

INTERNATIONAL GEOLOGICAL CONGRESS
XXI SESSION NORDEN 1960

**SULPHIDE AND IRON ORES
OF VÄSTERBOTTEN AND LAPPLAND,
NORTHERN SWEDEN**

GUIDE TO EXCURSIONS NOS. A 27 AND C 22

By

E. GRIP, P. QUENSEL, P. GEIJER, AND S. LJUNGGREN



The Swedish geological guide-books

are edited by

THE GEOLOGICAL SURVEY OF SWEDEN

INTERNATIONAL GEOLOGICAL CONGRESS

XXI SESSION NORDEN 1960

**SULPHIDE AND IRON ORES
OF VÄSTERBOTTEN AND LAPPLAND,
NORTHERN SWEDEN**

Guide to Excursions No. A 27 and No. C 22

By

E. GRIP, P. QUENSEL, P. GEIJER, and S. LJUNGGREN



The Swedish geological guide-books
are edited by

THE GEOLOGICAL SURVEY OF SWEDEN

CONTENTS

	Page
The Skellefte district and the Laisvall area	3
The Varuträsk pegmatite	15
The Kiruna iron ores	24
Geology of the Gällivare iron ore field	39
Road-log	45

Route map of the Skellefte district, see Fig. 1, p. 5.

Key map: see inside of back cover

Excursion no. A 27: Aug. 3rd—Aug. 13th, 1960.

Excursion no. C 22: Aug. 26th—Sept. 3rd, 1960.

Excursion leaders:

Chefsgeolog Erland Grip
 Bolidens Gruv AB
 Boliden

Professor O. H. Ödman
 Geologiska Inst.
 Tekniska Högskolan
 Stockholm 70

Bergsingeniör R. Westerlund
 LKAB
 Kiruna

Fil. kand. Sven Ljunggren
 LKAB
 Malmberget

Kartorna äro för spridning godkända i Rikets allmänna kartverk den 20/5 1960.

The Skellefte District and the Laisvall Area

By

ERLAND GRIP

INTRODUCTION

General purpose of the excursion. The purpose of the excursion is to show the principal ore deposits of northern Sweden and their geological setting. The excursion will start in the Skellefte District. Here prospecting was started in 1918 and a great many sulphide ore deposits have been found and exploited since 1926. The total output from this area is now about 1.2 mill. tons a year. The ore is concentrated in three plants and transported to the smelter at Rönnskär at the coast where it partly is smelted and partly shipped. The famous lithium pegmatite at Varuträsk will also be seen. After four days in the Skellefte District the excursion will proceed northwestward to the lead mine at Laisvall lying at the eastern border of the Caledonian Mountain range. This deposit discovered in 1938 is the largest lead deposit of this new ore province along the Caledonian border. All the mines in the two ore provinces mentioned above are worked by the Boliden Mining Co but some of them belong to the State.

There is a rich literature about the economic geology of the districts but only a few of the most modern papers also giving reference lists will be mentioned here. Parts of the following description have been extracted from some of these works.

- DU RIETZ, T., 1953, Geology and ores of the Kristineberg deposit, Västerbotten, Sweden. Geol. Surv. of Sweden, ser. C, no. 524.
- GAVELIN, S., 1942, Relations between ore deposition and structure in the Skellefte District. Geol. Surv. of Sweden, ser. C, no. 443.
- GAVELIN, S., 1948, Adakområdet (The Adak Area, English summary). Geol. Surv. of Sweden, ser. C, no. 490.
- GAVELIN, S. and KULLING, O., 1955, Västerbottens län (The Västerbotten County, English summary). Geol. Surv. of Sweden, ser. Ca, no. 37.
- GAVELIN, S., 1955, Sulphide mineralization in the Skellefte District, N. Sweden, and its relation to regional granitization. Economic Geology, Vol. 50, p. 815.
- GRIP, E., 1951, Geology of the sulphide deposits at Mensträsk and a comparison with other deposits in the Skellefte District. Geol. Surv. of Sweden, ser. C, no. 515.
- GRIP, E., 1959, The lead deposits of the eastern border of the Caledonides in Sweden. Int. Geol. Congr. 1960.
- KAUTSKY, G., 1957, Ein Beitrag zur Stratigraphie und dem Bau des Skelleftefeldes, Nordschweden. Geol. Surv. of Sweden, ser. C, no. 543.
- ÖDMAN, O., 1941, Geology and ores of the Boliden deposit, Sweden. Geol. Surv. of Sweden, ser. C, no. 438.
- QUENSEL, P., 1955, The Paragenesis of the Varuträsk pegmatite including a review of its mineral assemblage. Arkiv för mineralogi och geologi. Bd 2 nr 2, Stockholm.

GENERAL OUTLINE OF THE GEOLOGY OF THE SKELLEFTE DISTRICT

According to recent investigations (G. Kautsky, 1957) the stratigraphy, rocks and events in the Skellefte District are the following:

Sorsele granite

Revsund granite

Migmatization, metamorphism and ore formation

Shearing

Folding

Elvaberg series: "Phyllite series" a thick series of pelites and psammites. Black graphite-pyrrhotite disseminated schists are common.

Conglomerates with interlayered andesitic and dacitic volcanics. Limestones in some parts of the district. (Fluvial facies = Vargfors series).

Weathering breccia mostly rich in carbonates.

Important unconformity and hiatus

Gentle folding

Jörn granite

Weak sulphide mineralization

Maurliden series: Skogheden volcanics. Basalt-andesite.

Petiträsk schist. Graphite schists interlayered by rhyolites.

Maurliden volcanics. Acid lavas and tuffs, often felsitic.

Maurliden schists. Gray and black pelites, psammites and pefites, interlayered by acid and intermediate volcanics.

THE MINERALIZATION IN THE SKELLEFTE DISTRICT

Various types of mineralization occur in the Skellefte District and fig. 1 gives an idea about their distribution. The two types "small sulphide segregations in phyllite and gneiss" and "arsenic bearing quartz veins" are without any economic value and they have never been found minable, but they are mentioned as they are of interest for the understanding of the genesis of the ores and the mineralization of the whole district. The deposits of economic value are mostly compact sulphide ores where pyrite is the dominating mineral. Often there are considerable amounts of pyrrhotite too and then varying amounts of sphalerite, chalcopyrite, arsenopyrite, galena, a great many of accessory minerals and values of silver and gold. The average composition of the ores in the zone Boliden-Kristineberg is shown in the table below which comprises about 40 of the most important bodies of compact sulphide ores. However, it may be pointed out that the composition of the different ore bodies varies very much. Where copper is low mostly zinc and lead are high and vice versa. The ores of the Adak group are not included in this calculation, neither are a couple of large disseminated ore bodies exclusively consisting of iron sulphides. The depths of the ore bodies are not fully known, but it may be mentioned that the Renström

Total area at surface in m ²	ppm Ag	ppm Au	% Cu	% Zn	% Pb	% As	% S
105,780	2.9	48	0.8	2.8	0.4	1.4	29

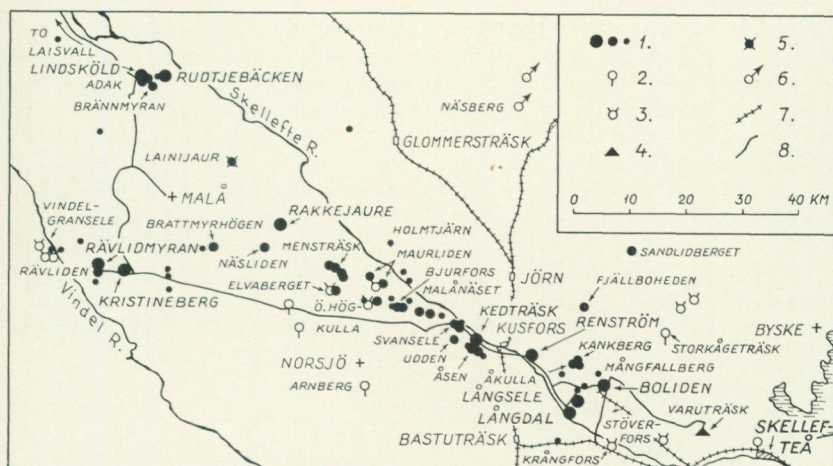


Fig. 1. Mineral Deposits of the Skellefte District.

1. Sulphide ore deposits in altered rocks and clearly epigenetic ore formation within the phyllite series.
2. Small sulphide segregations in phyllite and gneiss.
3. Arsenic bearing quartz veins.
4. Lithium pegmatite.
5. Nickel ores.
6. Iron ores.
7. Railway.
8. Excursion route.

ore body is indicated down to the 650 m level, Rakejaur to 320 and Kristineberg to 490 m.

The sulphide mineralization has been accompanied by an alteration of the wall rock in a more or less extensive scale. Where siliceous the wall rocks have been altered in sericite schists or chlorite schists, sometimes also with almandite, biotite, cordierite, andalusite, staurolite, cummingtonite. Where it originally has been calcareous it has been transformed into lime-silicates as diopside, amphibole, andradite, epidote-clinozoisite. Mostly the metasomatically altered rocks form aureoles around the ore bodies, but in some cases as in the Kristineberg area they have a very large extent.

The solid ore bodies commonly are surrounded by disseminations of sulphides lying in the altered rock. If chalcopryrite, gold, sphalerite or galena are abundant such parts may form a payable ore and it is mined in several of the mines.

The size and the shape of the individual ore bodies vary a great deal. The biggest ore body of the Skellefte District is Rakejaur with 20 000 m². Boliden was 12 000 m² at the surface and Renström only 360 m².

STRUCTURAL CONTROL OF ORE DEPOSITS IN THE SKELLEFTE DISTRICT

Most of the ore bodies of the Skellefte District lie in the boundary zone between the unconformity and the phyllite series. They are bound to steep structures formed during the latest folding phase when the Revsund granite was in-

truded. Thus the Boliden deposit lies in a dragfold just below the phyllite and is controlled by a shearing zone in the centre of the dragfold anticline. The Långsele ore bodies are found immediately below the phyllite where a shearing zone crosses the bedding at about 30°. Långdal also lies in the same stratigraphic position and here it is a soft fold. The Renström ore bodies follow the western and eastern limb of a cross-syncline. The ore bodies of the Rävliiden area lie in a W-plunging anticlinorium along shearing zones just below the phyllite. Kristineberg, however, does not follow the rule. The ore bodies here lie much deeper in the stratigraphy and they follow shearing zones parallel to the contact of an intrusion of Jörn granite.

The deposits of the Adak area follow the same stratigraphic horizon as the other deposits of the Skellefte District and structurally they are bound to a cupola, partly along shearing zones subparallel to the bedding and partly to pipe-like structures.

The Lainijaure nickel deposit finally is bound to the bottom of a phacolith and the two linear-shaped ore bodies lie there on both sides of a gabbro dike forming the feeding channel.

RELATION BETWEEN MINERALIZATION AND GRANITES

Most of the deposits are found to have been formed after the emplacement of the older granites but prior to the late-kinematic Revsund granite. Several facts indicate a close connection between sulphide mineralization and the Revsund granite.

The source of the ore minerals is considered to have been the supercrustal rocks with their small content of ore forming elements. By a granitization in the south and at deeper levels these elements were mobilized and emigrated northwards ahead of a migmatite front, and there during suitable structural, pressure and temperature conditions ore minerals were deposited.

BOLIDEN MINE

(According to O. H. Ödman 1941)

The first indication of the deposit was a glacial ore boulder found in 1921 5 km E of Boliden. After geological and geophysical work the deposit then was discovered by electrical prospecting and drilling in 1924. Mining operations started in 1925. Mining methods: open cut down to 90 m level, then cut and fill with pillar retrieving. Deepest level is 570 m. Total output 7.2 mill. metric tons grading 15 ppm Au, 49 ppm Ag, 1.5 % Cu, 7.0 % As, 26 % S. Reserves 0.8 mill. tons. Production in 1959 120 000 t.

The bedrock around the deposit is composed of acid to intermediate volcanic and sedimentary rocks overlain by phyllites and graywackes. A massive of Revsund granite intrudes the supercrustal rocks a few km south of the mine. The supercrustal rocks are folded and strike approximately E—W and dip steeply S.

The deposit is chiefly made up of two large ore bodies, the Western and the Eastern Ore, which have been brought into contact with each other by a fault. They have a total length of about 600 m and a maximum width of about 40 m. Originally the two bodies had an "en échelon" position and overlapped to the

right. The deposit is composed of three main types of ore, 1) arsenopyrite ore, 2) lamprophyres with quartz-tourmaline and sulphide ores, and 3) pyrite ore. These represent three stages in the mineralization and were formed in the above sequence. Each main type is composed of various kinds of ores of varying mineralogical composition. The ores are built up of a large number of minerals and the paragenetic conditions are exceedingly complex.

The development of an independent dragfold in the contact between the volcanic and the sedimentary rocks is of fundamental importance for the ore deposition. It was caused by a shearing stress, acting in the direction north-side-west and south-side-east. The axis of the dragfold pitches 50—60° E and this direction has exercised a structural control on the deposition of the ores.

In the dragfold the stress formed suitable channelways for ascending hydrothermal solutions which brought about an alteration of the bedrocks. The process was complicated and began with a thorough sericitization, resulting in the formation of various quartz-sericite schists. Some types also contain pyrite and chlorite. The alteration continued and the next phase was marked by the development of a pure sericite rock. During the third phase the sericite was broken down and andalusite rocks were formed. During the sericitization large amounts of CaO, MgO, and FeO were liberated and they partly migrated into the surrounding fresh rocks where they brought about a recrystallization and a formation of basic plagioclase, hornblende, biotite, etc. The altering solutions are considered to have been hydrothermal and from the beginning weakly acid or alkaline; in the final phase of the alteration the solutions were probably of a decidedly acid nature. The shearing in combination with the alteration produced a schisted bedrock, well suited for the formation of channelways by the shearing stress still acting on the dragfold. The formation of the altered rocks was largely accomplished even before the appearance of the ore solutions but it is believed that hydrothermal solutions were given off also during the different stages of ore deposition, thus widening the zone of alteration. A strong sericitization was particularly evident during the second stage. During the third stage, on the other hand, the alteration seems to have been very unimportant.

Along channelways in the schisted rocks the solution of the first, or arsenopyrite stage of mineralization now ascended. The ore bodies formed have the shape of elongate lenses with their long axes pitching steeply to the east, parallel to the axis of the dragfold. The solution of the arsenopyrite ore was presumably fairly concentrated and of a comparatively high temperature and was characterized as pneumotectic. The solution was very complex and contained a large number of metals, gangue-forming oxides, and volatiles. The crystallization began with the formation of various types of arsenopyrite ore in which the main component is arsenopyrite. The remaining solution was partly retained in pores in the arsenopyrite ore but the main part was squeezed out by the stress into fissures in the solidified arsenopyrite ore, forming a breccia. In some places the residual solution was pressed out in apophyses in the wallrock. The arsenopyrite ore is in some places accompanied by separate mineral associations, viz. rutile rock, pyrite-apatite ore, and quartz-plagioclase veins, which are considered to be differentiates of the original ore solution. They sometimes form separate bodies. After the displacement of the ore solution replacement set in and the pneumotectic solution tended to pass over into a hydrothermal solution which replaced the wallrocks.

The second stage was initiated by the intrusion of lamprophyres on fissures formed by a stress with the same direction as that which formed the dragfold and the channelways for the arsenopyrite solution. The lamprophyres are largely altered, mainly by chloritization, and the primary nature of the rocks cannot be ascertained. It can only be said that they were basic dyke rocks. The continued stress formed fissures, partly in the lamprophyres and partly in the surrounding altered rocks and arsenopyrite ore bodies, on which the quartz-tourmaline ore solution was brought in by displacement. Emanations from this solution brought about the chloritization of the lamprophyres and a sericitization of the andalusite rock. During the latter process also corundum, diasporite, and kaolin were formed. The ore solution contained SiO_2 , MgO , Al_2O_3 , alkalis, B, F, and other components but only relatively small amounts of metals. Arsenic is comparatively rare in this solution. Characteristic components are Bi, Te, and Se, elements which are comparatively rare in the solutions of the first and third stages. Also Cr is a characteristic component of the ore solution; it enters into the hydrothermal mineral mariposite. The ore solution is considered to have been fairly concentrated and of a high temperature and has been classed as pneumatocytic. Compared with the arsenopyrite solution, the quartz-tourmaline solution contained more gangue-forming components and was heavily loaded with B and H_2O . The ores formed by the solution are chiefly quartz-tourmaline veins and lenses. In some cases quartz is the predominant component, in others tourmaline forms almost the sole constituent. In local concentrations a number of metallic minerals are found, including some rare minerals characteristic of this locality, as "selenocosalite", "selenokobellite", tellurobismuthite, and tetradymite. One of the tourmaline lenses in its upper portion passes over into a sulphide ore composed of pyrrhotite and chalcopyrite. It forms a sulphidic fraction which was squeezed out from the quartz-tourmaline solution. The range of temperature of the solution was exceptionally wide, as high temperature minerals occur side by side with such low-temperature minerals as pyrrargyrite.

The last stage is characterized by the formation of chiefly pyrite ores, forming two large ore bodies and a number of smaller ones. The pitch of the Eastern Ore is on the whole parallel to the axis of the dragfold and the pitch of the older ores. The ore bodies contain brecciated lenses of arsenopyrite ore and in some places replaced remnants of wallrocks and lamprophyres. The pyrite solution entered the ore zone along several channelways formed by a stress with the same direction as before. The solution was brought in by displacement but replacement is very pronounced in this stage and from the channelways the solution largely replaced the intervening portions of wallrocks, lamprophyres, and bodies of older ores. The replacement resulted in the formation of the two large ore bodies. The ore solution is considered to have been of a pneumatocytic character at the time of the displacement but its strong replacing ability indicates that in some respects it was different to the earlier solutions. It probably rapidly changed to hydrothermal conditions. The crystallization began with the formation of pyrite and some other minerals, the remaining solution being enriched in chalcopyrite, pyrrhotite, and quartz. Parts of this solution crystallized as groundmass in the ore but a large part was squeezed out towards the margins of the ore bodies or into the wallrocks, where apophyses were formed. Another fraction of the ore solution formed veins of quartz, plagioclase, and sulphides at

the contacts of the ore bodies. Also in the pyrite stage the range of temperature was exceptionally wide as is evident from the appearance of apophyllite, which constitutes the last manifestation of mineralization in the deposit.

RENSTRÖM MINE

Indicated by glacial boulders and electrical anomalies the deposit was proved by drilling in 1927. The overburden is up to 8 m thick. After development work in several stages production started in 1952. Mining method: cut and fill. Deepest level 450 m. Total output 1.1 mill. tons grading 4 ppm Au, 184 ppm Ag, 1.1 % Cu, 7.9 % Zn, 1.8 % Pb, 22 % S. Reserves 2.9 mill. tons. Production in 1959 230 000 tons.

The deposit lies in a thick series of quartzite overlying the unconformity (in the bottom of the Elvaberg series). Over the quartzite follow volcanics of dacitic composition. Partly the ore bodies are following or replacing sheared interlayers of black schist and limestone. Two km E of the mine there is a large tongue of Revsund granite coming in from the South. The whole series is weakly folded along flat foldaxes striking about NW—SE. Around the mine there is a steep cross fold supposed to have been formed when the granite of the tongue-like massive was intruded.

The deposit chiefly consists of two ore bodies, the Western and the Eastern ore lying 600 m apart. The Western ore body being 360 m² at the surface increases downwards and at the 200 m level the ore area is about ten times as large. The Eastern ore body at the surface is larger than the Western one but it decreases rapidly downwards.

The development of the crossfold has been important for the ore formation.

The mineralization follows the schistosity formed during the folding, the Western ore body lying along a shearing zone striking N—S and dipping vertical and the Eastern ore body along a shearing zone striking E—W and also dipping steeply. Along the shearing zones have been suitable channelways for mineralizing solutions, which have altered the wall rock and deposited the sulphide minerals. The alteration is lowgrade and the principal new minerals formed are sericite and chlorite. In the lime-rich layers there is a dolomitization and formation of lime-silicates.

The Western ore body is built up of fine grained solid ore. It is neat banded with bands rich in pyrite, chalcopyrite or sphalerite alternating. The contacts against the wall rock mostly are very sharp. Apophyses rich in copper sometimes go out from the solid ore body. The principal ore minerals in the Western ore body in order of abundance are: pyrite, sphalerite, chalcopyrite, galena, pyrrhotite, arsenopyrite, fahlerz, pyrargyrite, gold and other accessories.

Just S of the Western ore body the Southern ore body is situated. It is of the same composition as the Western one, but it partly follows a shearing zone striking NE.

The Eastern ore body also has about the same composition as the Western one, but it has a slightly lower grade. To the East it goes out in disseminations of pyrite and some chalcopyrite.

KRISTINEBERG—RÄVLIDEN AREA

This area forms the westernmost part of the sulphide bearing Skellefte District. It is built as an anticline or anticlinorium around a core of the oldest granite, the Jörn granite. Acid volcanics and various interlayered sediments are strongly sheared and altered in sericite-chlorite schists. Therefore their origin is difficult to determine. In the upper stratigraphic levels the sericite schists contain various sediments as psammites, psephites and limestone. There over follows the phyllite series with black schists rich in graphite and pyrrhotite. The super-crustal rocks are folded along foldaxes dipping 25° — 60° W.

The deposit at Kristineberg lies just above the Jörn granite, which is older than the ore formation. It lies unusually deep in the stratigraphy. The other deposits of the area, however, Rävliiden, Rävliidenmyran, Sture and Hornträskviken all are situated in the common stratigraphic level, just below the phyllites.

KRISTINEBERG MINE

(According to T. Du Rietz 1953 and E. Grip 1951)

Indicated by glacial boulders and disseminated outcrops the Kristineberg ore bodies were located by electrical prospecting in 1918. It was the first deposit in Sweden found with the new electrical prospecting methods, which then proved to be the most important aid by prospecting in the Skellefte District. Development mining work started in 1935 and production in 1940. Mining methods: open cut down to 90 m level and then cut and fill. Deepest level is 490 m. Total output 6.7 mill. tons grading, 0.8 ppm Au, 18 ppm Ag, 1.1 % Cu, 1.5 % Zn, 28 % S. Reserves 7.3 mill. tons. Production in 1959 135 000 t.

The Kristineberg deposit consists of a group of sulphide lenses distributed along two roughly parallel zones. They lie in sericite and chlorite schists. The proportion between sericite and chlorite is very variable but usually the chlorite is most plentiful within and around the ores. The hanging-wall of the ores is rich in talc, developed as talc-chlorite rock, especially in the northern so-called A-ore zone.

The strike of the ores is about E—W with a dip of about 60° S and the pitch 40° S 60° W. The ore bodies consist of pyrite with varying amounts of sphalerite and chalcopyrite as well as some accessory ore minerals. All transitions from compact sulphide ore via disseminations to almost barren rock exist.

It is possible to distinguish several different ore types and by studying the structures in the wall rock beneath the ores and relict parts within the ore, it is found that the ore deposition in general occurred in connection with three tectonic movements. The quartz-tourmaline veins which occur plentifully in the mine are considered to be older than the ore formation and to lie along Mohr's planes around the pitch-direction of the ores. The veins, which do not contain sulphide minerals but scheelite, are equivalent to the second ore-formation stage at Boliden. During the first ore-forming stage, when the quantitatively predominant pyrite ore was deposited, the pitch direction of the ores was the axis of the movement, which is also registered in the shape of rotation structures in the ores and in their footwall. In a great many places and on various levels in the mine and at the A-ores as well as the B-ores the same direction of movement has been found; it shows that the S-block moved in a direction 45° downwards towards

SE. It is evident that the dominating sulphide mineralization occurred in connection with this movement when, under the influence of decreasing stress and shearing movements, channels were opened for the solutions. The real sulphide mineralization was preceded by an intense magnesia metasomatism, which spread out chiefly from the above-mentioned lines, causing an extensive sericite, biotite and chlorite alteration. The metasomatism continued during the ore formation and to some extent after it. Zones with mica-rich, schistose rocks, formed during the metamorphism, were opened by release of the stress and ore-bearing solutions penetrated. As a result of this, the sulphide minerals crystallized in the chlorite schists which were replaced in part by the sulphides. The dense, almost non-permeable hanging-walls impounded and collected the penetrating solutions. The largest ore deposition occurred where the most space was provided during the movement, in the A-ore body area.

The pyrite ore consists mainly of pyrite, which especially in the impregnation parts is coarsely crystalline. Between the pyrite grains there are varying amounts of sphalerite and chalcopyrite, which crystallized later and partly replaced the pyrite and also often each other.

A second ore-formation stage is represented by the copper ore occurring around the pyrite bodies in the B-ore area. The chalcopyrite is especially enriched around quartz nodules where roll structures along horizontal axes indicate that the S-block was pushed up towards the N. The copper ore shows a clear connection with the compact sulphide bodies, but it is also connected with the stress directed towards the N. If the chalcopyrite which was the last mineral to crystallize in the pyrite ore, was not completely crystallized when the compression and the N stress began, the copper-rich solutions must have been squeezed out of the crystal mesh and flooded to places with less stress, e.g. fissures and the surrounding hard quartz nodules.

Along the hanging wall of the A-ore zone there is a narrow zinc ore with an uncommonly light sphalerite. It is evidently younger than the pyrite ore and also cuts sharply through its parallel structures caused by the N stress. Within the zinc ore there are often fragments of the chlorite schists of the wall rock. The evidence of rotation of these fragments and the drag-structures in the contact indicate that the zinc ore crystallized in its own fissure during a movement of the S-block horizontally towards the W. To judge from the sharp contacts and the angular fragments the pyrite as well as the wall rock was completely consolidated during this third ore-forming stage. This zinc ore, which also contains pyrite, sometimes occurs as veins within the pyrite ore and sometimes also in its footwall. Like other types of ore, it persists from the surface down to the deepest level of the mine, 490 m.

RÄVLIDMYRAN MINE

The mineralized area was indicated by glacial boulders in 1921 and then the ore bodies were established by electrical prospecting. Mining development work has been carried out since 1935. In the Rävliðmyran mine production started in 1953. Mining method is cut and fill. Deepest level 240 m. Total output 0.8 mill. tons grading 0.9 ppm Au, 34 ppm Ag, 1.4 % Cu, 2.6 % Zn, 0.3 % Pb, 23 % S. Reserves 2.7 mill. tons. Production in 1959 200 000 tons.

The Rävildmyran deposit consists of several ore bodies controlled by steep shearing planes and a fold axis dipping 25° W. Surrounding rocks are built up of black schist (phyllite), sericite schist, chlorite-talc schists and contaminated limestone of dolomite. Lime-silicate skarn connected with the carbonate rocks is common. The sericite schists often are rich in quartz and then very hard.

The solid ore bodies mostly are surrounded by chlorite-talc schists or dolomite. They consist of dominating pyrite together with varying amounts of chalcopyrite, sphalerite, galena and pyrrhotite. The solid pyrite ore often is banded with alternating bands rich in pyrite and sphalerite. Galena goes with the sphalerite. Outside the solid ore bodies sometimes appears disseminated ore in form of strings rich in chalcopyrite occurring in the schists. Another type of ore is the breccia ore where chalcopyrite, pyrrhotite and some pyrite together with some vein quartz occur as fissure fillings in a brittle white quartzite. This type is similar to the copper ore in the Kristineberg mine, and as there it is supposed to have been squeezed out from the solid ore during its crystallization.

ADAK—LINDSKÖLD MINES

The mineralization of the area was indicated by glacial boulders found in 1921 and the area then was investigated in geological and geophysical way. In 1930 the first ore body was discovered. Development work started in 1941 and production in 1944. Mining method is room and pillar mining. Deepest level is 275 m. Total output 2.2 mill. tons grading 2.7 % Cu. Reserves 0.8 mill. tons. Production in 1959 165 000 tons.

The predominant structural feature of the Adak area is that of a dome. The oldest rocks in the center of the dome consists of metasomatically strongly altered rocks, "ore quartzites". Over them probably follows the unconformity and then banded sediments mainly of tuffitic character and sometimes containing layers of limestone. A thick series of basic volcanics divides the banded sediments in two groups.

The supercrustal rocks are framed by granites, which are considered to represent the youngest group of pre-Cambrian granites in the Skellefte District and its environment. To a certain degree these granites lie conformably to the stratification, so they "superimpose" the supercrustal rock complexes.

The sulphide mineralization is mainly concentrated to the inner parts of the dome, characterized by cordierite- and mica-quartzites, and to the boundary zones between these rocks and the overlying banded complex. Up to the present, five deposits of economic importance have been located, viz. the deposits of Adak, Lindsköld, Karlsson, Brännmyran and Rudtjebäcken. Besides the deposits already mentioned there occur in several places mineralizations of a smaller extent. Mineralogically, the sulphide mineralization is characterized in the majority of cases by chalcopyrite and pyrrhotite, as a rule accompanied by more or less arsenopyrite. Pyrite also occurs in subordinate amounts and then as a rule in parts that are poor in chalcopyrite. The Rudtjebäcken ore is an exception, as it constitutes a compact ore where pyrite is quite predominant, while pyrrhotite, chalcopyrite, and sphalerite appear only in subordinate quantities.

The country rock of the ores consists of "ore-quartzite" containing quartz, cordierite, cummingtonite, micas and sometimes almandite. In some cases the

sulphide invasion has been accompanied by a fairly extensive lime-silicate formation.

Two main types of structural development are discernible:

1) The Adak-Karlsson ore where the sulphides constitute impregnations, breccias, networks, and minor concentrations of compact sulphides. In these cases the outlines of the ore bodies will be very irregular and only to a small degree determined by the stratification of the dome.

2) The Lindsköld and the Rudtjebäcken ores constitute pronounced "plate-formed" ore bodies. The ores are localized to the boundary zone between the massive "ore-quartzites" and the overlying banded rocks and the bodies are orientated parallel to the stratification of the dome.

There is assumed to be an intimate genetic relationship between the granites and the formation of the ores. A support for such a view is, too, the fact that in a few places pegmatites, which are supposed to belong to the granites, seem to be closely connected with the metamorphic processes leading to the sulphide mineralization. As, however, the granites superimpose the supercrustal rocks, while the mineralization front has moved upwards, the relation between the formation of granite and the formation of ore (if such a relation really exists) cannot be so simple as would appear from the map but should be looked for at a much deeper section of the Earth's crust than the present one.

LAISVALL MINE

The lead deposit was indicated by glacial boulders forming a long boulder train pointing to an area in Lake Storlaisan. The deposit was then located by drilling in 1939 and onwards. The mine has been in production since 1942. Mining method: room and pillar mining at about 100 m level. Total output 4.3 mill. tons with 4.8 % Pb. Reserves 28.5 mill. tons. Production in 1959 700 000 tons.

Along the eastern border of the Caledonides there is an autochthonous series of Eo-Cambrian and Cambrian sediments. They are partly developed as sandstones which are more or less quartzitic. Similar but more recrystallized quartzites also occur in overthrust nappes. During the last 20 years of intense prospecting activity extensive disseminations of galena and sphalerite have been found in these rocks, and in some places they are concentrated to real ore deposits. The principal mineralized areas are Laisvall and Dorotea in Lapland and Vassbo in the northernmost part of Dalecarlia. The paragenesis comprises galena, sphalerite, pyrite, calcite, barite, fluorite, sericite and accessories. The mineralization is found especially where quartzite lies between impounding beds of shale or shaly sandstone. It also depends on tectonic features such as faults and fissures and on crush zones associated with the overthrust movements. The mineralizing solutions have followed such structures and migrated into surrounding more or less brecciated quartzite. The mineralization is considered to be connected with hydrothermal solutions of low temperature originating from palinogenic zones in the inner parts of the Caledonides.

The stratigraphy of the Laisvall area is the following:

Yraf Complex = Seve nappe

Overthrust plane.

Kaskajaure Complex

Overthrust plane

Lower Cambrian shales

Eo-Cambrian: Shale conglomerate.

Upper Sandstone with shale conglomerate in the top and quartz conglomerate in the bottom.

Middle Sandstone with quartz conglomerate in the bottom.

Lower Sandstone with interlayered thin beds of shale.

Mudstone often with a polymict conglomerate in the bottom (= tillite).

Arkose.

Weathering Breccia of granite.

Sorsele Granite (Pre-Cambrian)

The mineralization occurs to the largest extent in the Lower Sandstone but also the Upper Sandstone may contain considerable amounts of galena. The ore minerals from disseminations in the sandstone and the lead vary between 0 and a maximum 30—40 % Pb. The galena occurs partly as fine grains between the sand grains and partly as poikiloblasts. Sphalerite is found together with the galena but mostly only in small amounts.

The Varuträsk pegmatite

By

PERCY QUENSEL

The Varuträsk pegmatite is situated 22 km S.E. of the Boliden mine and 15 km from Skellefteå town on the Baltic coast. It is assumed to be genetically connected with the so called Skellefte granite, representing a fine-grained variety of the more widespread Revsund granite.

The pegmatite forms a trough-like to tabular body, striking N.N.E.—S.S.W. In the eastern wing the dip is about 30° W.N.W., whereas the western wing lies all but horizontal. The exposed outcrop is about 350 m in length. The thickness varies from some few meters up to 30 meters, bounded both above and below by an amphibolitic rock (cp. Fig. 2).

The parts of the pegmatite, containing lithium-bearing minerals, are separated in two lenses, intersected by a part, devoid of these minerals. The two lenses lie about 50 m apart.

Four stages in the mineralogical development of the pegmatite can be distinguished. The first, named *the pegmatitic stage*, is taken to represent the original zonal structure of the pegmatite body, formed by fractional crystallisation from the walls inwards. This is assumed to have taken place in a closed system under epimagmatic conditions, *i.e.* above 600°.

The second stage, named *the pneumatogenic stage*, is taken to include all replacement units, succeeding the pegmatitic stage. Subsequent alterations, due to activity of thermal water of hypogene origin, are attributed to a third *hydatogenic stage*. A final development, due to the activity of percolating ground water or to superficial weathering, can be included as *a stage of supergene alterations*.

In the following, the principle minerals, representative for each of these stages will be given.

The *pegmatitic stage* can be divided into four divisions, the border zone, the wall zone, the intermediate zones and the core, denoting the sequence of fractional consolidation.

The mineral assemblage of the *border zone* is simple and uniform. The only minerals of primary origin are a fine-grained assemblage of quartz and muscovite. This zone seldom attains more than some 10 cm in thickness, often it is less than a few cm thick.

The *wall zone* may vary from some 5 dm to several meters in thickness. In one sense one may say that the border zone and the wall zone co-ordinate, inasmuch as the bulk mineral composition is the same, though the minerals of the wall zone are developed in large individuals. Muscovite can now occur in large silvery white books, up to one dm in width. Additional minerals of this zone are black tourmaline and beryl, the former a characteristic mineral of this stage and principally restricted thereto. Beryl crystals up to several dm in length have been found. *Löllingite* is found in some amount in one locality within the wall zone (between H₂ and K in the centre of the map).

The *intermediate zones* include the zonal development of the pegmatite between the wall zone and the core. At Varuträsk, as is the case in most other complex pegmatites, it forms the greater mass of the pegmatite. A sub-division into two phases can be made, denoted as an outer and an inner intermediate zone. The difference is that the outer zone has a simpler mineral composition than the inner zone.

The difference between the mineral assemblage of the wall zone and the outer intermediate zone is that *microcline perthite* now enters as the dominant mineral, developed in crystals or anhedral masses of great size. A single crystal measured 3 m in length and was then only partly exposed.

In the inner intermediate zone the mineral assemblage is the same as in the outer zone with the addition of some pronounced lithium-bearing minerals, evidently due to a content of lithium in residual solutions of the pegmatitic stage. The essential minerals in this respect are *spodumene* and *amblygonite (montebrasite)*, both present in large amounts.

Attention may be called to the considerable amount of rubidium in the *microcline perthite*. The medium of nine analyses from the eastern wing of the pegmatite gave 1.55 % Rb₂O (maximum 3.3 %). In other respects the outer and inner intermediate zones show no further dissimilarities and grade imperceptibly into each other.

As recorded from many other zonal pegmatites the *core* of the Varuträsk pegmatite is not centrally located but displaced towards the southern foot wall of the eastern wing, where it occupies a lens-formed body, about 50 m in length and 15 m in breadth. The core is almost exclusively composed of pure milky quartz. Though surrounded by mineral assemblages of later replacement units and locally intersected by minerals of the same, the core on the whole shows but insignificant signs of replacement by invading solutions of succeeding phases of mineralisation.

The *pneumatogenic stage* is used to denote the phases of replacement which followed the zonal consolidation of the pegmatite. Whereas the temperature prevailing during that stage was taken to have exceeded the 600° limit, the replacement units of the pneumatogenic stage are postulated to have taken

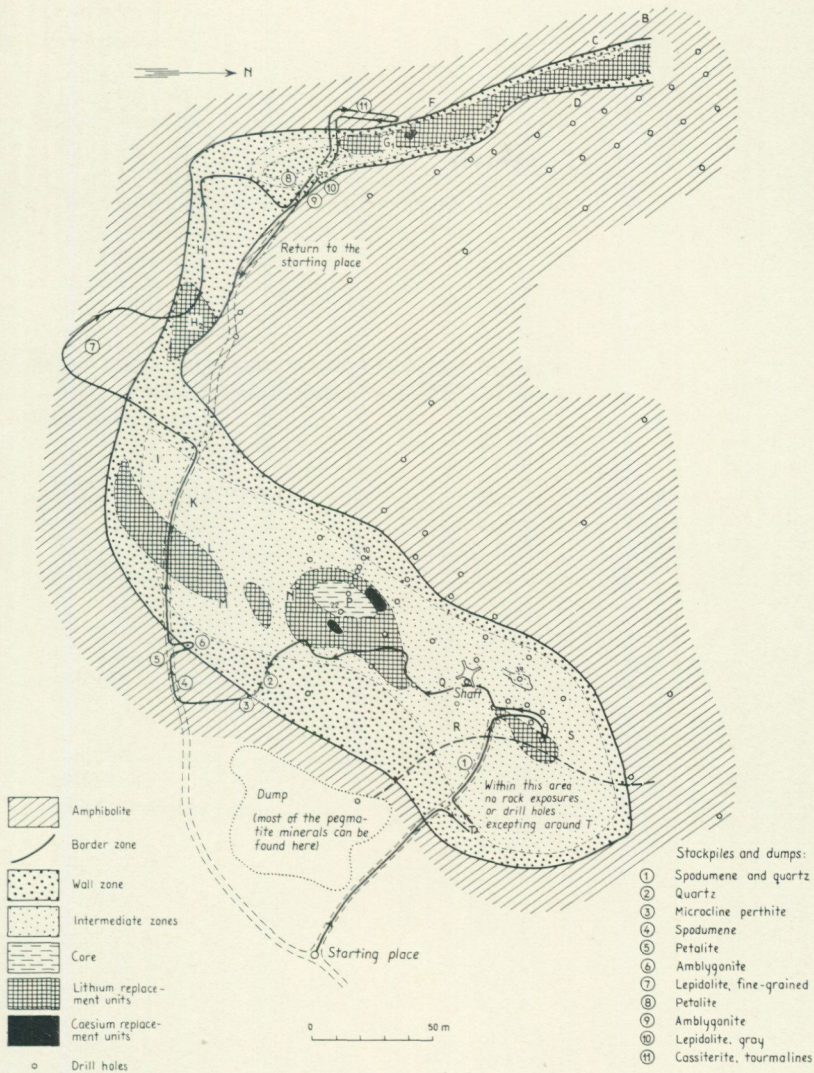


Fig. 2. Geological map of the Varuträsk pegmatite.

För spridning godkänd i Rikets allmänna kartverk den 27 april 1960.

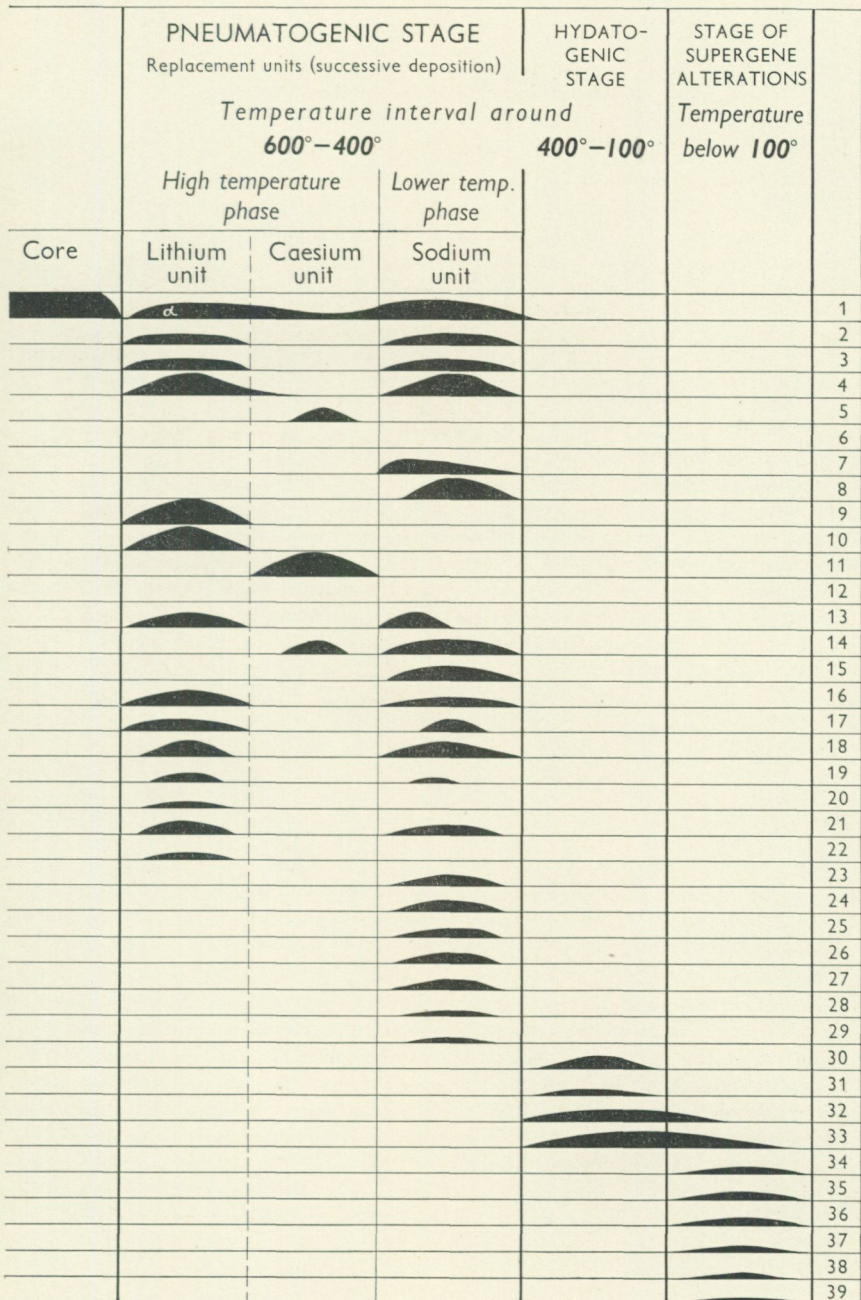
place between this limit and the critical temperatures of the co-operating solutions, *i.e.* between approximately 600° and 400° . This stage has been divided into a higher and a lower temperature phase, each characterized by its own mineral assemblages.

Table I

THE VARUTRÄSK Paragenesis of

	PEGMATITIC STAGE Fractional crystallisation (closed system)			
	<i>Temperature interval around 800°–600°</i>			
	Border zone	Wall zone	Intermediate zones outer	inner
1 Quartz	8			
2 Muscovite	8			
3 Lepidolitic micas			8	
4 Lepidolite			8	
5 Polylithionite			8	
6 Microline perthite			8	
7 Saccharoid albite			8	
8 Cleavelandite			8	
9 Spodumene			8	
10 Petalite			8	
11 Pollucite			8	
12 Schorl		8		
13 Verdelite			8	
14 Rubellite			8	
15 Indicolite			8	
16 Beryl		8		
17 Montebrasite			8	
18 Manganapatite			8	
19 Manganvoelkerite			8	
20 Triphylite			8	
21 Lithiophilite			8	
22 Varulite			8	
23 Cassiterite			8	
24 Columbite			8	
25 Tantalite			8	
26 Microlite			8	
27 Allemontite group			8	
28 Uraninite			8	
29 Fluorite			8	
30 Cookeite			8	
31 Vivianite			8	
32 Montmorillonite			8	
33 Kaoline group			8	
34 Ferri-sicklerite			8	
35 Sicklerite			8	
36 Heterosite			8	
37 Purpurite			8	
38 Alluaudite			8	
39 Oxid. prod. of uraninite			8	

PEGMATITE the minerals



The higher temperature phase has again been sub-divided into two stages, the lithium replacement unit and the caesium replacement unit, each characterized by specific mineral assemblages.

The lithium replacement unit is taken to represent the first epoch of renewed mineralisation after the final consolidation of the pegmatitic stage. The name is, however, only meant to indicate that the main concentration of lithium occurs within this unit, verified by the abundant occurrence of lepidolite, petalite, and a second generation of spodumene.

The greatest concentration of lepidolite is found in the form of a mauve-coloured fine-grained massive rock in the western wing together with some manganapatite (quarry H₂ on the map). Inclusions of pure white beryl with a vitreous lustre and granular texture, very different from the beryl of the pegmatitic stage, can there be found. The lepidolitic rock is in parts speckled with small grains of cassiterite and invaded by cleavelandite, pertaining to replacements of the lower temperature phase of this stage.

Together with lepidolite, petalite is the most abundant mineral of this unit. Though in general of rare occurrence in other lithium pegmatites, it is present in great quantities at Varuträsk.

The third lithium silicate mineral of quantitative importance in this unit is a second generation of spodumene. When now recurring in this unit, it is developed in an obviously different habit. Instead of the tabular masses of the pegmatitic stage, the mineral now occurs in the form of compact slender laths, which when uncontaminated, are semi-translucent. It is not unusual that the spodumene of this unit is highly altered to a mixture of clay minerals (rotten spodumene) which is never found to be the case with the earlier generation of the mineral in the pegmatitic stage.

Other minerals of this unit only occur in small quantities. They consist of a second generation of montebrazite, manganapatite, and of green tourmaline. A new type of beryl now is found in the form of small vitreous crystals.

The great masses of pollucite in the Varuträsk pegmatite seem to call for a separate replacement unit within the high temperature phase of the pneumatogenic stage. It seems hardly plausible that solutions of the same phase in some parts of the pegmatite have carried lithium as the main alkali component and close by have deposited great amounts of caesium in the form of the mineral pollucite. The localized distribution of the largest deposit along the core margin likewise seems indicative of new replacement channels. The quartz core has, however, not succumbed to any replacement by the invading solutions of this unit.

The lower temperature phase of the pneumatogenic stage expressively indicates that a further break in the mineralisation of the pegmatite now occurred. The solutions of this unit are universally found to traverse and replace all earlier mineral assemblages. Furthermore the mineralisation of this unit includes many minerals not before represented in the previous zones or units. With regard to the content of alkalis, sodium now enters as the principle component. As a result thereof the dominant mineral of this unit is an almost pure albite, predominantly in the form of cleavelandite, generally developed in spheroidal bursts or large radiating sheaves. In other parts, principally restricted

to the peripheral parts of the pegmatite, the mineral can occur in the form of a fine-grained saccharoid albite.

Next in importance of the minerals of this unit are several different modifications of mica minerals. Remarkable are the large purple crystals of lepidolite, up to 2 cm in breadth, principally to be found around a small prospecting pit in the eastern wing (T on the map). Other modifications are a delicately rose-coloured to nearly colourless lepidolite, forming concentric bundles as well as a medium-grained gray lepidolite, found as veins and in accumulated masses. Muscovite recurs, now in the form of a fine-grained rose-coloured species as well as in a cryptocrystalline form (oncosin), often traversing larger masses of pollucite.

The red and blue tourmalines (rubellite and indicolite) are characteristic minerals of this unit. Rubellite is often found in zonal development with the green tourmaline (verdelite). In that case the red type forms the core with an outer green shell. The red core is often completely altered to cookeite or replaced by albite.

Manganapatite recurs in this unit in the same aspect as in previous phases. The rare mineral *manganoan voelckerite* seems, however, to be restricted to this unit, connected with the gray lepidolite. It can easily be distinguished from manganapatite on account of that, on exposed surfaces, it is always found to occupy well-defined cavities, in contrast to manganapatite yielding to weathering.

The Li—Fe and Li—Mn phosphates are represented by the minerals *triphylite* and *lithiophilite*. They are, however, not found coordinated in the field. The natural cause is that triphylite is restricted to such occurrences where iron-containing solutions have circulated, whereas lithiophilite is found in connection with manganese concentration in the replacement units.

Triphylite has been rarely encountered in replacements within the wall zone. The usual occurrence of lithiophilite has on the other hand only been found in a small prospecting excavation (G_1 on the map) together with cleavelandite and its mineral assemblage. It is, however, there mostly altered to sicklerite → purpurite.

It has now been proved that the new mineral *varulite* itself is an alteration product of lithiophilite in replacements within the wall zone.

In the same small excavation, where lithiophilite was first found (G_1 on the map), many other minerals occur. A third generation of beryl as well as cassiterite are there relatively abundant. The only occurrence of uraninite is this locality. It mostly occurs in minute, generally oxidized crystals. Only one large specimen has been found.

The rare minerals *allemontite* and *stibiotantalite* also belong to this unit, only found in an excavation near G_1 . Several large specimens of both these minerals have been disclosed there.

Columbite and tantalite also belong to this unit. Columbite is not uncommon, though generally only found between cleavage planes of cleavelandite. Tantalite was seldom found during earlier stages of mining operations. Later large quantities of the mineral came to light in underground workings around the shaft in the eastern wing of the pegmatite, together with some few specimens of microlite.

Fluorite has only been found in two small vugs. As vugs are in the pegmatite all but absent this may explain the scarcity of fluorite. The want of fluorine in such minerals as montbrasite, voelckerite, and hydroxyl-apatite indicates that at no time during the deposition of the minerals of the pegmatite was there any excess of fluorine present.

The hydatogenic stage is taken to represent all processes, which may be ascribed to the influence of ascending hydrothermal water percolating throughout the consolidated mineral assemblages of the previous stages. During this stage the juvenile water seems not to have introduced new material of any importance. The residual fluids of the preceding stages have apparently concluded the transfer of soluble matter.

The most pronounced feature of the minerals pertaining to this stage is their high content of hydroxyl radicals.

A characteristic mineral of this stage is montmorillonite, mostly found as an alteration product of petalite. The decomposition of the younger generation of spodumene to kaolinite and to other kaolin minerals is also to be referred to this stage. Pollucite has in underground working also been found to have succumbed to an intense alteration to a soft white clay substance.

The alteration of the red core of the zonal tourmaline to cookeite should also be attributed to the thermal activity of this stage as well as to the formation of cookeite in independent depositions. The lower temperature prevailing during this stage would favour the formation of cookeite rather than the less hydrous micas.

The rare mineral mangan-hydroxylapatite, assumed to be a decomposition product of varulite, contains 2.56 % H_2O against about 1 % in the host mineral varulite. This would represent a typical example of hydration during the hydatogenic stage.

The stage of supergene decomposition represents an oxidation of selective minerals due to superficial weathering or to the action of phreatic water.

A good example of such processes is the successive oxidation of triphylite, lithiophilite, and varulite. In a first phase the bivalent iron ions in these minerals become trivalent, whereas the manganese ions remain bivalent, resulting in the formation of the minerals ferrian sicklerite—manganoan sicklerite, and manganoan alluaudite. Ultimately both the iron and the manganese ions become trivalent, forming the fully oxidized minerals heterosite and purpurite.

Arsenostibite (arsenian stibionite), an oxidation product of the alloy allomontite, must also be considered as an alteration product of this stage.

They hardly remain any further alteration products, than a frequent incrustation of manganese oxides on minerals containing manganese in their composition or on adjacent minerals. It must, however, be taken into consideration, that glacial erosion may have removed many products of weathering on exposed outcrops, which otherwise might have increased the mineral assemblage of this stage.

Attempts have been made to determine the age of the Varuträsk pegmatite. A determination of the lead isotopes in a specimen of uraninite has given an approximate age of 1.70×10^9 . A determination with the Rb/Sr method

gave an age of 1.74×10^9 . The two determinations tally well within the limits of experimental error. On the other hand a determination on lepidolite with the K/Ar method gave an age of 2.06×10^9 and on the same material with the Rb/Sr method likewise 2.06×10^9 . This is a singularly good correspondence, but of some reason probably giving a co-equal too high age.

The approximate age of the pegmatite is taken to be around 1.80×10^9 years, which would correspond with approximate ages, found in equivalent formations in middle Sweden.

In Table I the paragenetic association of the minerals is recapitulated. In Table II a list of the minerals is given in order after Strunz' tables (with the exception of alteration products, placed after their host mineral). Names in spaced types indicate those minerals which can be readily found.

Table II. List of described minerals from the Varuträsk pegmatite, in numerical order after Strunz' tables (with the exception of alteration products, here given after host mineral).

Elements: allemontite, stibarsen (alteration product: arsenostibite).

Sulphides: löllingite.

Halides: fluorite.

Oxides: quartz, cassiterite, columbite, tantalite, stibiotantalite, microlite, uraninite.

Phosphates: triphylite (alteration products: ferrisicklerite, heterosite), lithiophilite (alteration products: manganosicklerite, purpurite), varulite (alteration products: alluaudite, purpurite), triplite, amblygonite (var. montebrasite), manganapatite, mangan-hydroxylapatite, mangan-voelckerite, vivianite.

Silicates: beryl, tourmaline (green, blue, and red; alteration product in red kernel of zonal tourmaline: cookeite), spodumene (alteration product: kaolin minerals), muscovite (white and red), lepidolite (pink-gray, and white), cookeite, petalite (alteration product: montmorillonite), pollucite, albite (cleavelandite and saccharoid), microcline perthite.

The Kiruna iron ores

by

PER GEIJER

GENERAL GEOLOGICAL SETTING

The iron ore deposits at Kiruna, like those at Gällivare, Tuolluvaara, and a number of other places in the same region, occur in a supracrustal formation, almost entirely made up of volcanics, which forms the oldest section of the Precambrian in these parts and probably is to be correlated with the Svecofennian (Svionian) of Central Sweden.

The huge ore body of Kiirunavaara and the much smaller "twin deposit" of Luossavaara form sheet-like bodies between a foot-wall unit of syenite-porphiry and a hanging-wall of a quartz-bearing porphyry. North of Luossavaara the foot-wall unit is found to rest upon a sequence of spilitic extrusives ("Kiruna greenstones"), conformably capped by the Kurravaara conglomerate, whose pebbles are predominantly of volcanic rocks. Earlier studies (Lundbohm 1910, Sundius 1915) resulted in the view that there was present here the primary substratum of the ore-bearing porphyries, these forming with the Kiruna greenstones a co-magmatic volcanic sequence. But recent regional work (Ödman 1957) has given strong reasons for correlating the greenstones and the conglomerate with the Pajala series, wide-spread in the surrounding country, which is referred to a later Precambrian cycle, the Karelian. The present relative position of the rock units, therefore, should be due to structural disturbances. Scarcity of exposures makes it impossible to obtain definite proofs for this correlation. But, in any case, no conclusions as to the magmatic development of the ore-bearing rocks can now be based on the assumption that the Kiruna greenstones formed an earlier phase of the same volcanic activity.

On top of the hanging-wall unit follows the Lower Hauki complex, a series of rather highly altered flows and silicified rocks, most of the latter probably being altered tuffs. The hydrothermal action that has befallen this unit has also produced in it a great number of small deposits of siliceous hematite ore. On very long stretches of the contact between the hanging-wall unit and the Lower Hauki there is a body of iron ore very rich in apatite, mostly narrow but expanding to greater width e.g. as the Rektor ore body on the slope of Luossavaara.

Above the Lower Hauki, again, there follow the sediments of the Vakko series (earlier known as "the Upper Hauki complex"), in part resting normally upon the older rocks with a moderate angular unconformity and a basal conglomerate of local material, but in part thrust over them along flatly eastward-dipping slip planes. The Vakko series is referred to the Karelian cycle.

The general strike direction in the district is slightly E. of N., turning more to the N. E. north of the ore mountains. The dip of all units is eastwards, about 50°—60° in the southern part (Kiirunavaara), steeper in the north and north-east.

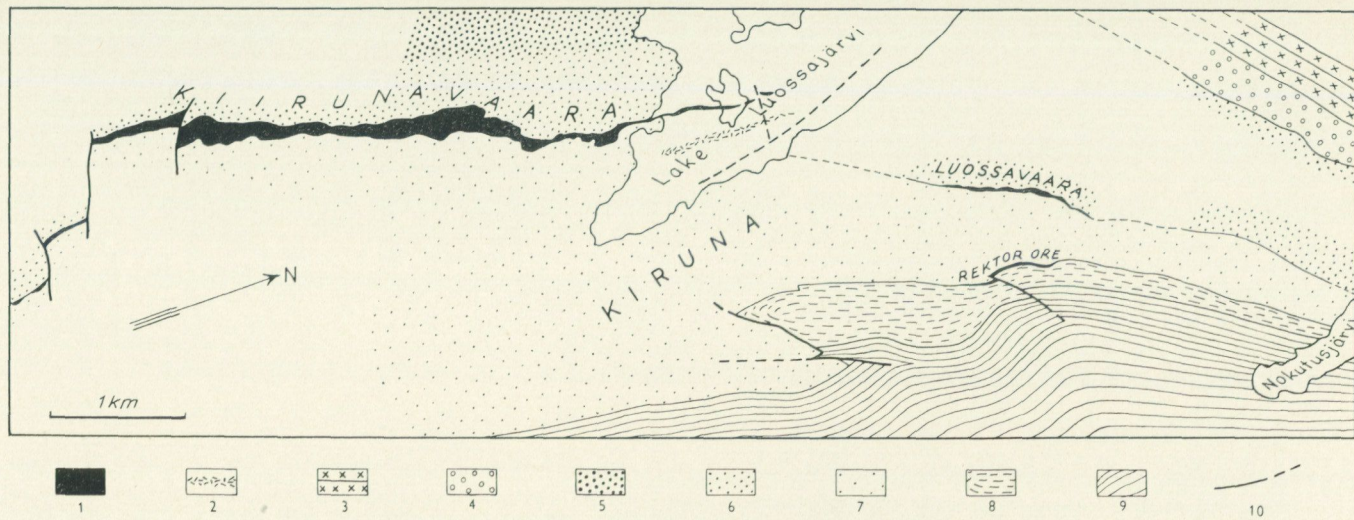


Fig. 10. Sketch map of the surroundings of the iron ore deposits at Kiruna.

- | | |
|---|-----------------------------|
| 1. Iron ore | 6. Syenite-porphry |
| 2. Zone with ore veins
("ore breccia") | 7. Quartz-bearing porphyry |
| 3. "Kiruna greenstones" | 8. Lower Hauki complex |
| 4. Kurravaara conglomerate | 9. Vakko sedimentary series |
| 5. Syenite | 10. Fault |

CONDITIONS OF FIELD STUDY

Before mining started (in 1903) the ore mountains illustrated very clearly the resistance that the hard ore had offered to erosion. The Kiirunavaara ore body formed a mostly bare ridge, culminating in a top 248 m above the level of Lake Luossajärvi, with the wall rocks sloping away on either side. The slight Post-Glacial weathering had brought out, in the ore outcrop, almost every detail in the relative distribution of magnetite and apatite. The much narrower Luossavaara ore was little exposed, and the ore mountain is roughly circular in outline, but its maximum height was only 20 m less than that of Kiirunavaara. The foot-wall unit was well exposed in outcrops on the northern part of Kiirunavaara, less so on the sister mountain, but again better N. E. of it. On the hanging-wall, outcrops were rather common, except on Kiirunavaara at greater distances from the ore body. Stripping of ore boundaries, etc., furnished new exposures. This was the general situation during the first decade of the present century, when most of the geological work was done on which present knowledge of the district rests, and still at the time of the visit by the international geological congress in 1910. The great progress of mining since that time, and the deep diamond drilling that was carried out in 1914—1923, have given much additional information. On the other hand, outcrops have largely become covered by dumps, and the instructive weathered ore surface has completely disappeared, the only rests being found in collections.

THE FOOT-WALL UNIT

On Kiirunavaara, this unit is known from the ore contact westwards for a distance corresponding to a thickness of about 700 m. Further W., beyond the foot of the mountain, extends a vast area of boggy ground with no exposures whatever. The lower part of the unit is developed as a fine- to medium-grained syenite with feldspars about 5 mm in length in the coarsest variety. The feldspar is a micropertthite with the albite component predominating. Further there generally are diopside, magnetite, titanite, zircon. A remarkable textural feature is that the titanite has been the last mineral to form, in part through reactions with apatite. The chemical composition may be summarily illustrated by giving normative figures from two analyses:

	I	II
Q	0.42	2.77
Or	12.86	19.57
Ab	53.21	52.15
An	4.18	3.90
P	11.10	11.63
M	17.04	9.52
A	0.93	?

Upwards the syenite changes into forms in which feldspars a few mm in length stand out as phenocrysts against a more fine-grained groundmass, and these in turn grade into the porphyries that make up the upper part of the unit, a thickness of about 350 to 470 m. All transitions are gradual, but there is no regular gradient in the change in grain size.

Of porphyries there are two main types. One is a grey rock with tabular feldspar phenocrysts, generally not numerous. Its groundmass is made up

chiefly of feldspars in broad laths mostly about 0.1 mm in length and arranged at random; also its other constituents are the same as in the syenite, and the bulk composition is like that of the latter. It may be noted that texture and grain size are comparable to those of proved extrusives of a syenitic composition, as the rhomben porphyries of the Oslo region. Sometimes there appear in this porphyry vesicle fillings of one or several of the minerals actinolitic hornblende, magnetite, apatite, titanite. These nodules are surrounded by a narrow, light-coloured halo. Through increasing frequency of such bodies a transition is effected to a rock in which they may make up even half the volume; then the haloes have coalesced and the rock mass, apart from the nodules, consists only of feldspars and is pink-coloured throughout. While the nodules often have the character of typical vesicle fillings, in other cases they are less distinctly set off from the groundmass ("embryonal nodules"). In bulk composition there is no general difference between rocks with or without nodules, showing that the latter have been formed as local concentrations in the crystallizing eruptive, but in varieties very rich in nodules there must have been at one stage an excess of the nodule-forming substances.

The scant exposures on Luossavaara indicate the same general characters of the porphyries. The deeper portions of the unit are concealed by drift, and it is therefore uncertain whether any more coarse-grained, syenitic phase occurs there. More numerous outcrops further N. E. show similar porphyries but also a peculiar variety that has been called magnetite-syenite-porphyry. It consists of albite and about 30 percent magnetite, in a fine-grained texture, the magnetite occupying the interstices between laths of albite. Nodules occur here, too, but consist of albite. In this part of the district, the foot-wall unit is exposed to a (calculated) depth of about 200 m from the contact with the hanging-wall unit. Further W. N. W. there is a covered gap, about 400 m wide, and then, along the contact with the Kurravaara conglomerate, a narrow belt with outcrops of porphyritic rocks conforming in a general way to types of the foot-wall unit.

The characters of the foot-wall unit on Kiirunavaara, as here described, show that, in this part at least, it is a continuous igneous body. It is unlikely that it ever formed a surface flow of anything approaching ordinary character. Probably it represents an outflow where the roof had collapsed over a comparatively wide area, rather than one from a fissure or a crater vent. Its extrusive nature is, in any case, evident from the general rock relations in the district, and from the depth to which surface textures go down in it. For reasons already given it cannot be ascertained whether the more northern parts of the unit are similarly built.

THE HANGING-WALL UNIT

The thickness of this unit is greatest in the south, on Kiirunavaara and eastwards, where it may perhaps surpass 1 200 m. The probability of some amount of faulting, and uncertainty about the actual dip in the eastern part, preclude a more precise estimate. On Luossavaara, again, it is about 400 m, and north-eastwards from there it gradually decreases further. The whole of this unit is, in spite of local variations, homogeneous with regard to the general nature of the rock. This is a porphyry with feldspar phenocrysts, mostly isometric and

red-coloured, in a dense groundmass generally red, or dark from finely distributed magnetite. The phenocrysts are perthitic, with the albite component predominant, and the groundmass is made up of alkali feldspar and quartz, in rhyolitic proportions. Among other constituents, magnetite is the most common one. In texture the groundmass is very often poikilitic, occasionally spherulitic, and else presents a very fine-grained aggregate with irregular grain boundaries, probably a slightly coarsened devitrification texture. Fluidal banding occurs, and "buttonholes" chiefly filled with quartz.

The megascopically visible variations mainly concern the frequency, shape, and size of the phenocrysts, which are often compound, and the colour of the groundmass. Locally on Kiirunavaara, near the ore, there is a greyish variety with white phenocrysts.

The chemical composition of the more common types may be illustrated by the following normative figures:

	III	IV	V	VI
Q	27.91	23.56	23.38	14.68
Or	26.27	17.89	12.86	16.21
Ab	33.19	48.99	52.68	54.25
An	1.39	1.95	4.26	4.46
C (Al ₂ O ₃)	1.02	—	0.20	—
P	1.21	2.82	1.70	3.56
M	8.31	4.39	3.18	4.99

Eutaxitic flow structures are found in many places, as in the southern part of Kiruna town where lumps of porphyry with a bluish groundmass are enclosed in a matrix that is reddish throughout. More remarkable is a belt on Luossavaara, about 100 m wide and with vaguely defined boundaries, which has been described as an agglomerate. It consists of fragments and a subordinate matrix that is mostly ordinary porphyry but partly considerably altered. The fragments, which occasionally surpass 1 m in size, generally are rounded but sometimes angular. Most of them represent types of the foot-wall unit but there are also many varieties of the hanging-wall unit. Fragments of iron ore also occur.

Isolated fragments of the foot-wall porphyries are sometimes encountered elsewhere as inclusions in the hanging-wall unit. More remarkable, both quantitatively and because of its geological significance, is the occurrence of inclusions of ore. These vary in size, generally between a few cm and some dm, and mostly — at least the larger ones — are angular in shape. They represent a number of varieties of ore, such as make up the main ore bodies of Kiirunavaara and Luossavaara, ranging from the richest magnetite even to pure apatite rock. The distribution of these fragments is noteworthy, as they are lacking near the ore body of Kiirunavaara, occurring there only some distance up in the unit, but plentiful just above this contact on Luossavaara, where they quite locally may even make up about half the volume of the rock. When first noted, these inclusions were regarded as proofs that the hanging-wall unit was younger than the ores. Later, however, it became quite clear that the latter are intrusive into the adjacent hanging-wall unit, and the conclusion became inevitable that the fragments must be derived from some older ore body of the same nature, otherwise unknown. It was once suggested (Stutzer 1907), apparently on ground of the distribution of the inclusions on Kiirunavaara, that the ores were later

than the bottom flow of the hanging-wall unit but earlier than subsequent members of it. This possibility, however, is ruled out by the relations on Luossavaara, as described above.

It would be against all geological experience to interpret the hanging-wall unit as one undivided magmatic body, as is the conclusion with regard to the foot-wall. With its thickness, such an origin would have manifested itself in textural variations. But it has not been possible, so far, to trace within it any separate flows. However, practically no study has been devoted to this unit after 1910. Certain features, as the Luossavaara agglomerate, may suggest to a geologist today the presence of "pyroclastic flows". Such an origin would be difficult to prove — or disprove — in the present state of the rocks. But most of the hanging-wall unit is texturally like the dike porphyries (compare the following), indicating that probably ordinary flows at least are the rule within it.

THE MAIN ORE BODIES OF KIIRUNAVAARA AND LUOSSAVAARA

In size, the deposits of these "twin ore mountains" are very different. That of Kiirunavaara probably is the largest continuous body of high-grade iron ore known anywhere, while Luossavaara is incomparably smaller and is surpassed also by several other deposits in the same region.

The Kiirunavaara ore body is a sheet with a strike length, on land, of about 4 400 m (incl. the faulted southern tip); a further continuation northwards, below Lake Luossajärvi, is narrow and of no economic interest at present, its length is about 1 000 m. The ore body follows the rather straight contact between the foot-wall and hanging-wall rock units.¹ A bend visible in fig. 10 is due to interference of dip and mountain slope. The dip is easterly, generally between 50° and 60°, the horizontal width varies somewhat and averages about 90 m. The deepest drill hole so far put down at Kiruna, "Zenobia II" E. of the northern end of the mountain, entered the ore body at 549 m below the level of the lake, and passed out of it into the foot-wall porphyry at 723 m. From the geological relations, including what has been brought out by deep drilling, and the carefully mapped magnetic anomaly, the probable now remaining ore quantity has been estimated at about 1 600 million metr. tons, possibly a good deal more. From the start of mining in 1903 through 1959, production has totaled 235 million tons (production from Luossavaara has been additional 13 million tons).

The ore mineral is magnetite. Hematite occurs as a primary mineral in very small amounts, as crystalline lumps enclosed in magnetite and as thin veinlets. Secondary (martitic) hematite is important within a portion in the southern part. The chief non-iron mineral is apatite, which is very unevenly distributed. It is a fluorine apatite with very little chlorine and carries about 0.9 percent oxides of the cerium metals. Of other constituents, diopside and actinolitic hornblende (in part uraltic) are found in some quantity within a few limited areas. Finally may be mentioned the regular presence of microscopical grains of zircon in the segregations of apatite rock.

¹ The southernmost part of the deposit, however, shifted eastwards along a fault, does not consist of a continuous ore body along the contact but of a chain of intrusions either at it, or close to it in the porphyries on both sides.

Magnetite and apatite, then, can be said to constitute the ore, in any case from the point of view of commercial exploitation. To suit the requirements of the market, the ore as shipped is graded into several "phosphorus classes". At present these are:

B	about 66 percent Fe,	< 0.1 percent P		
C ₁	» 65	»	» 0.1—0.4	» »
C ₂	» 63	»	» 0.4—0.8	» »
D	» 58	»	» 1.75	» »

Because of the great and often sudden variations in phosphorus content, mining is directed with the aid of "phosphorus maps" showing the results of sampling.

In the upper portions of the ore body, ore very low in phosphorus occurred, in minable units, only within a few rather small areas. Mining and deep drilling have disclosed a great increase in this quality when going down the dip. It must be remembered that this direction, in the ore body as it was formed, probably was almost horizontal.

The ore always is fine-grained and when low in apatite appears dense, steely. For the individual magnetite grains, 0.03 mm is a normal size. As in the associated rocks, there is no sign of any textural metamorphism, in strong contrast to the situation in the Gällivare deposits, originally similar in nature. The apatite mostly occurs as stout prisms, varying about 0.1 mm in length in the pure apatite rock. In ore varieties containing magnetite aggregates and such of pure apatite, the latter occasionally exhibit a beautiful trachytoidal arrangement of the prismatic grains.

Ore rich in apatite presents great and interesting variations in the relations between magnetite and apatite. These came out especially well in the weathered ore outcrops.

Sometimes the mixture is quite homogeneous, even when the apatite makes up about half the volume. But generally, when there is much apatite, one finds a streaky alternation of different varieties, ranging from aggregates or lumps of pure magnetite to pure apatite rock. A detail of great interest was first noted by Stutzer (1907): in ore with evenly distributed apatite there occur lumps of the latter, a few centimeters in size, which are surrounded by a mantle of pure magnetite. Where a sequence between different varieties can be discerned, as a rule the one richer in apatite is the later. This relation is especially well brought by bodies of pure apatite rock where in contact with high-grade magnetite, which they split up into angular fragments. Such apatite segregations are common in some parts and take various shapes: from irregular bodies that may reach meters in diameter, to tabular ones that combine a thickness of a few decimeters with a strike length of a score of meters. All units show in their shape a general conforming to the strike and dip of the ore body as such, although with local irregularities.

An especially remarkable ore variety is the "stratified" one that could be studied in the outcrop, locally near the foot-wall on northern Kiirunavaara. It shows a regular lamination of ore (with some apatite) in seams about 1 mm thick, and thinner ones of pure apatite. By more streaky forms it grades into the normal types of magnetite-apatite mixture. It may be noted that similar laminated forms are found also in deposits where the ore bodies form fissure-filling dikes, as at Tuolluvaara, 4 km E. of Kiruna.

Another peculiar form is the "skeleton ore", with an apatite matrix containing arborescent growths of magnetite, similar to such of microscopic dimensions found in some porphyries of the foot-wall unit, but here reaching up to about 5 cm in size.

Sulfides are very rare in the Kiirunavaara deposit. Probably none belong to its original constituents. Pyrite is occasionally found on joints and in the filling of fault fissures. A few small copper veins offer a certain scientific interest. They include one in the immediate foot-wall, which has bornite and chalcopyrite in a gangue chiefly of quartz and tourmaline, and one, possibly in the ore body itself, consisting of bornite and "high" chalcocite ("digenite") enclosing stalks of hornblende. Probably these copper veinlets are genetically connected with the iron ore deposit.

The first-mentioned vein also contributes information on the Pre-Glacial weathering of the Kiirunavaara deposit (Geijer, 1924 a). Only in the southern part of this deposit, but there within a wide area, such weathered ore has been found. The magnetite is largely oxidized to hematite, in the common martite pattern, apatite is generally removed (secondary iron phosphates have been identified in an ore shipment), and some quartz introduced into the pores thus formed. This weathering goes deep down but appears to end about 200 m below the outcrop. The copper vein shows secondary sulfide enrichment, with "low" chalcocite and covellite, and, as a later product, chrysocolla.

The contact relations of the ore body are, in principle, similar on both sides. At the foot-wall contact the ore often contains small inclusions of porphyry. A band, generally a few decimeters in width, of actinolitic hornblende skarn commonly occurs on the contact, sometimes with titanite. At a few places at or slightly above the contact there is found some tourmaline, otherwise foreign to the deposit. The boundary of the ore body is, from the mining point of view, very well defined, but very frequently there are numerous ore veins in the foot-wall rock, in part clearly seen to branch out from the ore body. In the southern part of the mountain, drilling has proved the occurrence of a network of such veins also deeper down in the foot-wall unit. Such systems are known as "ore breccia". They form a characteristic feature of many deposits of the Kiruna type, in different countries.

The foot-wall contact on northern Kiirunavaara, once very well exposed, has proved especially important for the understanding of the ore body's place in the sequence of geological events (fig. 11). Beside the foot-wall unit and the ore there occurs, in this part, a system of porphyry dikes in the foot-wall. This porphyry is similar to the other units in the character of its feldspar, intermediate in quartz content between the foot-wall and hanging-wall units, carries diopside like the former and is texturally similar, also in the shape and size of the feldspar phenocrysts, to the latter. About 10 such dikes are known. None have been found to cut the hanging-wall rock. But one has apparently, when reaching the contact with the latter, spread out as an intrusive sheet along this contact. This body has later been broken up by the ore body, large slabs of porphyry being enclosed in the latter and further penetrated by veinlets of ore rich in apatite and hornblende. Northwards the ore injects a spur, in part showing "stratified" ore, obliquely into the foot-wall. This spur grades into a system of ore veins in the contact zone between the foot-wall unit and the overlying dike porphyry, running for a distance of about 500 m and then

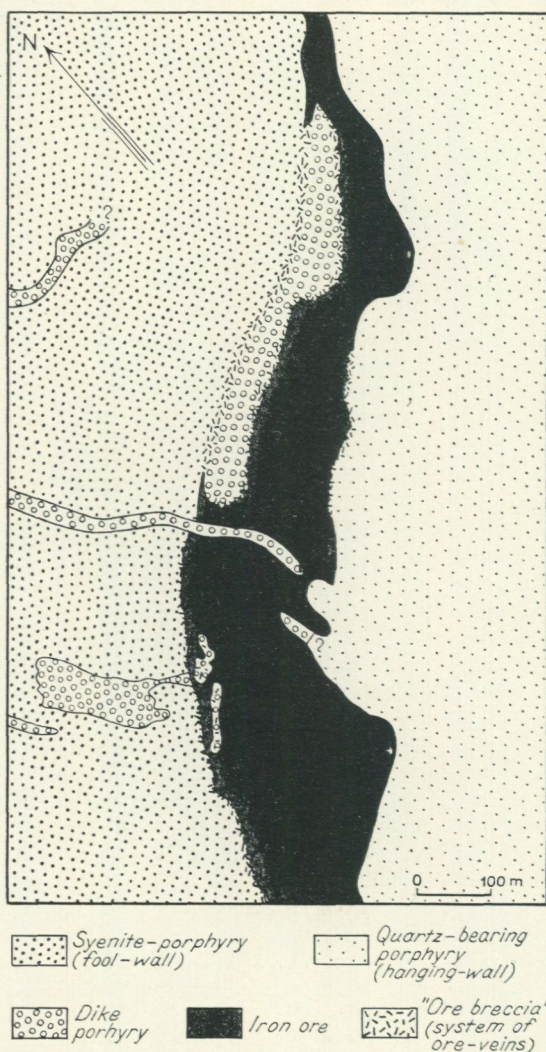
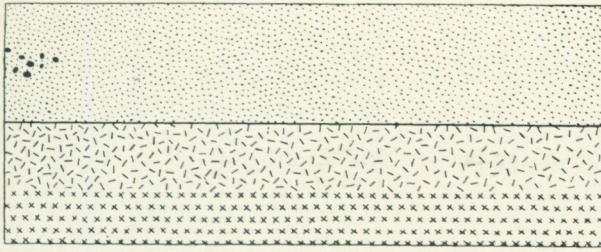


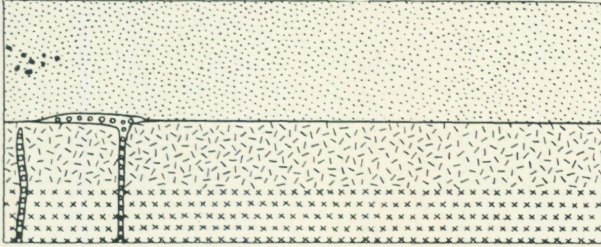
Fig. 11. Northern end of Kiirunavaara. Adapted from Geijer 1910.

uniting again with the ore body. The sharpest contrast to these relations is shown by another dike of the same kind of porphry, about 15—20 m wide, which cuts across also the ore body with straight and clean-cut boundaries. These relations make it clear that the intrusion of the ore body took place when some of the porphry dikes already were in existence, but before the last dike of this very characteristic set was intruded.

Beside the inclusions of dike porphry just mentioned, the ore body contains

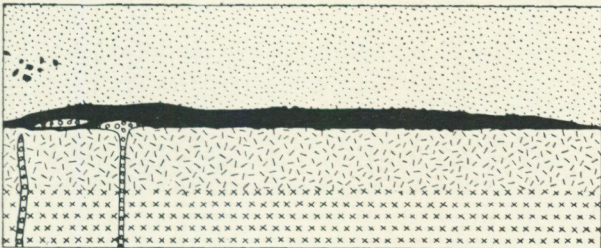


1



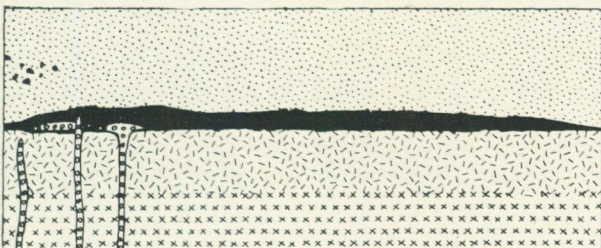
2

3



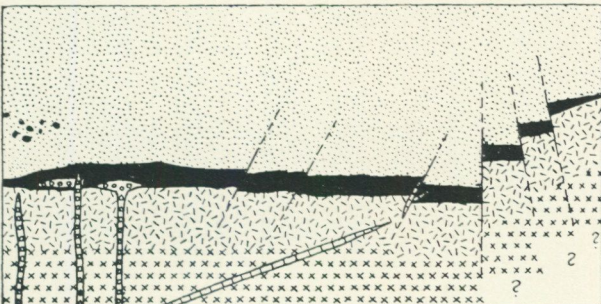
4

5



6

7



8

a couple of "horses" of albite rock that appear to represent altered inclusions of porphyry.

The hanging-wall contact in many places shows characteristic relations that prove the ore to be later than the adjacent porphyry. The ore, which then contains hornblende next to the contact, outwards begins to enclose fragments of porphyry, apparently in part replaced by hornblende. These fragments increase in frequency and size so that a transition is effected to porphyry with veins of ore, passing further into porphyry without such foreign matter. A zone of this nature reaches only a couple of meters in width. Drilling has shown that, at greater depth, veins of ore occur even some distance out in the hanging-wall, on a scale not seen at the surface.

The northern continuation of the ore body, below Lake Luossajärvi, is known only from two drill holes placed "in tandem". They show, along the contact between the porphyries, ore only a little over 2 m in thickness, and above it, in the hanging-wall unit, some meters' thickness of "ore breccia". The magnetically located "parallel ore" in the hanging-wall unit below the lake, is known only from one drill hole which shows a rather rich "ore breccia".

The ore body of Luossavaara exhibits nothing that requires a special description. In the foot-wall there is a wide zone of rather rich "ore breccia" below the ore body.

The latest events in the geological history of the ore mountains, before the weathering, were faulting and apparently accompanying granophyre intrusions. These are known only on Kiirunavaara. Its ore body is cut by a number of faults, generally striking about N. W. and probably always with a greater horizontal than vertical displacement. The largest granophyre dike runs in a N.—S. direction in the foot-wall unit. Other dikes of the same composition, in part with a felsitic groundmass, cut the ore body in its southern part. These dikes show no apparent affinity to the ore-bearing porphyries. In fig. 5 the most important stages in the geological evolution of the deposit are diagrammatically illustrated.

REKTOR AND HAUKI ORES

The Rektor ore body, on the southeastern slope of Luossavaara, is very rich in apatite. About 2.5 million tons of ore have been taken out there, most of it during World War II in order to supply the superphosphate industry with raw material.

The ore occurs on the contact between what is here called the hanging-wall unit, and the overlying pile of Lower Hauki volcanics. Its width is about 30 m. In composition it differs, in several respects, from the main ore bodies. The content of apatite averages above 20 percent. As ore mineral, hematite occurs in amounts comparable to those of magnetite. Small interstitial patches of

Fig. 12. Diagrammatic section through Kiirunavaara, illustrating stages of its early geological history. From Geijer 1919.

- | | |
|--|-----------------------|
| 1. Syenite-porphyry | 5. Iron ore |
| 2. Syenite | 6. Dike of porphyry |
| 3. Quartz-porphyry ("hanging-wall porphyry") | 7. Dike of granophyre |
| 4. Quartz-porphyry with inclusions of ore | 8. Fault |

quartz are rather common, as is also ankeritic carbonate. The apatite is, in part, rather evenly distributed but often forms a regular and fine banding with the iron minerals. A great portion occurs as segregations of pure apatite rock. Sometimes these show transitions to ore, in other cases they form distinct veins brecciating it, or bed-like bodies conforming roughly to the strike and dip of the ore body.

At the lower contact of this deposit, the quartz-bearing porphyry of the hanging-wall unit generally is altered to some meters' width, with new-formed sericite, ankerite, and biotite. It is also frequently intruded by veins of apatite, with or without iron minerals. Above the ore body, the bottom member of the Lower Hauki complex is the Rektor porphyry bed. This peculiar rock consists of a dominantly potassic feldspar, and quartz. Much of it has some small quartz phenocrysts and a granular aggregate of rounded feldspars, 0.2—0.3 mm in diameter. It has been suggested that these may represent recrystallized spherulites. For the rest — the upper portion of the bed at the mine workings, and its whole thickness northeastwards from there — the Rektor porphyry has spherulites and spherulite-fringed tabular feldspar phenocrysts in a dense, flinty quartz matrix. The latter clearly is a product of hydrothermal alteration and in places contains a great amount of iron ore minerals. Probably it has replaced a volcanic glass groundmass. Patches of sericite with tourmaline also occur in it.

At the upper contact, the ore body contains numerous and large inclusions of this porphyry, and also of a type that occurs on top of the Rektor porphyry bed. These fragments are in part silicified. A comparison suggests itself with the upper contact of the Kiirunavaara ore body, where instead replacement by hornblende has occurred in enclosed fragments.

The few exposures of the lower boundary of the Lower Hauki complex S. of the Rektor workings indicate that probably a narrow band, consisting chiefly of apatite, extends along it from the ore body for a length of about 1 400 m, dwindling to only about 1 m in width. In the northeastern direction, again, a similar body possibly extends all the way to Lake Nokutusjärvi (fig. 3), to expand, E. of the lake, as the Nokutusvaara ore body.

The silicified and ore-rich portions of the Rektor porphyry typically illustrate the development of the hematite ores of the Lower Hauki. This volcanic pile is made up of flows — syenite-porphyrines or trachytes, much sericitized, and porphyry related to the Rektor type — and of very strongly altered forms interpreted as originally tuffs. Minerals characteristic of this alteration, whose hydrothermal nature is evident, are quartz, hematite, sericite, barite, tourmaline and orthite. A trait that is remarkable from a geochemical point of view is the extreme scarcity of sulfides. Pyrite is totally lacking. Copper stains are not rare, and are derived from a very wide-spread but quantitatively most insignificant mineralization with chalcocite and bornite. The analogy with the copper occurrences in the huge magnetite bodies may be noted.

ORIGIN OF THE ORES

As aptly formulated by Stutzer (1907), "all earnest observers" have reckoned with a close genetic connection between the ores and the associated porphyries. The first important contribution was by Bäckström (1898, 1904), who emphasized the evidence of the vesicle-fillings in the foot-wall porphyry, which

show that minerals that normally are the first to crystallize in an igneous rock, here occur as the latest element. Their deposition was thought to be due to volcanic after-action, the material having been transported as gaseous compounds, chiefly chlorides and fluorides, and a similar origin was, in general terms, attributed also to the ore bodies. A somewhat more precise variation of this interpretation is represented by De Launay's pneumatolytic-sedimentary hypothesis (1903), rather ingenious with regard to the facts then known, but soon, by better exposures, proved inapplicable. Already in 1898, another hypothesis had been presented by Högbom, who drew attention to certain analogies with iron ores associated with syenitic rocks in the Urals, and concluded that there exists a group of magmatic non-titaniferous iron ores, analogous in origin to the titaniferous ones but connected with rocks of syenitic nature instead of with gabbroic types. Högbom clearly reckons with differentiation *in situ*. Stutzer (1907), who produced strong evidence for a magmatic origin of the ores, especially by noting illuminating details in the distribution of magnetite and apatite (compare above), regarded the ore as "eine gewanderte magmatische Ausscheidung", a conclusion confirmed by later investigations. Stutzer's characteristic of the ore body as a dike is less fortunate, as the rock series most probably occupied an approximately horizontal position at the time of the ore intrusion; an intrusive sheet or a sill would seem a more appropriate designation.

In 1905—1909, on the initiative of Hjalmar Lundbohm, then manager of the mines, a detailed geological investigation of the ores and associated rocks was carried out for the Luossavaara-Kiirunavaara mining company (Geijer 1910). The following views on the origin of the ores are those then arrived at, on some points modified or elaborated on the basis of new evidence obtained from these and related deposits (Geijer 1919, 1924 a, 1924 b, 1931, 1935, 1950). Data collected during these studies have also furnished most of the material for the above descriptions.

The ore bodies are intrusive, as shown by their contact relations, including the "ore breccias". Since the latter are offshoots from the main ore bodies, they cannot represent any later "mobilization" of material. Metasomatic action has been practically restricted to the development of hornblende in the contact zones. Similar relations are characteristic also of Precambrian, Mesozoic, and Tertiary deposits of the same nature elsewhere. The "ore magma" must have been characterized by a high mobility.

The magmatic origin of the main ore bodies is indicated by the following facts. All minerals are such as are also found in the associated igneous rocks. The texture is fully compatible with a magmatic formation, and some details, as the trachytoidal arrangement of apatite prisms, can hardly be explained in any other way. The relations of magnetite and apatite bear witness to differentiation processes within the ore intrusions. But they also show, on the other hand, a difference in age between certain phases. These variations indicate a solidification in stages, in a way hardly paralleled in a "normal" igneous rock.

The Rektor ore and related occurrences, as the dikes of apatite that at some places, particularly between Luossavaara and Lake Nokutjärvi, split up porphyry of the hanging-wall unit, have so much in common with the main ore bodies that their formation must have been closely related to that of the latter.

But their composition, with quartz and carbonate (and tourmaline in the apatite dikes), suggests formation at a lower temperature. This is also apparent from the associated wall-rock alteration, as described above, in contrast to the development of hornblende at the main ore bodies.

The Hauki hematite ores, finally, are the products of a replacement process of hydrothermal nature. But they exhibit geochemical features that may be said, with some extension of the term, to show consanguinity with the Rektor ore and even with the main ore bodies.

When seeking the cause of this huge-scale fractionation of iron and associated compounds from a mother magma, the following facts are pertinent.

The relation of the magnetite ores to the porphyries always is that of a later intrusion, no original gradations between the two having been noted. The geological effects of the differentiation, therefore, have been such as would result from a limited miscibility.

The vesicle-fillings or nodules in the foot-wall unit show that factors have been at work that caused the substance of magnetite, apatite, hornblende, and titanite to be kept in solution until the final stages of the crystallization of the feldspar rock. Their relations to the feldspar rock, as reported above, show that they are not the products of later fumarolic action as imagined by Bäckström. While these bodies are not, in their nature, directly comparable to the ore bodies, there is so much of similar relations that it cannot be doubted that the physico-chemical conditions which, in these two types of concentration of magnetite etc. have caused the separation, must have been closely related. In the case of the vesicle-fillings, the action of volatile magma constituents is most clearly indicated.

The Rektor ore (and related forms), when compared with the main ore bodies, by its mineral composition indicates a lower temperature of formation and more influence of volatiles, while still presenting textural features that appear to be best interpreted as magmatic.

With the Hauki hematite ores, finally, one enters the realm of typical hydrothermal after-action, with water, carbon dioxide, etc.

From these facts one arrives at the interpretation that the substances that formed the main ore bodies were fractionated out, as a separate magma, from its mother magma under the influence of volatile constituents. This separation must have taken place somewhere in the volcanic sub-structure or even deeper down. In the case of the Rektor ore, volatiles have remained until a later stage. The vesicle-fillings may be regarded as *in situ* examples of a related although not quite identical form of fractionation.

An interesting support to this interpretation has been given by Fischer (1950), who melted sodium silicate, magnetite, and apatite, with fluorite, and obtained two separate melts, magnetite and apatite being concentrated in one of them. The results of Fischer's experiment thus point in the same direction as the accumulated field evidence: that the ore substances were concentrated through a process of magmatic differentiation in which volatiles were a deciding factor.

REFERENCES

- BÄCKSTRÖM, HELGE, 1898. See Lundbohm 1898.
- 1904. Ekströmsbergs och Mertainens järnmalmsfält. Geol. Fören. Stockholm Förh., 26, pp. 180—183.
- DE LAUNAY, L., 1903. L'Origine et les caractères des gisements de fer scandinaves, Annales des Mines, pp. 49—211.
- FISCHER, REINHARD, 1950. Entmischungen in Schmelzen von Schwermetalloxyden, Silikaten und Phosphaten. Neues Jahrb. f. Min., etc. Abh., 81, pp. 315—364.
- GEIJER, PER, 1910. Igneous rocks and iron ores of Kiirunavaara, Luossavaara and Tuolluvaara. In the series "Scientific and practical researches in Lapland arranged by Luossavaara-Kiirunavaara Aktiebolag". Stockholm. 278 pp. (Also dissertation, Uppsala.)
- 1919. Recent developments at Kiruna. Sveriges Geol. Unders., ser. C no. 288. 22 pp.
- 1924. a. Swedish occurrences of bornite and chalcocite. Sveriges Geol. Unders., ser. C no. 321, 52 pp.
- 1924. b. Kiirunavaaras geologi i djupborrningarnas belysning. Jernkont. Annaler, pp. 243—254.
- 1931. The iron ores of the Kiruna type. Sveriges Geol. Unders., ser. C no. 367, 39 pp.
- 1935. Die nordschwedischen Eisenerze und verwandte Lagerstätten als Beispiele eruptiver Spaltungsprozesse. Geol. Rundschau, 26, pp. 351—366.
- 1950. The Rektor ore body at Kiruna. Sveriges Geol. Unders., ser. C no. 514. 18 pp.
- HÖGBOM, A. G. 1898. Om de vid syenitbergarter bundna järnmalmera i Östra Ural. Geol. Fören. Stockholm Förh., 20, pp. 115—134.
- LUNDBOHM, HJALMAR och BÄCKSTRÖM, HELGE 1898. Kirunavaratraktens geologi. Geol. Fören. Stockholm Förh., 20, pp. 68—74.
- 1910. Sketch of the geology of the Kiruna district, Geol. Fören. Stockholm Förh., 32, pp. 751—788. (Also as guide-book, XI int. geol. congr.)
- ÖDMAN, OLOF H., 1957. Beskr. t. berggrundskarta över Norrbottens län. Sveriges Geol. Unders., ser. Ca no. 41. 148 pp. Eng. summary (Precambrian rocks of the Norrbotten County) pp. 132—148.
- STUTZER, O., 1907. Geologie und Genesis der lappländischen Eisenerzlagertstätten. Neues Jahrb. f. Min., etc., Beil. Bd 24, pp. 548—675.
- SUNDIUS, NILS, 1915. Beitr. z. Geologie d. südl. Teils des Kirunagebietes. In the series "Scientific and practical researches in Lapland arranged by Luossavaara-Kiirunavaara Aktiebolag". 237 pp. (Also dissertation, Stockholm.)

Geology of the Gällivare iron ore field

by

SVEN LJUNGGREN

INTRODUCTION

History. The Gällivare iron ore field was known already in the 17th century though exploitation was not started until about 1740. As the ore had to be transported by reindeers to blast furnaces at the coast of the Gulf of Bothnia, only small quantities of ore were mined. Mining operations on a large scale were not possible until the railway line between Luleå (at the Gulf of Bothnia) and Malmberget was completed in 1887.

Ownership. In 1903 the Luossavaara-Kiirunavaara AB (LKAB) became the owner of the mines and since 1907 the share capital of the LKAB became equally divided between the Trafik AB Grängesberg-Oxelösund (TGO) and the Swedish State. In 1950 the company also became the owner of the Bergverks AB Freja and its mine, Koskullskulle, in the easternmost part of the field. On October 1st 1957 the State took over the rest of the shares except for a small part that will still belong to the TGO. On that date the TGO and LKAB also formed a joint ore sales organisation, Malmexport AB, the shares of which are owned to 50 % by each company.

Location. The field and its mining community, Malmberget, are situated at 67.2 degrees North or about 70 kms (45 miles) north of the Arctic Circle. It lies in the middle of Gällivare parish which ranges over some 17 000 km² (6 500 sq. miles) and has 25 000 inhabitants, 10 000 of which make their homes in the mining communities. — The distance by rail to the shipping ports of Luleå and Narvik (Norway) is 211 kms (130 miles) and 275 kms (170 miles) respectively. To Stockholm the same distance is 1 319 kms (820 miles).

Topography. The hills which are called Gällivare Malmberg (transl: G. Ore mountain), chiefly extend east-west. The highest point (also the datum point for the mines) is at an elevation of 616 m (2 000 feet) above sea level.

Production. Underground mining mainly by shrinkage stoping (a variety called stope — and pillar mining), longhole mining and sub-level caving. All ore from the various ore-bodies is being hauled on the 300 m level to a central underground crusher station. From bins under the crushers the ore is fed onto rubbercoated steel-sheet conveyor belts carrying it to the surface sorting plant. The sorted ore then is transported by rail to Luleå or Narvik. Middlings from the sorting plant are transferred to the wet concentrating plant. Part of its products go to the pelletizing plant.

In 1958 the total production from the field was 3.3 million tons of ores, concentrates, and pellets. Out of this production 2.3 million tons is P-rich ore. These figures mean that about one fifth of the total Swedish iron ore production comes from this field. About 90 % of the production is exported. — From 1962 there will be production facilities for 5 million tons a year.

Total number of employees is about 3 100.

THE REGIONAL GEOLOGICAL PICTURE

Except for the Caledonian mountains in the westernmost part of the county the whole of Norrbotten is made up of Archean rocks (the area of the county comprises more than 1/5 of Sweden). These mainly belong to two orogenic periods, the Svonian and the Karelian. The regional trend of strike in the county is approx. NNE with fold axes remarkably uniform in a 40° — 60° plunge to the S or SW.

Between the district S of Kiruna (80 kms — 50 miles — to the NNW of Gällivare) and the Jokkmokk district (80 kms — 50 miles — to the SSW) there is a relatively narrow belt of gneissic, mainly acid volcanics of Svonian age. This N—S striking belt is incompletely surrounded by late orogenic Karelian granites. On the same latitude as Gällivare there is an easterly directed offset from this belt. The Gällivare ore field is situated in the NE part of the offset, the width of which is some 6 kms (4 miles). Beyond the SE contact of the offset there is a gabbro mountain — to the N and E of the ore field and to the S of the gabbro the late Karelian granite reappears.

ROCK DISTRIBUTION WITHIN THE FIELD

- | | |
|----------------------|---------------|
| 3. Granitic rocks | Late Karelian |
| 2. Ores | } Svonian |
| 1. Ore-bearing rocks | |

1. The ore-bearing rocks belong to the acid and intermediate volcanics of the Kiruna series. During the Karelian deformation they were recrystallized and are now classified as leptites or gneisses. The original porphyric characters are destroyed everywhere except in a few, tectonically relatively undisturbed parts of the field. On the present mine maps only red and grey leptites are distinguished though Geijer has defined seven different kinds of these rocks. The most common one, the red Kaptens leptite, is composed of some 50 % potash feldspar, 30 % albite, and 20 % quartz. The Puoitak leptite (see enclosed map) has 30—35 % quartz and sometimes shows granulated quartz phenocrysts. The greyish leptites are almost quartz-free and mainly consist of an oligoclase-albite (sometimes scapolitized) and some 20 % femic minerals (biotite and/or hornblende).

2. The ores belong to the Kiruna type of iron ores i.e. Fe-rich ores with an intermediate to high content of the phosphorus mineral, apatite (for analyses of the ores see p. 42). They are mainly magnetite ores — hematite ores only occur in the western part of the field. Production of hematite ore only amounts to some 10 per cent of the total production of the field. The distribution of phosphorus in the ores is fairly regular so that a certain orebody generally consists of only one quality (GD, GC or FA, see p. 42). — The ores are younger than the main part of the leptite series but have a close genetical connection with these rocks. Like the ore-bearing rocks the ores too have undergone deformation and recrystallization during the Karelian orogeny. From a milling point of view the coarse grain of the ores (aver. 0.7 mm) is favourable especially as intergrowths are not very common.

The question in which form the hematites have originally been formed is

not solved. As a rule detailed genetical discussions are difficult to perform on account of the degree of metamorphism. It is felt that such problems largely must be solved by comparison with analogous phenomena in the other Norrbottnian iron ores fields which are generally less metamorphosed. It seems to be generally accepted that, whatever the primary origin of the ore deposits at Kiruna might be, the Gällivare ores have been formed under closely related — if not identical — conditions.

Here should be mentioned also that the ores as well as the leptytes quite often have a content of low-calcic skarn minerals, mainly hornblende. This is especially often the case in the reddish leptytes which generally have a spread and irregularly distributed net of hornblende veins. On certain places, especially in leptytes close to the ore, number and thickness of the veins is increased so that a skarn breccia is formed. The rock material around the veins in this stage has a tendency to be diffusely replaced by hornblende and — in places — by a white or slightly pinkish albite mass between the hornblende veins. The final stage is a rock composed entirely of hornblende and albite. — Generally the greyish leptytes are not “brecciated” by the skarn hornblende to the same extent as the reddish ones, though when the replacement process once is initiated in them it seems to have reached the final stage relatively easier. — The formation of the hornblende skarns seems to be syngenetical with and casually connected to the ore formation, though some mobilization of the skarn material also has taken part in Karelian time. The albite formation must not necessarily be connected to the ore formation — it might as well be of a late Karelian age.

3. The granitic rocks are considered as being palingenic and formed from older rocks (mainly porphyries) at the time of the Karelian deformation. This regeneration supposedly took place partly as a simple grain enlargement in situ without much metasomatic exchange and partly through melting whereby the neomagmatic material gave rise to those rocks which are now labelled as clearly intrusive.

a) The characteristic small- to mediumgrained biotite granite occurs in three places. It is slightly potash-dominant and has SiO_2 approx. 68 %.

b) Pegmatite granites and clearly intrusive granites generally occur in the northeastern part of the field, i.e. close to its granitic foot-wall.

c) “Other granitic rocks” on the map comprise a few imperfectly known granitic bodies and also undoubtedly in situ-granitized leptytes.

Finally the migmatization should be mentioned. It is most intense in the northern parts of the field where it may sometimes be rather arbitrary if the rock in question is called a migmatite or a granite with remnants of leptyte.

TECTONICS

Prior to the Karelian folding the ores probably occurred as rather straight and consistent sheets in the volcanites. It is not known with certainty whether the ores originally intruded the porphyries when these were in a horizontal or inclined position.

All of the more important structural features of the field may be traced back to the Karelian folding. The moderately steep to steep dips to the south are determined by the position of the folding axes, plunging about 45° to the S

or SSW. Strictly local variations in the plunge may, however, give dips approaching the horizontal (crossfolding!).

It is not possible to state if the field is an isoclinally folded and to the north overturned syncline or if it is composed of a parallel series of rocks, being strongly compressed in its eastern parts.

Faults are scarce — at least such with a movement of more than a few inches. The largest movement that has been found is 5 m (17 feet).

The shape of the orebodies have been strongly changed during the deformation time. As the ores have been more plastic than their wall-rocks there are many examples of mechanical transport of ore over fold apices. The greater ore mass thereby has been moved in an anti-clockwise direction so that it is now found in the western limbs of synclines and the eastern limbs of anticlines.

GENERAL DATA ABOUT THE ORES

Plunge	45° to the S
Total horiz. area	185.000 m ² —2.000.000 sq. feet
» » length	8.000 m — 27.000 feet
Average width	23 m — 77 feet
Maximum »	150 m — 500 feet
Tons per m depth	700.000
Present annual production	3.500.000 tons
Total production to date	110 million tons
Average depth of mining	160 m — 530 feet

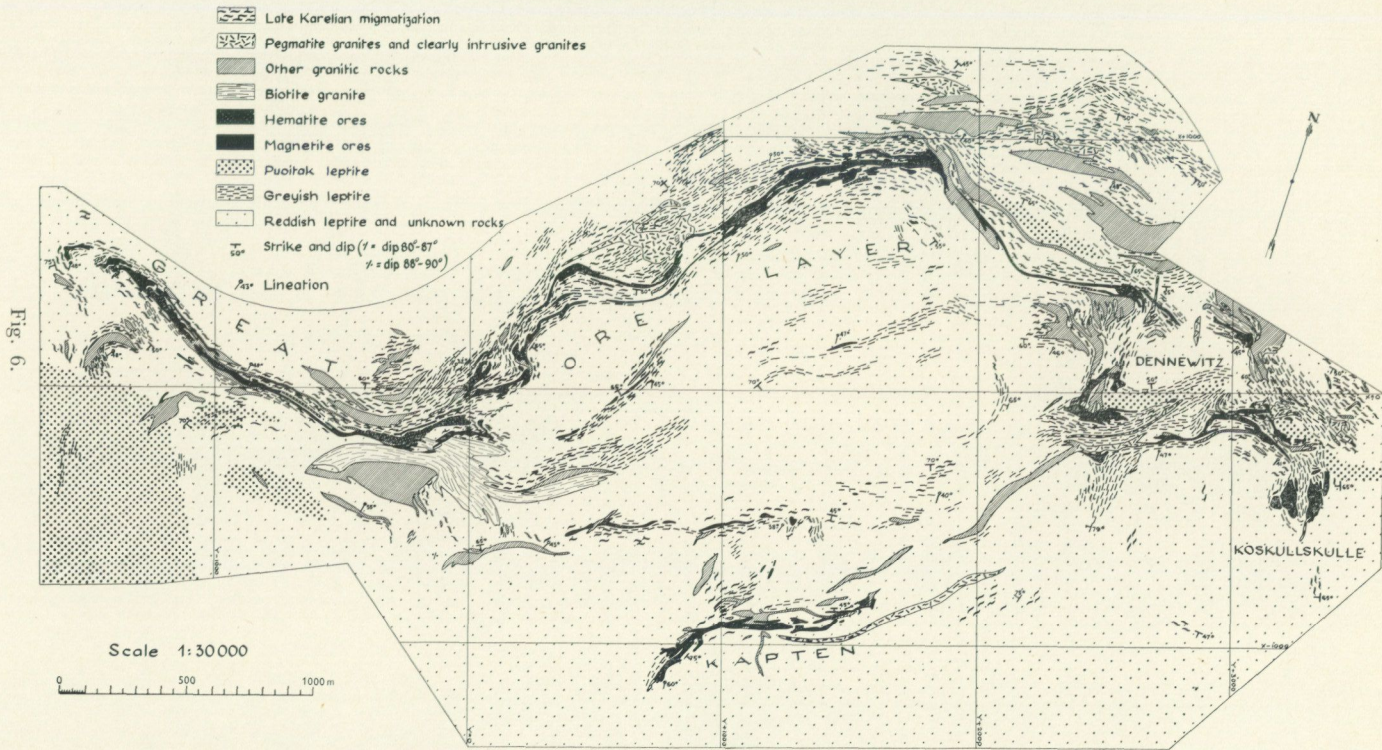
Average analyses of sorted ores			
	Ore quality		
	GC	GD	FA
Fe %	63.5	59.7	62.5
P %	0.3	0.7	0.04
SiO ₂ %	6.6	8.3	7.4
S %	0.05	0.05	0.06

Considering the economically important factors of
total horiz. ore area,
quantity relation magnetite ore/hematite ore,
distribution of phosphorus, and
frequency of intrusive granites

in the upper and lower parts of the field there are as yet no traceable changes. — It is necessary, however, to stress the fact that the mined-out depth is only 160 m (530 feet) — a very small figure as compared to the total horizontal ore length of 8 000 m (27 000 feet).

THE GÄLLIVARE IRON ORE FIELD

Geological map of the 250m. level.
Compiled at LKAB, Malmberget by S. Ljunggren.



ORE RESERVES

The official estimate of the reserves are 400 million tons to 800 m depth (2 700 feet). There are no direct ore observations on greater depths. An airborne magnetic investigation carried out in the early 1950's does, however, indicate a considerably greater depth and larger tonnage.

EXPLORATION

Drilling. Diamond drilling with Craelius X—2, X—4, XC—42, and XB—2 drills amounting to 2 000—3 000 m per year (7 000—10 000 feet). Since 1894 a total of 75 000 m (250 000 feet) have been drilled for exploration purposes. Average length of holes is 110 m (370 feet).

Extension steel drilling with Atlas Copco BBC 52 drills amounts to some 6 000 m per year (20 000 feet per year) and is used for most horizontally and upwards directed exploration holes shorter than 60 m (200 feet).

Sampling is presently done by collecting the sludge from dry-drilled percussion holes, which are drilled in the walls of crosscut drifts. Depth of holes 0.6 m (2 feet), distance between successive holes in the same wall 3 m (10 feet). Assay figures are plotted on iron and phosphorus assay maps.

Special surveying. Deflection surveying in drill holes is regularly done in most diamond drill holes and in some extension steel-drilled holes. This surveying is made with the Craelius electromagnetic dip indicator.

Rock pressure measurements have been performed in a shaft pillar with the device constructed by prof. Nils Hast. — For control of block caving operations and for estimates of rock strength in pillars there is used a Mikroseis instrument (geophone with amplifiers).

Geophysical surveying. Almost the entire field has been surveyed with a dip needle instrument in a 10 m (33 feet) square grid net (total number of stations 190 000). — An airborne magnetic survey was made in 1951. — Gravity surveys have been done underground as well as on the surface on various objects.

Mapping. Mine geological mapping is done by "mappers", with no or very little geological education who have been trained at the mine. The mapping scale is 1 : 800. Special emphasis is laid on registration of changes of strike, dip and lineation directions in the wall rock as such generally signify corresponding directional changes of the underlying ores.

Core logging is done by the "mappers". The cores are stored in steel shacks with a capacity of approx. 1 000 m core (3 300 feet) per m³. 95 % of the cores from most holes are thereby discarded so that only 1/20 of the original core length is stored.

Simplified "ore maps" in 1 : 800 scale are distributed to the production leaders in the mine (foremen, mine captains and engineers). These maps and profiles are pocket-sized (form A6) and have only two signs: ore (black) and ore breccia (cross-hatched) — non-mineralized rock its left white.

LITERATURE

- BGIU = Bulletin of the Geological Institutions of Upsala
SGU = Sveriges Geologiska Undersökning
- GEIJER, P., 1930: Gällivare malmfält. Geologisk beskrivning. With a summary: Geology of the Gällivare iron ore field. — SGU, Ca 22.
— 1931: The iron ores of the Kiruna type. — SGU, C 367.
- KOARK, H. J., 1952: Über Querfaltung, Bewegung // B und Erzlagerung mit Beispiele aus Malmberget/Gällivare. — BGIU 34.
- LANDERGREN, S., 1948: On the geochemistry of Swedish iron ores and associated rocks. — SGU, C 496.
- ÖDMAN, O. H., 1957: 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). — SGU, Ca 41.

Road-log

First day (Aug. 4th and Aug. 27th). Arrival at Finnforsfallet by train from Stockholm. Bus Finnforsfallet—Boliden—Varuträsk—Skellefteå.

The village of Boliden, museum of the Boliden Mining Co. Informations and lectures.

Varuträsk pegmatite quarry.

Phyllite exposures.

Dinner at Skellefteå, host Boliden Mining Co. Overnight stay in Skellefteå.

Second day (Aug. 5th and Aug. 28th). Bus Skellefteå—Boliden—Renström—S. Åkulla—Skellefteå.

Boliden Mine, underground visit.

Renström Mine, underground visit.

Exposure of Revsund granite et S. Åkulla.

Overnight stay in Skellefteå.

Third day (Aug. 6th and Aug. 29th). Bus Skellefteå—Lillholmträsk—Kristineberg—Rävliden—Kristineberg—Malå.

Passing the cableway Kristineberg—Boliden (96 km, 60 miles. Longest in the world).

Phyllite exposure at Lillholmträsk.

Kristineberg Mine, underground visit.

Rävlidenmyran Mine, underground visit.

Overnight stay in Malå.

Fourth day (Aug. 7th and Aug. 30th). Bus Malå—Adak—Ledfat—Slagnäs—Laisvall.

Adak Mine, underground visit.

Ledfat at the Skellefteå River. Examination of the Ledfat conglomerate.

Passing the mountain of Aistjakk. Overthrust nappes, covering Cambrian miles), 380 000 volt.

Passing the mountain of Aistjakk. Overthrust nappes, covering Cambrian shale, Eocambrian sandstone, and Precambrian granite.

Dinner at Laisvall, host Boliden Mining Co. Overnight stay in Laisvall.

Fifth day (Aug. 8th and Aug. 31st).

Laisvall Mine, underground visit.

In the afternoon bus Laisvall—Arvidsjaur, overnight stay in Arvidsjaur.

Sixth day (Aug. 9th and Sept. 1st). Bus Arvidsjaur—Gällivare.

Exposures of granodiorites at Pite River and Lina granite at Lule River.

The power stations of Harsprånget and Porjus at Lule River.

Train Gällivare—Kiruna, overnight stay in Kiruna.

Seventh day (Aug. 10th and Sept. 2nd).

Visits at the iron ores of Kiruna (Kiirunavaara, the Rektor ore, etc)

Dinner at Kiruna, host LKAB (Luossavaara-Kiirunavaara Mining Co). Overnight stay in Kiruna.

Eighth day (Aug. 11th and Sept. 3rd). Train Kiruna—Gällivare.

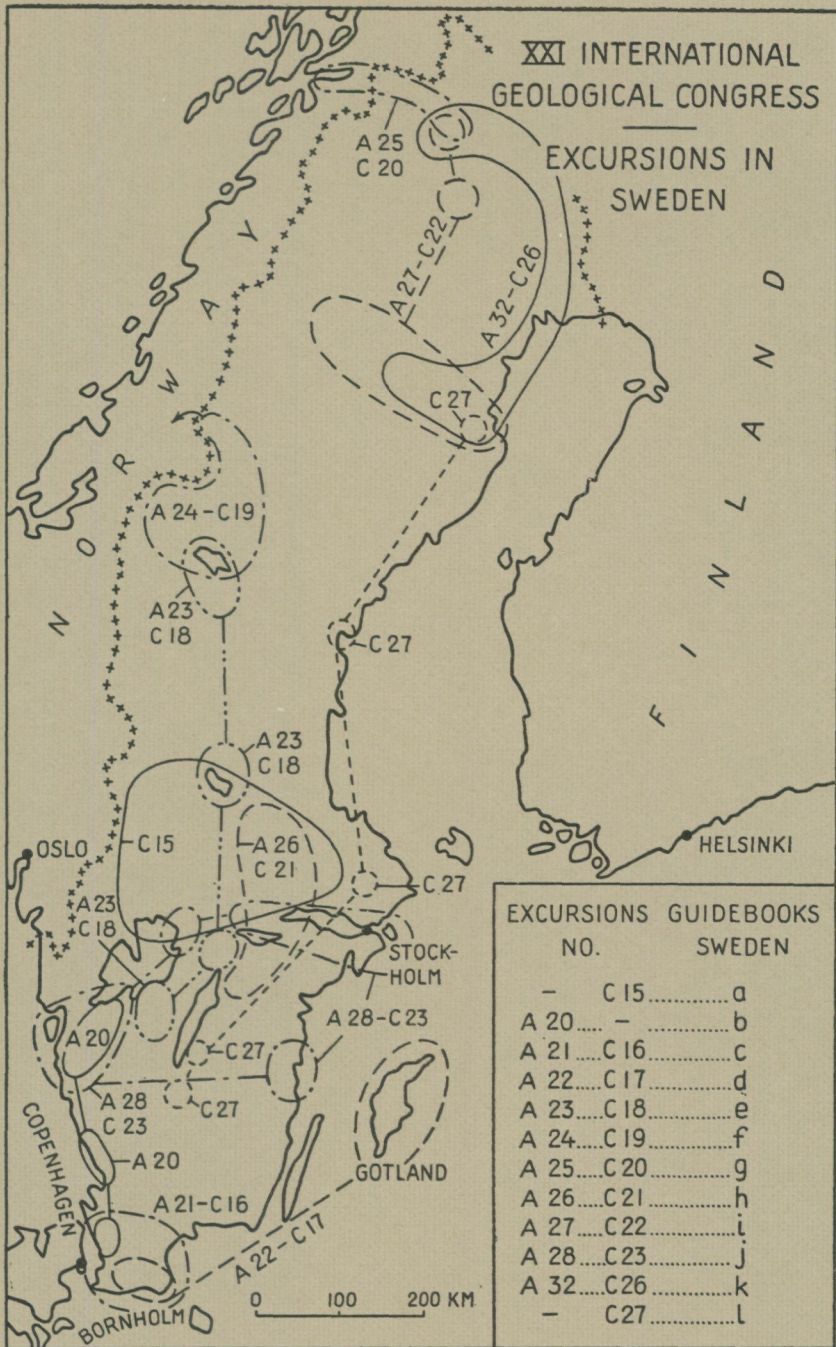
Visits at the iron ore mines of Gällivare—Malmberget.

Overnight stay in Gällivare.

Ninth day (Aug. 12th and Sept. 4th). In the afternoon departure from Gällivare by train to Stockholm.

XXI INTERNATIONAL
GEOLOGICAL CONGRESS

EXCURSIONS IN
SWEDEN



EXCURSIONS GUIDEBOOKS
NO. SWEDEN

-	C 15	.....	a
A 20	-	.....	b
A 21	C 16	.....	c
A 22	C 17	.....	d
A 23	C 18	.....	e
A 24	C 19	.....	f
A 25	C 20	.....	g
A 26	C 21	.....	h
A 27	C 22	.....	i
A 28	C 23	.....	j
A 32	C 26	.....	k
-	C 27	.....	l

SWEDEN

Guide-book i

Key map, see inside of this cover

PRINTED IN SWEDEN

Price 5 Sw. crowns