel cannot be determined with the naked eye. From the type of dissemination, however, it can be deduced whether a nickel content is probable or not. Pyrrhotite dissemination alone is not a good indicator of nickel while on the contrary a dissemination of pyrrhotite accompanied by smaller amounts of chalcopyrite has proved to be a good indication of nickel. — After analysis the ratio S : Ni in poorly disseminated rocks may decide if an area is worth a careful investigation or not.

In our nickel prospecting those areas investigated first were those favourably located from a transportation point of view. Greenstones up in Caledonian Mountains were investigated in connection with chrome prospecting carried out in the Caledonian of Västerbotten and Jämtland in 1942 (cf. Du Rietz 1956), but greenstone massifs in other parts of the Caledonides and others far away in most remote northern parts of Sweden have not been examined.

In order to find regularities in the nickel-grades of the greenstones I have tried to divide the intrusives according to their age, but the nickel-grade of the rocks does not seem to be dependent on the age. In the following pages therefore I describe the deposits and prospects geographically beginning with the Caledonides and taking the Precambrian from north to south.

Except for intrusive basics various rocks with disseminations of pyrrhotite such as schists, porphyries, and medium acid intrusives have also been sampled and analysed but with completely negative result. A total of 559 nickel determinations have been made on rocks from Northern Sweden excluding those from the deposits at Lainijaur, Storbodsund, and Förnätra, and about 2 000 nickel analyses from Southern Sweden. — It is to be noted, that it has been possible to exclude most of the greenstones without any analyses just by ocular examination. — 41 % of the nickel analyses from N. Sweden have given a higher percentage of Ni than 0.10 %. On the following pages only those areas will be described, which have given Ni percentages higher than 0.1 %. Arranged by increasing S : Ni ratios the ratios S : Ni, Ni : Cu and Ni : Co of the different Swedish deposits are grouped together in Table XIII.

Nickel in Ultrabasic Rocks of Caledonian age

In connection with prospecting for chrome in 1942 nickel analyses and in several cases cobalt analyses also were carried out. It was proved that the chrome-bearing ultrabasites always contained nickel and some cobalt. 108 analyses of chrome-bearing ultrabasites with less than 1 % Cr gave an average of 0.29 % Cr, O.25 % Ni, and Cr : Ni = 1.2. Mostly the ratio Ni : Co is about 10. With increasing percentage of chrome the percentage of nickel decreases a little. Thus samples of rich chrome ore show lower contents of nickel than the chrome disseminated greenstone.

Du Rietz, who made this survey in the Caledonides, states in his paper of 1955: "The nickel content of the peridotites is fairly constant, averaging a little above 0.2 %. The content is not, however, so constant as that of chromium. It may thus vary between 0.1 and 0.5 % in neighbouring occurrences, but it is very disseminated and never concentrated as the chromium often is."

"The weathering of the Swedish ultrabasic rocks is very slight so no secondary enrichtments of nickel at the surface have occurred."

Du Rietz found the nickel partly bound to the magnesium silicates, partly to nickel and iron sulphides and to a lesser degree to primary chromite and chromiferous magnetite. The content of sulphides increases with serpentinization of the peridotite. The most common sulphides found were pentlandite, heazlewoodite, and nickel-bearing pyrite. Other minerals recognized were bravoite, pyrrhotite, marcasite, chalcopyrite, and awaruite.

Nickel in Pre-Cambrian Basic Intrusives[1]

The nickel deposit at *Ö. Skogträsk,* 8 km S of Nederkalix, is situated in the southern margin of a basic massif with an area of about 25 km^2. The massif largely consists of tonalite and only on its southern border is it gabbroic or gabbro-dioritic. S of the gabbro there are black, graphite-bearing schists older than the gabbro and dipping steeply below it. Thus the schist forms the foot-wall of the ore.

The nickel ore has been investigated by trenching and drilling in 1940—41 and I had the opportunity to examine the exposures and drill-cores at that time. The nickeliferous pyrrhotite occurs as rich disseminations in the gabbro. The disseminated gabbro is especially brecciated towards the foot-wall and the fissures filled with pentlandite-bearing pyrrhotite and some chalcopyrite. The pyrrhotite here is very coarse-grained. There is no concentration of pure sulphides along the contact to the schist, but in the schist there also occur some very dispersed disseminations of pyrrhotite. Disseminated pyrrhotite is also found in the tonalite, but there the ratio S : Ni is high while in the gabbro this was found to be 25 and 23 with Ni-percentages of 0.10 and 0.19.

At the surface the area of the ore-body is about 850 m^2. At the 20 m level

---

[1] The locations of the principal Swedish deposits and prospects are indicated on Fig. 1.

where the ore is traversed by 7 diamond drill-holes it is about 500 m^2 and contains 9.3 % S, 0.44 % Ni, 0.34 % Cu.

The *Påläng* massif, W of the former, is about 5 km^2 in area and has a similar composition. Nickel is lacking except in one sample, which contains 3.5 % S, 0.13 % Ni.

The *Rian* massif, NW of Nederkalix, is similar to the Skogträsk massif. It is also a tonalitic massif with a basic margin in the south. Here rich pyrrhotite concentrations are found, but the nickel percentages are low throughout except in two glacial boulders which have slightly higher percentages:

A.	16.7 % S	0.46 % Ni	0.23 % Cu.
B.	24.3	0.61	0.14

At *Notträsk,* E of Boden, there is a gabbro massif with rich disseminations of pyrrhotite. Local people here have carried out some excavations. The nickel percentages, however, are low and the ratio S : Ni high with some exceptions:

A. A boulder....	2.3 % S	0.10 % Ni	0.12 % Cu.
B. An excavation	3.6	0.22	

In the Jokkmokk area two intrusives have proved to be nickeliferous, namely, one at *Routevare* and one at *Appojokk,* both S of Jokkmokk. Analyses with more than 0.1 % Ni have the following averages:

	S, %	Ni, %	Cu, %
Routevare. A. 3 boulders	2.3	0.16	0.11
» B. An outcrop........	1.2	0.11	0.25
Appojokk, 12 boulders	3.8	0.32	0.17

The highest Ni-value at Routevare was 0.29 % and at Appojokk 0.48 %. Gabbro, gabbro-diorite, and diorite at Appojokk occur as fragments swimming in Lina granite and the basic rocks are disseminated with magnetite and more or less nickeliferous pyrrhotite. W. Larsson (1942) determined two samples from Routevare as calciclase-gabbro-yamaskite and yamaskite-peridotite respectively and two other samples from Appojokk as meladiorite and melagabbro respectively.

The geological setting of the Lainijaur nickel deposit was the basis for investigations of other gabbros around massifs of Sorsele granite. During this survey the string of glacial boulders was found which, when followed 60 km, led to the discovery of the nickel deposit of *Storbodsund* on the north side of lake Storavan (Grip 1953). Here was found a gabbro intrusion previously unknown and forming a border along the western margin of a massif of Sorsele granite (Grip 1946). The gabbro is partly disseminated with sulphides and the nickel ore is bound to such a part of the gabbro.

The Storbodsund deposit, covered by 5 m of moraine, consists of a flat sheet of nickeliferous pyrrhotite with an area of 700 m^2 and a thickness of 0.6—2.7 m. The tonnage of ore proved by drilling is 3 000 tons. Beside pyrrhotite and pentlandite the ore contains some chalcopyrite and considerable amounts of pyrite and magnetite. The hanging-wall of the ore consists of gabbro with fragments of metarhyolite and granite, which are often highly assimilated. A hybrid rock is the result. — The foot-wall of the ore consists of metarhyolite and Arvidsjaur granite, both of which are older than the gabbro.

The following table shows analyses of the sulphide disseminated gabbro boulders, which led to the discovery of the deposit at Storbodsund, and the composition of the ore there:

	S, %	Co, %	Ni, %	Cu, %	As, %	Au, ppm	Ag, ppm
A. Average of 34 boulders	3.0		0.27	0.24			
B. Average of proved ore	22.2		2.4	0·5			
C. Dh 1. 1.3 m section	34.4	0.10	3.70	0.24	0.09	tr.	3

The values for S : Ni are very similar, 10.2, 9.1 and 9.2 respectively, and they also are very near the S : Ni ratio of the Lainijaur ore which is 10.

In the Skellefte District contents of nickel are very rare. A glacial boulder at *Löparliden,* 10 km WNW of Malå contains 1.4 % S and 0.11 % Ni. — At *Kvavisträsk* a glacial boulder contains 2.2 % S and 0.17 % Ni. — A series of boulders, of which three contain more than 0.1 % Ni, seem to originate from a gabbro massif at *Bastuträsk.* On average the three best of these boulders contain 2.8 % S, 0.14 % Ni, 0.12 % Cu. — Samples from two exposures of serpentinite (hornblende-bearing pyroxene-dunite according to Larsson 1942) at *Nilsliden,* 20 km NW of Boliden show 0.5 % S and 0.14 % Ni.

A small occurrence of peridotite more or less altered to serpentinite at *Gravmark* in Sävar, 30 km NNE of Umeå, is reported to contain small amounts of niccolite (Hedström 1923). This mineral, however, must be very rare or entirely removed with the asbestos mined during World War I because on our examination we could not find any trace of nickel minerals at the old excavation.

The sulphide deposit at *Förnätra,* 14 km SW of Örnsköldsvik, is bound to a fine-grained diorite or to its more basic parent rock. Du Rietz 1943 found the ore and diorite magmas to have been intruded in flat dipping fracture zones through an earlier consolidated granodiorite or mostly along the contact zone between the granodiorite and a highly metamorphosed graywacke. Apparently a sulphidic phase separated from the mother magma and was in a liquid state longer than the crystallizing diorite magma. The fine-grained texture of both the ores and the surrounding diorite indicates a rapid consolidation. There are two ore bodies. The western and bigger of them with an area of 700 m^2 gives the following analyses:

	S, %	Fe, %	Co, %	Ni, %	Cu, %	As, %	Pt, ppm
Surface	19.1			0.51	1.0		tr.
15 m level	15.6			0.43	0.7		tr.
Hand sample	23.8	37.8	0.08	0.75	0.24	0.09	

At *Rossvik,* Nora, about 20 km N of Härnösand, a couple of gabbro boulders containing some nickel were found:

A.	2.8 % S	0.11 % Ni	0.25 % Cu
B.	11.0	0,43	0.16

In the Västernorrland County Jotnian basic intrusives are widespread forming flat-lying intrusive bodies or sills. The gabbro-diabase there sometimes being titanomagnetite-bearing, is commonly free from or very poor in sulphide minerals. One exception, however, has been noted. At *Åvike,* S of Sundsvall, pyrrhotite disseminations occur in gabbro-diabase. A sample from an outcrop A and another one from a boulder B contained:

A.	1.0 % S	0.19 % Ni	0.16 % Cu
B.	1.7	0.17	0.15

In the southern part of Sweden several nickeliferous deposits have been known for a long time and mined during longer or shorter periods. During our nickel prospecting campaign there comprising systematic investigations of almost all greenstone areas no new deposits of any value were discovered nor was much ore found remaining in the old mines. None of the older deposits have been large, but some of them at an early time have been discussed in the literature especially by J. H. L. Vogt and have played a certain role for the development of theories about the genesis of nickel deposits. Therefore I will mention the most important of them.

In the *Loos-Hamra region,* described by von Eckermann in 1936, there is an extensive area with greenstones belonging to the "Lower Loos Series". In the neighbourhood of Loos they consist of "old basaltic lava flows erupted from a N—S fissure", and here, bound to late-magmatic albitic concentrations, there occur ore concentrations "which, in the 18th century, gave birth to extensive mining in the Loos Hills. These ore-bodies — or rather impregnated ore zones — occur mostly in the vicinity of the boundaries towards the surrounding rocks." In the Loos cobalt mine, however, the ore occurs in a "N—S striking calcite-filled fissure in the lava. The minerals recorded from the Loos mines are pyrites, pyrrhotite, chalcocite, chalcopyrite, sphalerite, galenite, arsenopyrite, niccolite, smaltite, cobaltite, native bismuth, bismuthenite and fahlerz." — Also gersdorffite has been found, and in gersdorffite from Loos in 1751 the Swedish chemist A. F. Cronstedt discovered the element nickel (Tegengren 1924).

During the prospecting work carried out about 30 years ago by the Boliden Mining Co in the Loos area some new but small ore mineralizations were found. Within the area there are small deposits both of the disseminated nickel-pyrrhotite type (e.g. Rullbo) and the nickel-arsenic type. The latter type occurs as veins and in these arsenic and also cobalt play an important role. The dominating nickel mineral seems to be gersdorffite and the cobalt mineral cobaltite. A section in a drill-hole at Kvarnsjögruvan, 4 km NW of Loos, gave the following analysis: 11.00 % S, 0.12 % Co, 0.11 % Ni, 2.79 % Cu, 65 ppm Ag, 0.5 ppm Au. The ore is banded and schlieren rich in lead, zinc, copper, and nickel alternate. Sometimes Co dominates over Ni, and sometimes Ni is dominant.

The largest nickel deposits in Southern Sweden are *Kuså* and *Slättberg* in the Kopparberg County, which up to 1920 have together produced 35 384 tons of ore yielding 510 tons of nickel, and *Kleva* in the Jönköping County, which up to the same year has produced 54 380 tons yielding 1 027 tons of nickel. Of these deposits Kuså and Kleva belong to the common type of disseminated nickel-pyrrhotite ore. Slättberg on the contrary is of quite another type with the ore bound to a metabasite dike 1 600 m long and 2—6 m wide. Pyrite, chalcopyrite, and nickel-pyrrhotite here seem to be the dominant ore minerals.

E. Dahlström in 1943 gave a report on the *Kuså* mine and with his permission I follow his description. The Kuså deposit is situated in the margin of a small gabbro intrusion. The composition of the intrusive is very variable. Hornblendite seems to be the most common type, but at the 32 m level in the mine the ore occurs in an olivine-hypersthene gabbro. In the contacts to the surrounding granites there occur hybrid rocks with hornblende, andesine, biotite, and sometimes a lot of quartz. Also monzonitic types are found in the vicinity of the boundaries to the granite. — The relation between the gabbro and the surrounding Archean granite is not quite certain, but the gabbro seems to be younger. It is, however, cut by a granite dike.

The gabbro intrusion, striking NW and dipping NE, is 150 m long. The ore which has been mined forms an irregular body dipping 50° N 40° E and plunging ca 30° N 18° W. The ore consists of disseminated nickeliferous pyrrhotite and chalcopyrite in the gabbro. Commonly the dissemination is very evenly distributed and the ore minerals constitute up to the half of the rock mass. The dissemination seems to be richer towards the contact to the granite and the ore minerals also occur in the granite in the vicinity of the contact. Commonly the pyrrhotite and the chalcopyrite are intimately grown together, but sometimes the pyrrhotite is pure and according to older reports a very pure copper ore was mined in the hanging-wall on the 20 m level.

By microscopic examination Dahlström found the following ore minerals: pyrrhotite, chalcopyrite, pentlandite, bravoite, magnetite, probably some cobaltite, and linneite. Also some sphalerite has been noted. An analysis showed that there is some platinum in the ore.

Mining for copper at Kuså was started in 1805. In 1817 nickel was identified in the ore. Mining operations have since then been carried out at several periods. In 1940—41 the Boliden Mining Co examined the mine and made some drillings. Much of the remaining disseminated ore was found and taken out. — The total production of the Kuså mine has been 3 500 tons of ore with 13.0 % S, 0.93 % Ni and 1.02 % Cu.

300 m and 600 m SE of the Kuså mine are similar small gabbro intrusions but with lower contents of sulphides.

The *Kleva* deposit was discovered in 1691 and it was mined for copper during a course of years. The content of nickel in the ore was discovered by Berzelius in 1838, and then the ore was treated for nickel and copper (Santesson 1887).

Tegengren (1924) has delivered a summary of the geology of the mine and below I follow his account.

The ore-bearing rock at Kleva consists of gabbro and gabbro-diorite forming numerous small massifs and dikes through the bedrock of the area made up of leptite, gneiss, and granite. The Kleva deposit is situated in one of the largest of these gabbro massifs forming a well marked hill in the terrain.

The central part of this intrusive consists of a gabbro rich in bronzite, partly also of bronzite-norite. Towards the margin of the massif the pyroxene is more or less altered to hornblende. All the ore-bodies are concentrated in the centre of the massif and they seem to be intimately bound to flow structure schlieren striking ENE in the gabbro. The ore forms irregular, mostly steep dipping bodies of nickeliferous pyrrhotite with chalcopyrite. The richest and practically solid ore is found in the central parts of the ore-bodies while the percentage of sulphides decreases outwards to the margins where disseminated ore occurs.

Chalcopyrite and pyrite are found together with the nickeliferous pyrrhotite, but are mostly concentrated in veins which, according to Brögger and Vogt 1887, are slightly younger than the ore-bodies. These authors also have concluded that the ore is a differentiation product of the gabbro magma and formed at the same time as the crystallization of the gabbro.

In 1944 I paid a short visit to Kleva and noted the rich occurrence of more or less assimilated portions of sedimentary rock in the gabbro near the ore-bodies. The sediments contain a rather rich dissemination of chalcopyrite and also some magnetite. I got the impression that the ore or at least one of the ore-bodies was bound to the contact zone between gabbro and partly assimilated sedimentary rocks and that the sulphide liquid has been intruded especially along the inclusions of sediments, where shearing seems also to have occurred.

Table XIV shows analyses of two grades of Kleva ore, taken from the dumps. The figures for Au include also the Pt-metals.

Table XIV. Nickel ore from Kleva and Petsamo

Component	Kleva		Petsamo
	I qual.	II qual.	
SiO_2	2.1	18.7	23.2
Al_2O_3	0.23	7.17	2.56
MgO	0.31	0.85	15.4
CaO	0.87	3.76	3.40
S	33.0	19.6	12.5
Fe	56.9	34.6	24.2
Co	0.34	0.17	—
Ni	2.56	1.40	4.80
Cu	0.53	0.8	2.50
Zn	0.00	0.0	0.00
As	0.04	0.05	0.013
Ag	0.0006	0.0006	0.0025
Au	0.00004	0.00003	0.00002
Ni : Cu	4.8	1.8	1.9
Ni : Co	7.5	8.2	—
FeS + (Fe, Ni) S	87	50	27
100 Ni : [FeS + (Fe, Ni) S]	2.9	2.8	18

Calculation, see Table V.

The average nickel content in the exhausted ore at Kleva is calculated to have been 1.9 % Ni.

The Ekedal and Gaddbo nickel deposits are situated in the Västmanland County, respectively 20 km NE and 15 km SE of the town of Sala. The deposit of *Ekedal* lies at the contact between an olivine-hypersthene gabbro (melagabbro according to W. Larsson) and a diorite, but especially in the former. The ore consists of nickeliferous pyrrhotite, pyrite, and chalcopyrite. There are schlieren of different composition in the intrusive, and the ore especially is concentrated in the basic parts and shows sharp contacts against more acid schlieren. — A total of 1 030 tons of nickel ore have been mined. An average sample taken by Dahlström gave the following analysis: 11.66 % S, 0.10 % Co, 0.70 % Ni, 0.12 % Cu.

The *Gaddbo* deposit lies in the eastern part of a small massif of melaquartz-gabbro to the south bordering upon gneiss-granite. To the north it borders on grey Oldest Archean granite. The margins of the basic massif are often pyrrhotite-bearing and here, in a coarse-grained uralite gabbro, the ore consisting of nickeliferous pyrrhotite and chalcopyrite, is found. It is a disseminated ore sometimes concentrated in richer lumps. — A total of 1 432 tons of nickel ore has been mined. An average sample taken by E. Dahlström in 1941 gave 15.19 % S, 0.03 % Co, 0.66 % Ni, 0.26 % Cu.

The *Frustuna* nickel deposit is situated 3 km south of Gnesta in the Södermanland County. According to Walfr. Petersson (1905), nickeliferous pyrrhotite and chalcopyrite occur as irregular disseminations and minor lumps in gabbro within an area of about 4 000 m^2 forming an E—W zone about 200 m in length. In 1876—78 a quantity of 814 tons of ore were mined from an adit going about 50 m into the mineralized area. On an average the nickel content was calculated to be 0.3 % Ni. From this mined portion a rich ore containing 0.07 % Co, 1.35 % Ni and 0.46 % Cu was picked out.

When Dahlström 1941 inspected the area he found the richest mineralization concentrated in a narrow zone about two meters wide lying in gabbro of varying grain size. The sulphides are bound to the gabbro but lie near the contact to a red granite, forming the main rock in the district. A sample from an old dump of ore gave 19.77 % S, 0.08 % Co, 0.90 % Ni, 0.84 % Cu.

The *Ruda* nickel deposit in the Östergötland County is bound to a norite intruded in the grey gneiss of the area. The ore minerals are nickeliferous pyrrhotite and chalcopyrite and they occur as disseminations in the norite or as irregular lumps.

A total of a little more than 2 000 tons of nickel ore have been mined and of these 1 200 tons of solid ore had an average of 3.5 % Ni. The disseminated ore had lower percentages of metals. Some average samples from the contact zones of the two principal mines gave the following analyses (Tegengren 1924).

	Co, %	Ni, %	Cu, %
1. Ruda, Storgruvan	0.04	0.87	0.43
2. » »	tr.	0.59	0.64
3. » Haggruvan	0.04	0.29	0.43
4. » »	0.02	0.73	0.25

Conclusions

Our prospecting campaign did not give any new nickel deposit of economic value, but I have given this account just to show the types and the distribution of the nickel mineralization in Sweden. Lainijaur was found to be the largest nickel deposit in the country followed by Kleva, which has produced about half as much nickel as Lainijaur. I have tried to classify the nickel mineralizations according to their age, but the formation of nickel deposits did not prove to have been fixed at any special geological period. — Most of the Pre-Cambrian nickel deposits mentioned above are bound to rather small basic intrusions and that fact also may be the reason why the deposits are of such a small size. J. H. L. Vogt as early as 1893 pointed out that the size of a nickel deposit depends on the size of the related basic intrusion. According to Wager (1957) the solubility of the sulphide phase in a basic magma is rather small, namely 0.01—0.05 % S. Large amounts of magma then are necessary to account for the sulphides of a real deposit. If all sulphides were extracted from a basic magma the proportion magma: sulphide would be 1 000: 1, but in general the basic rocks around nickel deposits still contain considerable amounts of sulphides and evidently only a small part of the sulphide content of the original basic magma contributes to the formation of a nickel deposit.

The ratios Ni : Cu of the Swedish nickel deposits (Table XIII) have a mean value of 1.2, but the spread is very large and there is no relation to the ratio S:Ni giving any hint of the origin of the ores.

In his microscopical study on the relation between nickel grade and rock type W. Larsson (1942) found high nickel grades to be preferentially bound to melanocratic intrusives while leucocratic rocks were poor in nickel. This fact was clearly established in several of the areas examined by us, for example in the basic intrusive of Ö. Skogträsk. — It is also illustrated by Table XIII which shows that the S:Ni ratios of the Swedish nickel deposits increase with increasing acidity of the rocks. — Larsson concluded that the sulphides and the early crystallized dark minerals had been segregated by gravitative differentiation, and he considered this type of differentiation to be of the greatest importance for the formation of nickel deposits.

I agree with Larsson in the possibility of such ore formation, but Lainijaur as well as several other deposits, for example Kleva and Förnätra, show features indicating the importance of tectonic movements for the concentration of the ore in the deposits. Therefore I do not think that the formation of our nickel deposits can be explained by gravitative differentiation in a liquid state alone. Such a process may have been a primary and very important stage of the ore formation, but the concentration into solid sulphide ore has been controlled by tectonic movements during phases of decreasing temperature and pressure with a squeezing out of the sulphide liquid. Intrusion of this liquid into suitable structures such as breccias and shearing planes has then taken place especially along contacts against the older wall-rock.

Comparisons between Lainijaur and Other Nickel Deposits

The Lainijaur deposit is similar to many other nickel deposits in the world, even if it has peculiarities such as the linear shape of its ore-bodies controlled by a gabbro dike, and its quantitatively important nickel-arsenic ore. The disseminated ore and the compact nickel-pyrrhotite ore are types often found in nickel deposits. They occur in most of the Swedish and Norwegian nickel deposits, e.g. in Kuså and Kleva (p. 71), in Flåt (Björklykke 1947) and Hosanger (Björklykke 1949), and they also form the main part of the ores in the Sudbury deposits (Lindgren 1933, Int. Nickel 1946), where also a breccia ore partly seems to correspond to the nickel-arsenic ore at Lainijaur (Yates 1948, Davidson 1948).

Like most nickel deposits Lainijaur is a "marginal deposit" also, and the ore is concentrated along the contact with an older rock in the bottom. The disseminated ore is a little enriched towards the foot-wall and gravitative differentiation may have contributed to this fact, but the compact ore in the bottom is a clear injection phenomenon along a tectonic fracture zone running about parallel to the contact between the gabbro and the sedimentary rocks. Conditions are similar at several of the Sudbury deposits (Lindgren 1933) as well as at Flåt and Hosanger in Norway, Makola (Huhta 1954) in Finland and at Petsamo (Väyrynen 1938, Haapala 1945) in that part of Finland ceded to the U. S. S. R. Especially in the Petsamo deposits, as shown by Väyrynen, it cannot be a question of a gravitative differentiation in situ, but the ore must have been injected as a liquid in tectonic zones of weakness.

The disseminated ore and the compact nickel-pyrrhotite ore of Lainijaur are similar to other Swedish nickel deposits while the nickel-arsenic ore only has analogies with the Loos cobalt veins and in some ore pegmatites in other sulphide deposits in Northern Sweden such as the copper deposits at Laver (Ödman 1945) and Adak (S. Gavelin 1945).

The comparatively high percentage of zinc, 0.05 % Zn in the disseminated gabbro is a special feature of Lainijaur. P. H. Lundegårdh (1948) showed that gabbros and similar rocks of the easternmost part of Central Sweden contain $<$ 0.0005—0.0350 % Zn with an average of 0.0110 % and are thus considerably lower in zinc than Lainijaur.

An interesting fact is that the end products of the ore formation at Lainijaur more and more grow similar to the end products (ore pegmatites) of other sulphide deposits, for instance those of the Skellefte District. — In the micropegmatite of the Sudbury basin there occurs a copper-zinc-lead mineralization along faults. This mineralization is strongly bound to the Sudbury intrusive and is by Wilson (1953) supposed to originate from a hydrothermal phase of the Sudbury intrusive. This mineralization ~~phase~~ may correspond to the outer parts of the Lainijaur veins belonging to the nickel-arsenic stage.

In the nickel-arsenic stage Lainijaur also has similarities with the nickel deposits of Nassau in Germany described by Ahlfeld 1933. There the sulphide mineralization is bound to an olivine-diabase and the sulphides are supposed to originate from a deep-seated magma of gabbroic composition. Nickeliferous pyrrhotite and chalcopyrite form the oldest ore mineralization. In connection with a carbonatization an intensive re-mineralization with replacement of older sulphides then took place and a suite of new sulphide minerals like niccolite, chloantite, gersdorffite, sphalerite and galena was formed. This suite is a parallel to the nickel-arsenic stage at Lainijaur.

In 1923 J. H. L. Vogt showed that in Scandinavian nickel deposits there is a tendency for the ratio S:Ni to increase with increasing acidity of the associated rock. Wilson (1953) has shown that Vogt's conclusion is also valid for Canadian nickel ores. The present new analyses from Swedish nickel deposits only verifies this fact as shown in the collocation Table XIII, where for comparison some characteristics of the principal Swedish nickel deposits and prospects dealt with above and some others have been put together. In general the ratio S:Ni in the Swedish deposits lies between 9 and 15. Extremely low figures are found in the ultrabasic rock at Nilsliden and the gabbro-diabase at Åvike, while the cobalt-rich ore at Loos has an extremely high figure.

The ratio Ni:Cu varies within wide limits not only from deposit to deposit but also in different parts and different ore types in the same deposit as, for example in Storbodsund 1.1—15.4 and Lainijaur 0.7—17. Also the ratio Ni:Co is very variable, the extremities being 1.1 in Loos and 273 in parts of the nickel-pyrrhotite ore in Lainijaur.

It is especially the ratios between nickel and copper that characterize the ores. J. H. L. Vogt (1893) in his well known work on nickel deposits wrote among other things, that the ratio Ni:Cu should be 100 Ni: 40—50 Cu in the Scandinavian deposits, while it should be 100 Ni: 100—150 Cu in the American ones. Wilson and Anderson (1959) state that Canadian sulphide deposits generally have characteristic compositions. The ratios Ni:S, Ni:Cu and Ni:Co in copper-nickel sulphide ores are characteristic for most ore bodies. The values appearing in Table XIII, however, vary within wide limits, and the largest variations are found within the Lainijaur deposit itself. There every ore type shows a value for Ni:Cu widely different from the others. If the ratio Ni:Cu shall be used for characterizing deposits it is thus necessary to keep the different ore types within the deposit apart or/and to have a very good average of the total ore, which seldom is the case before all the ore is taken out. If plenty of analyses are available the best thing is to construct frequency curves for ratios between certain elements and to use them for characterizing deposits (Wilson and Anderson 1959). How the composition of the ore can vary with depth is shown by reports from the Frood mine at Sudbury (Wilson and Anderson 1959), where the ratio Cu:(Cu + Ni) from the upper parts and down to the 3 300 foot level has the following modes 0.43, 0.50, 0.52, 0.63, 0.87. Other mines show other patterns and for instance in Falconbridge the ratios are constant down to the 4 000 foot level. These two types are considered to represent two different types of ore formation, namely, sulphide segregation in place (Frood) and injection of a pool of sulphide or sulphide-silicate liquid (Falconbridge).

The contents of precious metals in different nickel deposits are difficult to compare because they are incompletely recorded in the literature. Determinations of these metals are difficult to make and considerable faults in analysis therefore can be expected. Nickel ore often contains varying amounts of platina metals. The Lainijaur deposit, however, has not shown any notable content of these metals, and in cases when analyses have been carried out the values have been below 0.1 ppm platina metals. As to Table XIII it must be remembered that the platina metals when not separately determined are included in the values given for gold. (The Kleva ore for instance may contain platina metals but in that case they are included in the figures given for gold, 0.4 resp. 0.3 ppm). — Remarkable is the high content of gold in the nickel-arsenic ore of Lainijaur. None of the other ores quoted in Table XIII have such high gold values. A comparison with the As-Co-Ni-Ag veins in the Lindsköld mine lying only 20 km away and described by S. Gavelin (1945) is obvious. There the same nickel-cobalt minerals are found as in Lainijaur, but the paragenesis also includes plenty of silver minerals, which are completely wanting in the Lainijaur deposit. Gold is very low in the veins at Lindsköld. — The content of gold in the nickel-arsenic ore at Lainijaur also indicates a resemblance with other sulphide ores in the Skellefte District, where gold occurs in arsenic bearing ore. It is a characteristic feature of the Skellefte District that most of the sulphide ore deposits there contain arsenic and gold, and this is also the case with some quartz veins. Therefore the gold content at Lainijaur must be regarded as an inheritance of the milieu in which the ore appears.

Contrary to the other nickel deposits in Fennoscandia Lainijaur is very rich in different minerals (Table VIII). The rich mineral assemblage occurs in the nickel-arsenic ore and to some degree also in the disseminated ore, while the nickel-pyrrhotite ore is very simple in its mineral composition. In Fennoscandia there is no equivalent to the Lainijaur deposit as a whole with its three different ore types, but in the Sudbury District there are deposits where also the nickel-arsenic stage is represented and which have a very rich mineral paragenesis. Michener (1943, 1944, and personal communications) reports more than thirty species of ore minerals there containing a considerable variety of metallic elements. Among these minerals the following also are found at Lainijaur: niccolite, maucherite and other nickel arsenides, galena and sphalerite. In Sudbury these minerals are found in small amounts in the extremities of the common type ore with pyrrhotite, pentlandite and chalcopyrite and generally in quartz or carbonate veinlets. Galena and sphalerite also occur in later, low-temperature fracture fillings.

On account of its limited size and its excellent underground and drill-hole exposures the Lainijaur mine has offered a wonderful opportunity for studying the course of formation of a nickel ore. The mine gives examples of all stages of sulphide ore formation between a late magmatic stage via pneumatolytic-hydrothermal to a low temperature hydrothermal stage. Among all the sulphide deposits of the Skellefte District the Lainijaur deposit is unique, but in these hydrothermal stages it establishes a connection with the other deposits and especially with their ore pegmatites (cf. Grip 1951) even if these deposits do not emanate from basic magmas.

(Manuscript received from Boliden in April 1960.)

References

GFF = Geologiska Föreningens Förhandlingar, Stockholm
SGU = Sveriges Geologiska Undersökning, Stockholm
NGU = Norges Geologiske Undersökelse, Oslo

Ahlfeld, Fr., 1933: Die an Diabase gebundene Nickelvorkommen in Nassau. Sitzungsber. d. Gesellsch. zur Beförd. der gesamten Naturwissenschaften zu Marburg, Bd 68.
Aho, Aaro, E., 1956: Geology and genesis of ultrabasic nickel-copper-pyrrhotite deposits at the Pacific Nickel Property, SW British Columbia. Econ. Geol., Vol. 51.
Aminoff, G., 1943: En rheniumrik molygdenglans. GFF, Vol. 65.
— 1947: Kungl. Vetenskapsakademiens årsbok 1947, p. 202.
Barth, T., 1947: The nickeliferous Iveland-Evje amphibolite and its relations. NGU, No 168 a.
Björlykke, H., 1944: De norske nikkelmalmers mineralsammansetning. Det Kongl. Norske Videnskabers Selskab. Forh., Bd XVII, No 24.
— 1947: Flåt nickel mine. NGU, No 168 b.
— 1949: Hosanger nickelgruve. NGU, No 172.
Dahlström, E., 1941: Frustuna. Unpublished report to the Boliden Mining Co.
— 1943: Kuså gruva. Unpublished report to the Boliden Mining Co.
Du Rietz, T., 1955: The Content of chromium and nickel in the ultrabasic rocks of Sweden. GFF, Vol. 78.
Davidson, S., 1948: Falconbridge Mine. Structural geology of Canadian ore deposits. Can. Inst. Min. Met. Montreal.
von Eckermann, H., 1936: The Loos-Hamra Region. GFF, Vol. 58.
Falconbridge Story. Can. Min. Journ. 1959, p. 122.
Foslie, St. og Johnson Höst, M., 1932: Platina i sulfidisk nickelmalm. NGU, No 137.
Gavelin, S., 1943: On the distribution of metals at Rävliden, N. Sweden, and in some other copper-zinc ores. SGU, Ser. C, No 454.
— 1945: Arsenik-cobalt-nickel-silver veins in the Lindsköld copper Mine, N. Sweden, SGU, Ser. C, No 469.
— 1948: Adakområdet, översikt av berggrund och malmer. SGU, Ser. C, No 490.
— 1955: Beskrivning till berggrundskarta över Västerbottens län. SGU, Ser. Ca, No 37.
Grip, E., 1941: Die Tektonik und Stratigraphie der zentralen und östlichen Teile des Skelleftefeldes. Bull. Geol. Inst. Upsala, Vol. XXIX.
— 1942: Nickelförekomsten Lainijaur. GFF, Vol. 64.
— 1946: Arvidsjaurfältet och dess förhållande till omgivande berggrund. SGU, Ser. C, No 474.
— 1948: On the occurrence of mercury in Boliden and in some other sulphide deposits in Northern Sweden. SGU, Ser. C, No 499.
— 1951: Geology of the sulphide deposits at Mensträsk and a comparison with other deposits in the Skellefte district. SGU, Ser. C, No 515.
— 1951: Tungsten and molybdenum in sulphide ores in Northern Sweden. GFF, Vol. 73.
— 1953: Tracing of glacial boulders as an aid to ore prospecting. Econ. Geol., Vol. 48.
— and Ödman, O. H., 1944: Den geologiska karteringen vid Bolidens Gruvaktiebolags gruvor. GFF, Vol. 66.
Haapala, P., 1945: Petsamo nickelmalmsområde etc. Bergshanteringen nr 1—2, Helsingfors.
Hawley, J. E., Colgrove, G. L., and Zurbrigg, H. F., 1943: The Fe-Ni-S-system Econ. Geol., Vol. 38.
Hedström, H., 1923: Om en ny fyndort för mineralet nickelin i Sverige. SGU, Ser. C, No 317.
Huhta, J., 1954: The nickel-copper ore deposit of Makola. Geol. tutkim., No 55, Helsinki.
Högbom, A., 1937: Nya iakttagelser från Norr- och Västerbottens urberg. GFF, Vol. 59.
Kautsky, G., 1957: Ein Beitrag zur Stratigraphie und dem Bau des Skelleftefeldes, Nordschweden. SGU, Ser. C, No 543.
Larsson, W., 1942: Om sambandet mellan bergsartstyp och nickelhalt i svenska magnetkisförande grönstenar. Unpublished report to the Boliden Mining Co.
Lindgren, W., 1933: Mineral deposits. New York and London.
Lundegårdh, P. H., 1948: Some aspects to the determination and distribution of zinc. Ann. Royal. Agr. Coll. Sweden, Vol. 15.

Mc Kinstry, H., 1959: Mineral assemblage in sulphide ore. Econ. Geol., Vol. 54, No 6.

Michener, C. E. and Peacock, M. A., 1943: Parkerite ($Ni_3Bi_2S_2$) from Sudbury, Ontario. Am. Min., Vol. 28.

— and Yates, A. B., 1944: Oxidation of primary nickel sulphides. Econ. Geol., Vol. 39.

Neumann, H., 1956: Preliminary report on the rhenium content in Norwegian molybdenites. NGT, Vol. 36.

Newhouse, W. H., 1936: Bull. Geol. Soc. Am., Vol. 47.

Pehrman, G., 1954: Über den Magnetismus einiger Magnetkiese. Acta Acad. Aboensis. Math. et Physica XIX: 10.

Phemister, T. C., 1957: The Copper Cliff Rhyolite in Mc Kim Township, District of Sudbury. Ann. Report of the Ontario Dept. of Mines, Vol. 65.

Quinn, H. A., 1956—57: Mineral occurrences between Chipewyan and Herb Lakes, Manitoba. Precambrian.

Ramdohr, P., 1950: Die Erzmineralien und ihre Verwachsungen. Berlin.

Schneiderhöhn, H., 1941: Lehrbuch der Erzlagerstätten. Bd I, Jena, p. 94.

— 1958: Die Erzlagerstätten der Erde. Bd I, Stuttgart.

Staff, International Nickel Company of Canada Ltd., 1946. The operations and plants. Can. Mining Journ., Vol. 67, No 5.

Tegengren, F. R. and co-workers, 1924: Sveriges ädlare malmer och bergverk. SGU. Ser. Ca, No 17.

Thomson, J. E. and Williams, H., 1956: The myth of the Sudbury Lopolith. XX Congr. Geol. Int. Resumenes de los trabajos presentados, Mexico, p. 300.

Thomson, J. E., 1957: Geology of the Sudbury Basin. Ann. report of the Ontario Dept. of Mines, Vol. 65.

Vogt, J. H. L., 1893: Bildung von Erzlagerstätten durch Differentiationsprocesse in basischen Eruptivmagmata. Zeitschr. für praktische Geologie, Berlin.

— 1923: Nickel in igneous rocks. Econ. Geol., Vol. 18.

Väyrynen, H., 1938: Petrologie des Nickelerzfeldes Kaulatunturi-Kammikivitunturi in Petsamo. Bull. Comm. Géol. de Finlande, No 116.

Wager, L. R., Vincent, E. A., and Smales, A. A., 1957: Sulphides in the Skærgaard intrusion, East Greenland. Econ. Geol., Vol. 52, p. 855.

Williams, H., 1957: Glowing avalanche deposits of the Sudbury Basin. Ann. Report of the Ontario Dept. of Mines, Vol. 65.

Wilson, H. D. B., 1953: Geology and geochemistry of base metal deposits. Econ. Geol., Vol. 48.

— and Anderson, D. T., 1959: The composition of Canadian sulphide ore deposits. Can. Min. Met. Bull., Vol. 52.

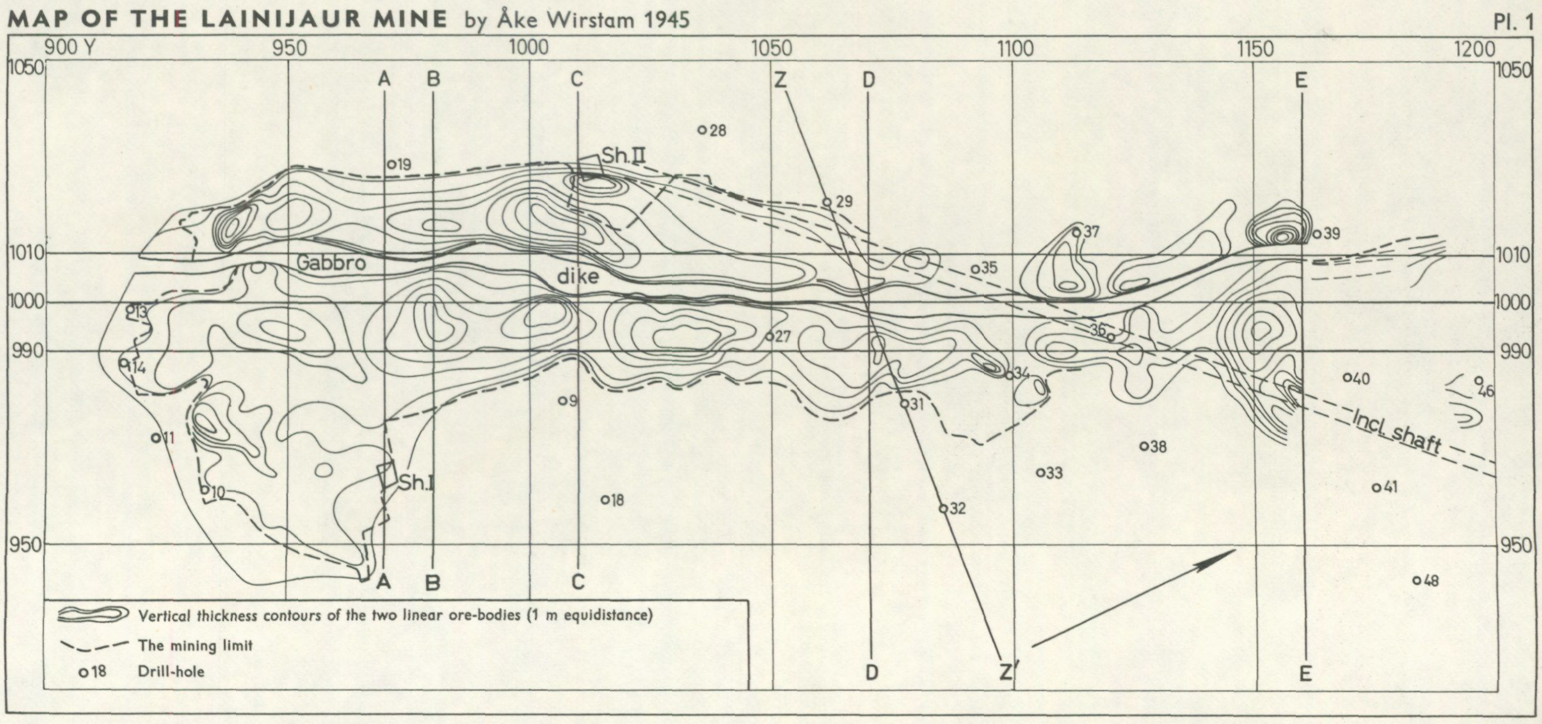
Yates, A. B., 1948: Properties of International Nickel Company of Canada. Structural geology of Canadian ore deposits. A symposium. Can. Int. Min. Met. Montreal.

Ödman, O. H., 1932: Mineragraphic study on the opaque minerals in the lavas from M. Elgon, British East Africa. GFF, Vol. 54.

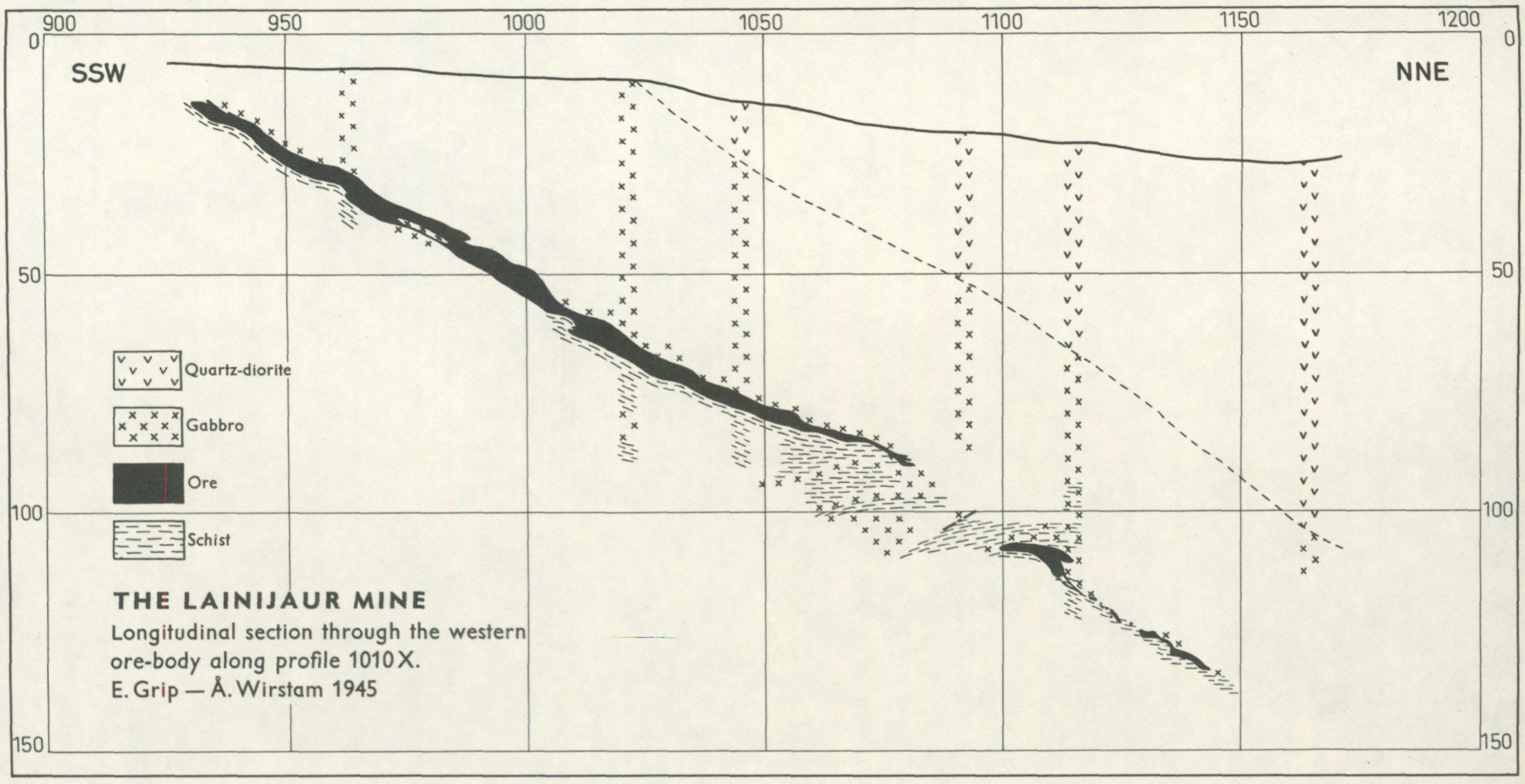
— 1945: A nickel-cobalt-silver-mineralization in the Laver copper mine, N. Sweden. SGU Ser. C, No 470.

MAP OF THE LAINIJAUR MINE by Åke Wirstam 1945

Pl. 1



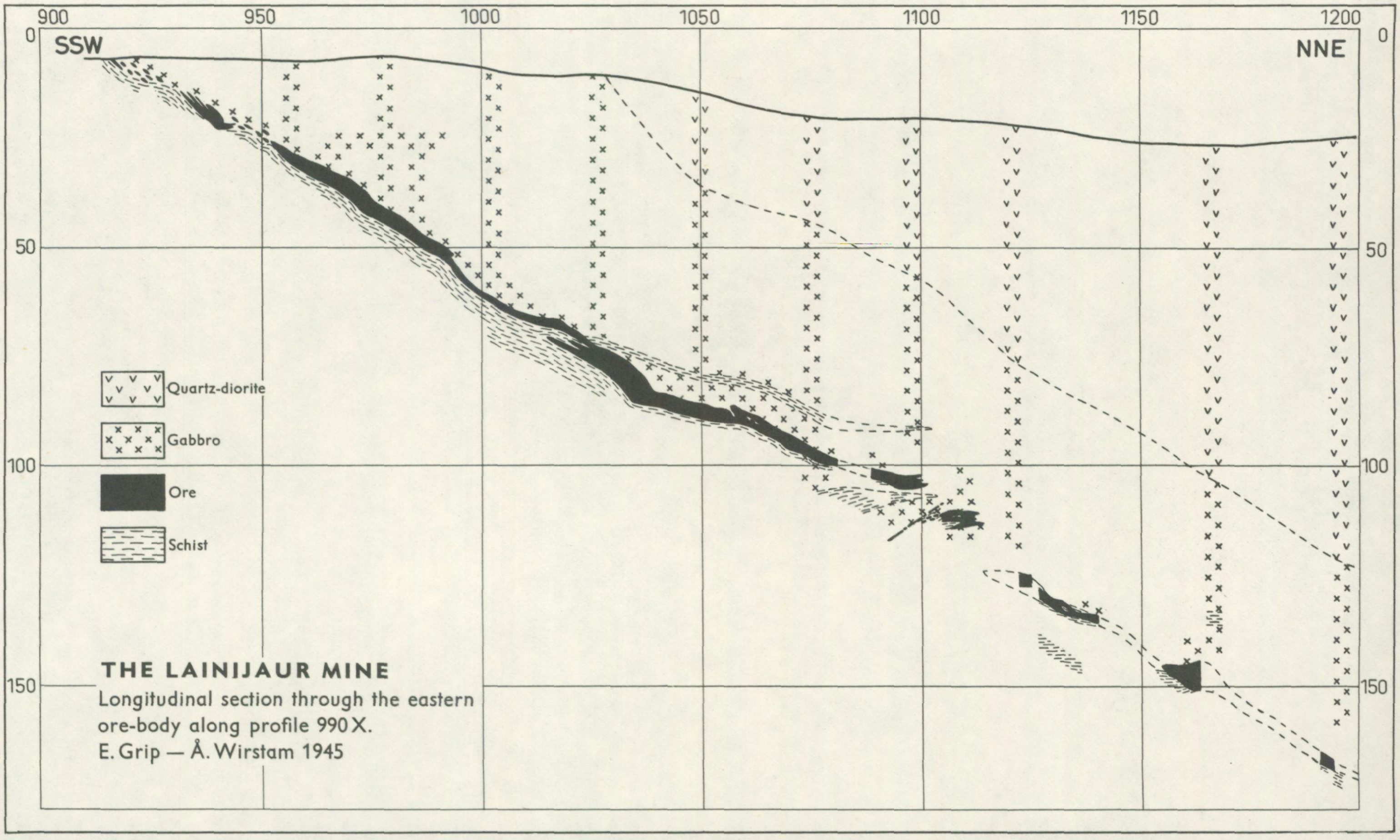
Pl. 2



THE LAINIJAUR MINE

Longitudinal section through the western ore-body along profile 1010 X.
E. Grip — Å. Wirstam 1945

Pl. 3



THE LAINIJAUR MINE

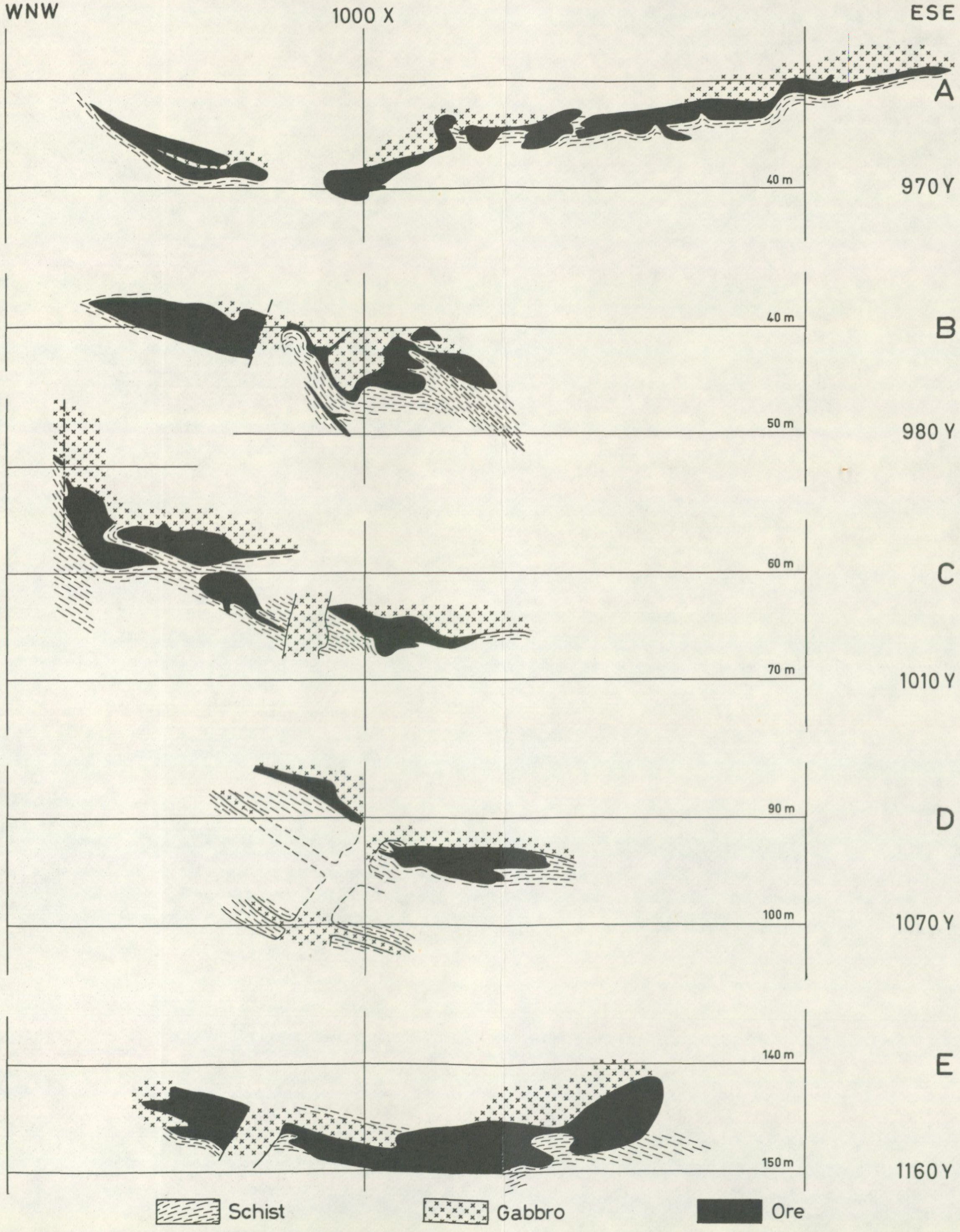
Longitudinal section through the eastern ore-body along profile 990 X.
E. Grip — Å. Wirstam 1945

REPRODUCERAD VID AB KARTOGRAFISKA INSTITUTET
ESSELTE AB. STOCKHOLM 1961

CROSS SECTIONS THROUGH THE LAINIJAUR ORE-BODIES

E. Grip — Å. Wirstam 1945

The situation of the sections are indicated in Pl. I



REPRODUCERAD VID AB KARTOGRAFISKA INSTITUTET
ESSELTE AB. STOCKHOLM 1961

Årsbok 54 (1960)

N:o	570	Lundegårdh, P. H., The miogeosynclinal rocks of Eastern Central Sweden. With one plate. 1960	6,00
»	571	Brotzen, F., On Tylocidaris species (Echinoidea) and the stratigraphy of the Danian of Sweden. — With a bibliography of the Danian and the Paleocene. With three plates. 1959	7,00
»	572	Frietsch, R., En zon av kaolinlera och vittrad blodsten vid Svappavaara, Norrbotten. Summary: A zone of kaolin clay and weathered hematite ore at Svappavaara, Norrbotten. 1960	6,00
»	573	Lundqvist, J., Issjöar och isavsmältning i östra Jämtland. Summary: Ice-lakes and ice recession in Eastern Jämtland, Central Sweden. 1959	2,00
»	574	Fromm, E., An interglacial peat at Ale near Luleå, Northern Sweden. — With contributions by R. W. Kolbe and Herman Persson. 1960	2,00
»	575	Lundqvist G., The interglacial ooze at Porsi in Lapland. 1960	3,00
»	576	Quensel, P., Vaggerydssyeniten. Summary: The Vaggeryd syenite in Southern Sweden. Med en plansch. 1960	4,00

Årsbok 55 (1961)

N:o	577	Grip, E., Geology of the nickel deposit at Lainijaur in Northern Sweden. With four plates. 1961	8,00

Ser. Ba. Översiktskartor (Survey maps)

N:o	15	Jordartskarta över Uppsalatrakten. 1:20000. Av N. G. Hörner † och B. Järnefors. Berggrunden sammanställd av P. H. Lundegårdh. [Quaternary deposits of the Uppsala region.] 1956	8,00
		Beskrivning till Jordartskarta över Uppsalatrakten. Av B. Järnefors. Summary: Quaternary deposits in the Uppsala region. 1958	5,00
»	16	Karta över Sveriges berggrund. (Pre-Quaternary rocks of Sweden.) Skala 1:1 milj. Sammanställd av N. H. Magnusson m. fl. 1958. Karta i tre blad. (Map in three sheets; each 15 Sw. cr.) Pris per blad.	15,00
		Description to this map in English by N. H. Magnusson, P. Thorslund, F. Brotzen, B. Asklund, and O. Kulling. 1960	15,00
»	17	Karta över Sveriges jordarter. (Quaternary deposits of Sweden.) Skala 1:1 milj. Sammanställd av G. Lundqvist 1958. Karta i tre blad. (Map in three sheets; each 15 Sw. cr.) Pris per blad.	15,00
		Beskrivning till Jordartskarta över Sverige. Av G. Lundqvist. 1958.	5,00
		Description to accompany the Map of the Quaternary deposits of Sweden. English edition by G. Lundqvist. 1959	5,00
»	20	Jordartskarta över Götaälvdalen. (Quaternary deposits in the Göta älv valley). Skala 1:20000. Av B. Järnefors 1959. Karta i tre blad. (Map in three sheets; each 11 Sw. cr.) Pris per blad	11,00
»	21	Beskrivning till karta över berggrunden inom Västerbottens fjällområde. Av P. Quensel. Zusammenfassung: Beschreibung zur geologischen Karte über das Hochgebirge Västerbottens, Nordschweden. Karta i skalan 1:200 000. 1960	10,00

Ser. Ca.

N:o	38	**Lundqvist, J.**, Beskrivning till jordartskarta över Värmlands län. (Quaternary deposits of the county of Värmland.) Karta i skala 1:200000. 1958. Beskrivning med karta (Text with map)	65,00
		Karta i två blad (Map in two sheets)	30,00
»	41	**Ödman, O. H.**, Beskrivning till berggrundskarta över urberget i Norrbottens län. English summary: Description to map of the Pre-Cambrian rocks of the Norrbotten County, N. Sweden, excl. the Caledonian mountain range. Karta i skala 1:400000. 1957. Beskrivning med karta. (Text with map)	45,00
		Karta i två blad (Map in two sheets)	20,00

Meddelanden i stencil.

N:o	4	**Stålhös, G.**, Bidrag till kännedomen om den radioaktiva strålningens fördelning inom den svenska berggrunden. Summary: Contribution to the knowledge of the distribution of the radioactivity in the bedrock of Sweden.	3,00

21. International Geological Congress Excursions in Sweden

Excursion nr	Guide-book	Price	Excursion nr	Guide-book	Price
C 15	a	5.00	A25-C20	g	6.00
A 20	b	6.00	A26-C21	h	6.00
A21-C16	c	2.00	A27 C22	i	5.00
A22-C17	d	8.00	A28-C23	j	4.00
A23-C18	e	6.00	A32-C26	k	5.00
A24-C19	f	6.00	C27	l	4.00

Complete set 63.00

Pris kronor 8,00

Distribueras genom

Generalstabens Litografiska Anstalts Förlag, Vasagatan 16, Stockholm 1

KUNGL. BOKTR. STHLM 1961

PRINTED IN SWEDEN