SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. N:O 288.

ÅRSBOK 12 (1918): N:O 5.

RECENT DEVELOPMENTS AT KIRUNA

BY

PER GEIJER

WITH ONE PLATE

Price 0.50 kr.

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STOCKHOLM 1919
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Introduction.

In the summer of 1917, and during the whole field season of 1918, the author was engaged in economic work in the Kiruna district. Some part of the time, however, could be devoted to investigations of a theoretical nature. All recent exposures, due to the progress of mining operations and exploratory work, were studied, with the result that the author's previous views on the geology of this district were modified on some important points, and corroborated on others. Thus, observations were made which settle definitely one of the most debated questions, and settle it in a way that proves the author to have been in wrong in his previous opinion on this point. The other new material is, for the most part, of little interest except to those well acquainted with the geology of the district, but it is deemed appropriate to publish it along with the information which is of a more general interest.

Observations bearing on the mode of eruption of the Kiirunavaara ore body.

During the first careful study of the geology of the Kiruna district, carried out by LUNDBOHM and BÄCKSTRÖM [1] in the nineties, one of the most interesting discoveries made was that of the occurrence of ore fragments in the porphyry which forms the *hanging wall* of the Kiirunavaara

[1] G. F. F. Vol. 20. p. 68.

and Luossavaara ore bodies. These fragments were in every respect similar to the ore of the main ore bodies, and were accepted as proving that the porphyry in question was younger than the ore. At the same time, the relations between the ore body and the rocks of the *foot wall* showed the former to be the younger one. BÄCKSTRÖM's conclusions were that the ores are of pneumatolytic origin, and deposited after the eruption of the foot-wall rocks, but before that of the hanging-wall porphyry. This explanation has, in its main points, been accepted by DE LAUNAY (1903).[1] On the other hand, STUTZER, who visited Kiruna in 1905 and 1906,[2] found reasons for a wholly different view: according to him, the rocks surrounding the ores are intrusives, not extrusives, and the ore bodies are *dikes*. The presence of ore inclusions in the hanging-wall porphyry is explained by assuming a difference of age between parts of the mass of this rock: while most of it is older than the ores, part of it may be younger, and even younger than the ore bodies.

The author, working in the Kiruna district from 1905 to 1909,[3] came to the conclusion that, all facts considered, there was more in favour of BÄCKSTRÖM's opinion of the age relations than in that advocated by STUTZER. (A most important difference between the views of BÄCKSTRÖM and the author lies in the acceptance of a magmatic origin of the ores, instead of BÄCKSTRÖM's pneumatolytic hypothesis; this, however, does not affect the point now at issue). Thus, the contact influence of the ore bodies, manifested in the occurrence of numerous dikes and veins of ore in the wall rock, and in the local change of the latter, just at the contact, into an amphibole rock, was found to be strong and re-

[1] L'origine et les charactères des gisements de fer scandinaves. Ann. des Mines, 1903.

[2] Geologie und Genesis der lappl. Eisenerzlagerstätten. Neues Jahr b. f. Min. etc. B. B. 24, 1907, p. 548.

[3] Igneous rocks and iron ores of Kiirunavaara, Luossavaara and Tuolluvaara. Stockholm 1910.

gular all along the foot-wall contact, while similar phenomena were practically wanting at the hanging wall. Also, nothing was found in favor of STUTZER's hypothesis of two sets of hanging-wall porphyry, one older than the ores but the other distinctly younger, although particular attention was given to this possibility. Finally, an intrusive nature of the wall rocks, which in itself would prove a similar origin for the ores, was found improbable, all observations tending to support BÄCKSTRÖM's view on this point.

The idea, that these enormous ore bodies should be surface flows was, however, met by a very vigorous opposition. Among the many distinguished geologists, who visited Kiruna in 1910 as members of the International Geological Congress meeting in Stockholm in that year, many would not believe in the possibility of such an extraordinary phenomenon.[1] The criticism caused the author to take up the discussion once more, in a paper published in 1912.[2] In this contribution, an extrusive origin of the wall rocks is still found most probable, but concerning the ore bodies certain weak points in the author's views are admitted, as the magnitude of the contact action at the foot wall, which seems too great for an extrusive body, and the lack of agreement between the author's views on the differentiation process and the supposed mode of eruption.

In 1914, R. A. DALY spent several days in the district. His results are stated in a paper published in the following year.[3] While convinced of the magmatic nature of the ore bodies, DALY follows, with regard to their mode of eruption, neither STUTZER nor the author. Instead, he advocates differentiation by gravity out of the mass of the hanging-wall

[1] Compare A. BERGEAT, Die genetische Deutung der nord- und mittelschwedischen Eisenerze etc. (Fortschr. d. Mineralogie, etc. I. 1912), and L. L. FERMOR, On the origin of the iron ores of Swedish Lapland. Journ. Iron and Steel Inst. 1911, p. 113.

[2] Studies on the geology of the iron ores of Lappland. G. F. F. Vol. 34. p. 727.

[3] Origin of the iron ores at Kiruna. Stockholm 1910.

porphyry. The ore inclusions in this rock are regarded as segregations that were trapped, while sinking, by the solidifying of the porphyry. DALY is inclined to regard the porphyry as an intrusive, but admits that this view may be disputed. DALY's hypothesis would class Kiirunavaara with the sulphide deposits of Sudbury and Insizwa and other more or less clear cases of differentiation by gravity.

Several objections may be made to this explanation of the geological conditions at Kiruna. It postulates liquation as a factor in magmatic differentiation, otherwise the ore body could not show its actual textural features, which admittedly prove it to have crystallized as an igneous rock and not as a precipitation of crystals. The texture of the porphyry shows this rock to have been in a highly viscous state, as it has originally partly solidified as a glass or as a very fine-grained mass. This is a fact that is entirely independent of its extrusive or intrusive nature. To the author, no facts are known making it probable that segregations of ore magma could sink for many hundred meters through such a viscous mass. It is evident that no *conclusive* evidence can as yet be produced for or against the various estimates of these factors in the process advocated by Professor DALY, as several of them are too imperfectly known. There is, however, no necessity to discuss the arguments in detail, and weigh the various pieces of evidence, as the recent observations made by the author settle the question in a way different both from that advocated by Daly and from the view previously held by the author himself.

Returning to Kiruna after an absence of several years, the author immediately turned his attention to the southern part of Kiirunavaara, where the progress of the mining operations had resulted in several good exposures of the hanging-wall contact — in former years, good exposures of this contact existed only in the northernmost part of the mountain. In four places, contact phenomena were found that exactly correspond to those long known from the foot-wall contact.

These localities are situated, two on Jägmästaren, the southernmost part of the mountain, one 200 meters further to the north, on Professorn, and one on Kapten, about 800 meters from the locality on Professorn. On the intervening stretches, the exposures are not yet satisfactory, and it is to be expected that contact phenomena of this nature will in time be found to be more widespread. Indeed, on Landshövdingen, between Professorn and Kapten, a typical »ore breccia», that is, a system of ore dikes in the porphyry, has been observed by Mr. P. A. Anderson, who took a photograph that he has kindly put at the writer's disposal. This point is now quarried away. In the cases studied by the writer, there is a more or less marked embayment of the contact line, and the ore seems to dip at a low angle under the tongue of porphyry. The width of this embayment may be about 10 to 30 meters. On Kapten, however, the contact line is rather straight.

There is practically no variation in the general character of the contact zone at these various localities. When going from the relatively pure ore mass towards the contact, one encounters first a zone, a couple of meters wide, of ore richly mixed with green hornblende, appearing as regularly distributed platy crystals but also as irregular masses, frequently of a drusy nature. The ore is sometimes gathered in patches in the amphibole mass. Proceeding outwards, porphyry fragments are encountered in the hornblendic ore, at first only as pieces less than an inch across, or isolated phenocrysts, and few and scattered, but gradually becoming larger and more numerous, until the mixture of ore and rock must be described as porphyry with dikes and veins of a more or less hornblendic ore. This »ore breccia», as it may be called in agreement with local usage, passes into porphyry without any foreign matter. The width of the zone, from the first porphyry fragments to the disappearance of the ore veins, generally amounts to 2 or 3 meters. The porphyry of the fragments, including those of the outer

breccia zone, generally contain numerous prismatic individuals of a green hornblende, which are lacking in the porphyry outside the contact zone. Small brown garnets are not uncommon in this zone, occurring on joints or in druses.

The phenomena we have just described correspond exactly to those found at the foot-wall contact of the ore body, and previously examined by the author, particularly in the northern part of the mountain. Every detail is familiar: the high content of hornblende, the gradual change from ore with small and few porphyry fragments to porphyry with ore veins, and in turn to typical porphyry without any visible introduced material, the appearance of hornblende stalks in the porphyry fragments and of garnet crystals, the width of the contact zone.

Renewed examinations of the hanging-wall contact in the northern part of Kiirunavaara showed that, in at least one place, there is a contact zone similar to those now described, although much narrower and greatly masked by later (local) pressure metamorphism, which may perhaps account for its having been misinterpreted by the author.

The contact relations of the Kiirunavaara ore body, as they are now known, seem to the author to admit of no other explanation than the ore's being an intrusive body, injected between the syenitic porphyries of the foot-wall and the quartz-bearing porphyry of the hanging-wall. Thus STUTZER's view has been confirmed, and the other hypotheses, including that embraced by the author, have been found wrong.

Regarding the conditions of intrusion, it ought to be remembered that the dip of the contact plane followed by the ore certainly was much lower than it is today, after extensive tilting and mountain-building, as it is roughly parallel to that of the lower Hauki complex, which overlies the hanging-wall porphyry. Therefore, the ore body ought to be classed as a sill and not as a dike.

Relations between the hanging-wall porphyry and the porphyry dikes of Kiirunavaara.

The fact that the ore body is intrusive brings up a new problem in the geology of Kiirunavaara. In the northern part of that mountain there occurs a set of porphyry dikes. These dikes are younger than the syenite and the porphyries into which this rock grades. One or a few of them reached the upper surface of the older porphyries, where they spread out into a sheet. This porphyry is overlain by the ore body and shows the same phenomena as do the older porphyries where they are in contact with the ore. Several dikes of entirely the same petrographical character are, however, plainly younger than the ore body.

The dike rock was called a syenite-porphyry in the previous description, the hanging-wall rock being termed quartz-porphyry. This was done in a too painstaking effort to use an exact petrographic nomenclature, following ROSENBUSCH as closely as possible. The choice of names, however, diverted attention from the fact that the dike rock is more similar to the hanging-wall porphyry than to the »older syenite-porphyries». One phase of the hanging-wall rock, in particular, shows a very great resemblance to the dike porphyry. This is the gray rock (»quartz-porphyry type no. 2» of the previous description) forming the bottom parts of the hanging-wall body for a considerable distance.

Now since the ore body is an intrusive, and its level does not necessarily mark an older geological boundary, it is necessary to consider the possibility that the dikes may belong to the hanging-wall porphyry and represent some of its »feeders». This would mean that the dike-porphyry sheet underlying the ore should be a part of the hanging-wall mass, cut off by the intrusion of the ore body, which in this case should not have in every detail followed the contact between the syenitic complex and the hanging-wall porphyry.

A revision of old observations, and examinations of recent exposures in the hanging-wall, have proved, however, the old view to be correct. The difference between the dike porphyry and the gray hanging-wall porphyry are the somewhat lower quartz content of the former, combined with a considerably higher percentage of augite and uralite, both as phenocrysts and in the groundmass. In the analyses, these differences appear in the lower silica content of the dike porphyries and the higher percentage of lime and magnesia. As another argument for a difference in age may be pointed out the fact that in northernmost Kiirunavaara, where the foot wall is formed by the dike porphyry sheet, the hanging wall consists of the common reddish phase; if the rocks below and above the ore at this point had once been contigous, it seems highly improbable that the ore body could have so neatly separated the two phases — particularly as it would be impossibe to separate in this way the gray and the reddish phases in the actual hanging-wall further south on the mountain, because of the absence of sharp and regular boundaries. Finally, those dikes that are younger than the ore bodies, and consequently cannot be directly connected with the hanging-wall porphyry, have the same general characters, geologically, chemically, and texturally, as the older ones, and appear in the midst of them. This fact would be surprising, if the latter should be the feeders of the hanging-wall rock, while the younger dikes apparently do not have this nature.

Thus, by weighing all the various pieces of evidence, we come to the conclusion that the porphyry dikes and the associated sheet have never been continuous with the hanging-wall porphyry, but their close similarity to this rock shows them to represent a somewhat younger »Nachschub» of a slightly different composition.

Faulting and granophyre dikes on Kiirunavaara.

The shape of the Kiirunavaara ore body strongly suggests the existence of several faults, cutting obliquely across it, as between Jägmästaren and Professorn, and between Gruvingeniören and Vaktmästaren. It also seemed possible that the Konsul ore bodies, which form an isolated group to the southeast of Jägmästaren, had been cut off from the main body and from each other by faults. At first, however, lack of exposures at the crucial points excluded the possibility of definite conclusions.

An examination of diamond drill cores from the Konsuln group, which is completely covered by glacial drift (moraine), was undertaken by Mr. N. Zenzén and the writer, with the result that syenite-porphyries belonging to the foot-wall body were found to underlie these ore bodies, which are thus shown to represent the displaced southernmost part of the Kiirunavaara ore body.[1] Stripping on the area between Jägmästaren and Professorn proved the existence of the supposed fault between these two summits of the ore ridge. On the geological map of the Kiruna district, on the scale 1 : 100 000, compiled by N. Zenzén and N. Sundius, and published in a monograph by the latter,[2] these faults are shown.

More recently, several faults crossing the middle of the ore body have been found. These faults find their surface expression in the deep notches that cut across this part of the ore ridge, dividing it into the hills Bergmästaren, Direktören-Pojken, Kapten, and Landshövdingen. They have been encountered in the railway adit which enters the mountain near its northern end, a little above the level of the lake Luossajärvi, and is being driven south along its axis, but they have also been partly exposed at the surface, where

[1] G. F. F. Vol. 34. p. 727.
[2] Geologie des südl. Teils des Kirunagebietes (Upsala 1915).

they have been identified and mapped by the mine surveyor, Mr. P. A. Anderson. The fault between Kapten and Landshövdingen is now well exposed, after the removing of the moraine covering. It is marked by a typical fault breccia, consisting of ore fragments, generally less than an inch across, in a whitish-gray matrix, made up of fragmental apatite grains, cemented by finely crystalline quartz, with frequent cubes of pyrite and druses lined with quartz crystals. The width of the breccia is 1.5 meters. On both sides, it is bounded by a slickensided surface with a steep dip to the southwest. At the foot wall contact, there is evidence of a certain amount of drag. The horizontal displacement caused by this fault amounts to about 20 meters. Where the fault cuts the hanging-wall porphyry, this rock is decomposed, clayey.

A little to the north of this fault there are two others, striking nearly parallel to it, but having a much smaller displacement and no breccia.

The fault between Jägmästaren and Professorn has a horizontal displacement of at least 120 meters. Its dip is steep to the SSW. Within the ore body of Jägmästaren, there are several slickensides, striking and dipping in the same general direction as this fault. They mark faults of a smaller magnitude, as is sometimes seen where they cross the boundaries of the ore body.

The strike of the faults across the ore ridge is NW—SE, with only small differences, but the fault that has cut off the Konsul group from the Jägmästaren ore, and also those occurring within the former, appear to run more nearly W—E, as far as one can judge from the rather scant knowledge of the actual shape of these ore bodies. There seems, however, to be no reason why they should be of different age.

The dip, when observed, is always found to be steep to the SW, or nearly vertical, an exception being the northernmost small fault on Kapten, which dips 50° NE. The direc-

tions of displacement are seen from the diagram (pl. 1). The amount of the vertical throw is unknown. In one case, on the fault on Kapten that was just mentioned for its exceptional dip, there is a broad grooving on the slickenside, dipping to the east at a low angle. This would suggest that the movement, in this one case at least, was mainly in a plane that is now nearly horizontal. On the other hand, the width of the ore on the different sides of the Kapten-Landshövdingen fault is somewhat different, which indicates a certain amount of vertical movement.

On Jägmästaren, the ore body is cut by a number of dikes. These belong to the group that has been described by the author as »dikes of quartz-porphyry», siliceous rocks with a silica percentage of about 76, phenocrysts of quartz and feldspar, and a groundmass that is granophyric, particularly in the larger dikes, or fine-grained microgranitic (»felsitic»). The term »granophyre» is perhaps the one best suited to give instantly an idea of the general character of this dike rock, and is therefore used here.

A big dike of granophyre cuts the syenitic rocks of the foot wall, but it is only on Jägmästaren that such dikes are found within the ore body. These dikes are only a couple of meters wide. On the whole, they run parallel to the faults, and their ore walls are often slickensided. This suggests a certain contemporanity of faulting and dike intrusion, which is also made probable by the conditions between Jägmästaren and Professorn, where a dike runs for some distance along the fault, and inserts an apophysis into the ore on the southwestern side. The rock is highly jointed, but shows no sign of crushing, consequently it cannot be older than the fault.

Notes on the Rektor and Nokutusvaara ores.

The *upper* surface of the »hanging-wall» porphyry has also been the locus of ore intrusions. The ore bodies on this

level are the so-called Rektor ore of eastern Luossavaara, and the main ore body in the Nokutusvaara ore field, about 2.5 kilometers from the former. In the summer of 1918, rather extensive exploratory work on these deposits was carried on by the Geological Survey of Sweden, resulting in several discoveries of a considerable theoretical interest besides those new data on the size and character of the ore bodies, the obtaining of which formed the main object of the investigation.

The Rektor ore consists of a mixture of magnetite, specular hematite and apatite. The apatite percentage is always very high. The foot wall is made up of the »hanging-wall porphyry» of the main ore bodies of the district, Kiirunavaara and Luossavaara. Within a width of several meters from the ore contact, this porphyry is strongly altered. Generally, it has the character of a sericite schist. The microscopic examination shows a very fine-grained mass of sericite and quartz, with the strongly sericitized feldspar phenocrysts still discernible. Rhombohedra of a ferruginous carbonate and grains of specular hematite are plentiful. The rock may possibly have been vesicular, as there are rounded quartz patches, with carbonate and rutile, that look like altered amygdules. The rutile occurs in the same way as in the »nodules» of the Kiruna syenite-porphyries, where it forms through the decomposition of titanite.

In one place, the alteration of the porphyry is somewhat different: the resultant rock consists of calcite, quartz, apatite, sericite and hematite, with remnants of feldspars. Little of the original texture is discernible in this case, but what there is indicates that the rock very probably belongs to the Rektor porphyry, which forms the hanging-wall of the Rektor ore body. Thus the intrusion did not exactly follow the contact plane between the two porphyries, but for a short distance took a higher level. It is only in the southern end of the Julia claim that the Rektor porphyry is thus probably present also in the foot wall of the ore body.

The foot-wall contact in the Apollonia claim was described at length already in the Kiruna monograph of 1910. It exhibits a phenomenon not found in other exposures: a net of highly apatitic ore veins in the porphyry.

The rock above the ore body is called the Rektor porphyry, it is a volcanic rock of somewhat varying character, and often strongly silicified or sericitized. The uppermost part of the ore, with a width of a meter or two, is nothing but such porphyry very heavily impregnated with specular hematite. This phase shows a fairly sharp boundary against the overlying porphyry.

The contact phenomena, as now described, apparently point to an intrusive origin of the ore body.

Some part of the Rektor ore body contain a considerable quantity of calcite. Microscopic examinations reveal irregular, more or less corroded apatite grains enclosed in the carbonate, which makes it probable that the calcite is an alteration product of the apatite, formed during the period of hydrothermal action, which must have followed immediately upon the ore intrusion.

The work on the Nokutusvaara ore field resulted in several important changes in the previous picture of the geological relations in this field. Here, only features of a theoretical interest will be reviewed. Below the largest ore body there appears a strongly altered rock, which may safely be referred to the »hanging-wall» porphyry. Thus, the gap between the occurrences of this rock south of the lake Nokutusjärvi and north of lake Syväjärvi is filled out. In the eastern part of the ore field, the ore largely occurs as narrow bands alternating with altered syenite-porphyry of the lower Hauki complex, or as narrow veins in this rock.

The larger ore bodies at Nokutusvaara are magnetite ores with much apatite. Some of them also contain rather much calcite and quartz, probably secondary as in the Rektor ore, as is shown from similar relations to the apatite. A little part of the quartz, however, may possibly be of primary origin.

A local phase of the main ore body of this field is *vesicular*, with well rounded calcite amygdules about 5 mm in size. The structure of the ore is thus analogous to that of an amygdaloid lava rock.

Summary and conclusions.

The intrusive nature of the ore bodies is the only important change in the old picture, as drawn by the writer, of the geological evolution of the Kiruna district. All other main points remain unchanged, nothing having been found that calls for a revision. This also holds true of the probable mode of eruption of the main porphyry units, which are still held to be extrusives. The somewhat debated latter problem has lost much of its general interest through the change in opinion regarding the ore bodies, but this is, of course, no reason why one should not still emphasize the direction in which the facts in the case point.

The main features in the pre-Cambrian geology of the Kiruna district, according to the evidence now at hand, may be summarized as follows.[1]

On a substratum, probably represented by certain gneissic granites north of Kiruna, there was poured out a series of lava flows of diabase. Between these flows were now and then deposited layers of volcanic ejectamenta of the same composition as the diabase and of varying coarseness. Part of the diabase magma did not reach the surface, but was injected into the volcanic pile, mainly as sills. The diabasic rocks, now albitized, have received the local name of the »Kiruna greenstones». Above the greenstones was conformably deposited the Kurravaara conglomerate, a clastic sedimentary deposit consisting mainly of fragments of volcanic rocks, among which predominate types originally mainly made up

[1] In this summary, use has been made of the results of all students of the geology of the Kiruna district, and particularly of data gathered by LUNDBOHM, SUNDIUS, ZENZÉN and LOOSTRÖM.

of an albitic plagioclase (now transformed into pure albite) and closely related to the next member in the sequence. This member is the syenite-porphyry (keratophyre of BÄCKSTRÖM and some other writers) which forms an extrusive body of enormous thickness, amounting on Kiirunavaara, where its unity is most conclusively proved, to nearly 1000 meters, and possibly more. The slow cooling determined by this great thickness has caused the bottom parts of the flow to crystallize as a syenite of fine to medium grain, while the upper parts show textures similar to those appearing in admittedly extrusive bodies of the same general composition, as the rhomben-porphyries of Christiania. The extrusion of the syenitic body was followed by that of a quartz-bearing porphyry (or keratophyre), which shows a pronounced consanguinity with the former. The quartz-porphyry reaches about the same thickness as the syenitic body, but may possibly consist of several flows. It is a fact worthy of mention that the extrusive nature of both the porphyry bodies is most clearly demonstrated in their north-eastern ends, where they taper out into thinner flows. The extrusion of the quartz-bearing porphyry was in turn followed by the deposition of considerable quantities of tuffaceous materials, at several times interrupted by the extrusion of comparatively thin flows of various porphyritic rocks, now highly altered. Earlier than the building up of this complex — now called the lower division of the Hauki complex — or contemporaneous with its beginning, was in all probability the intrusion of a »Nachschub» of a magma only slightly different from the quartz-bearing porphyry. This was a local phenomenon, being restricted to northern Kiirunavaara, and took the form of dikes which filled fissures in the syenitic body but stopped when reaching the lower surface of the quartz-bearing porphyry, where the magma was to some extent injected along this contact surface as a sheet. During this periode of dike intrusion, which was in all probability a short one, geologically speaking, there was injected along

the contact surface just mentioned a body of apatitic iron ore, the now famous Kiirunavaara ore body. The smaller ore body of Luossavaara was probably formed at the same time, but may have been an independent intrusion. The *upper* surface of the quartz-bearing porphyry was also the scene of injections of ore magma. The Rektor ore body, and at least the largest ore body of Nokutusvaara follow this plane. Apparently, these intrusions could not have taken place until there was some cover above the porphyry. This does not imply any long time, as tuffaceous rocks may be built up very quickly. Then followed a period of intensive hydrothermal alteration, under the development of quartz, hematite, sericite, calcite, apatite and more sparingly barite, orthite, tourmaline and fluorite. This alteration has been most strong in the tuffaceous rocks, which are transformed to quartzites, sericite schists, and specular hematite ore, but has also left traces in the uppermost parts of the quartz-porphyry, in the ore bodies at the upper contact of this rock, and sometimes also in the syenite-porphyries, where the quartz-porphyry cover has been thin (as on Hopukka).

The age of the faulting and the contemporaneous granophyre intrusions on Kiirunavaara cannot be determined with certainty.

After an erosion interval of unknown length, a transgression led to the deposition of the conglomerate with pebbles of hematite ore and porphyry, which is the bottom member of the upper Hauki complex. Above this conglomerate there followed in turn a more fine-grained clastic sediment (the graywacke) and a slate (now phyllite). The uppermost, and by far the thickest, member is a quartzitic sandstone, a typical shallow-water deposit with crossbedding and several conglomerate horizons. This sandstone is also found as scattered patches at several places in the ore-bearing region of northern Lappland, which points to a one-time extension comparable to, for instance, that of the late-pre-Cambrian (Jotnian) sandstone of Dalecarlia. The tectonical unconformity between

the ore-bearing volcanic complex and the normal sedimentary upper Hauki complex is not great, and the tilting of these complexes to their present rather steep dip apparently did not take place until after the deposition of the sandstone.

The sequence of the various porphyries and the Kiirunavaara ore body is schematically illustrated in the accompanying diagram (pl. 1).

It will be noted that the view of an intimate genetic relation between the ores and the porphyries, and particularly the hanging-wall porphyry, is by no means weakened by the change in opinion regarding the relations of age. The ore body is now known to have been intruded during the period of intrusion of dikes that must be regarded as »Nachschübe» to the hanging-wall porphyry, it thus holds itself a similar relation to this porphyry. It may be noted, that the same relations of age are exemplified by the neighboring Tuolluvaara deposit and the surrounding porphyry, which is very similar to the hanging-wall rock of Kiirunavaara.

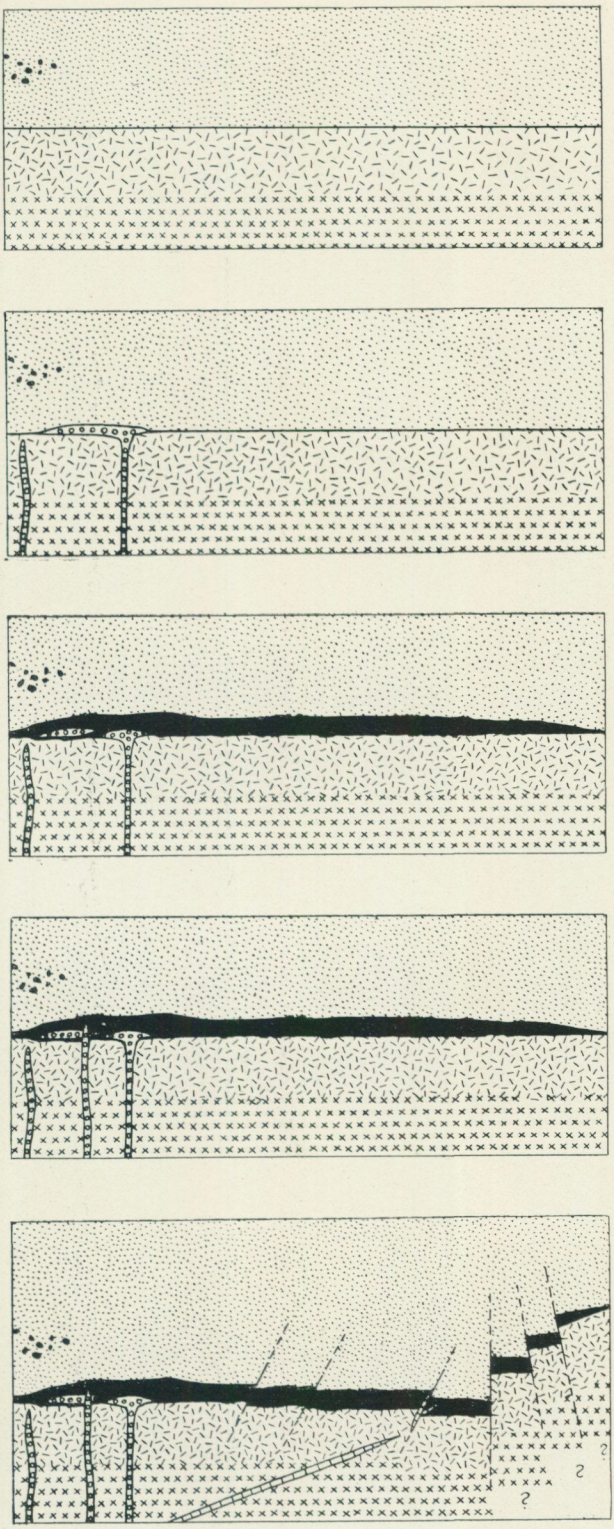
The ore inclusions in the porphyry must be derived from an ore body analogous to that of Kiirunavaara, but somewhat older. Only guesses can be made about its position at the time of intrusion. The distribution of the inclusions[1] does not uphold DALY's view of their nature of sinking segregations in the porphyry. The fact that many textural variations are represented points to the inclusions' once having formed parts of a larger body. DALY's hypothesis postulates liquation, and implies that the ore segregations have solidified before the surrounding porphyry, as they are sometimes broken into sharply angular pieces. This is inconsistent with the fact, exemplified by Tuolluvaara and Kiirunavaara, that the ores have solidified later than the associated porphyries. This phenomenon is, in fact, characteristic of all phases of ore differentiation in Lappland, and is to be considered along with the fact that the ore products of the process in question

[1] Compare fig. 52 in »Igneous rocks and iron ores», etc.

combine characteristics of magmatic and »pneumatolytic» bodies.

The strong hydrothermal alteration of the lower Hauki complex is held by DALY to speak for an intrusive origin of the underlying (»hanging-wall») porphyry, although it is admitted that the evidence is not conclusive [1] The greater permeability of the tuffaceous rocks, as compared to the more compact porphyry, seems to the writer to offer a satisfactory explanation of the fact that the former are so extensively altered, while the latter exhibits signs of a similar metamorphism only in its uppermost parts. Thus the hydrothermal solutions may have risen along fractures in the porphyry, and been absorbed, through metasomatic interaction, by the overlying more porous rocks, just as well if the porphyry was extrusive. Entirely similar conditions appear to have existed at Pilot Knob, in the analogous iron ore region of Missouri.

[1] DALY also mentions as a possibility that some of the porphyry sheets in the lower Hauki complex should be intrusives, and belong to the hanging-wall porphyry. They are, however, very distinctly different from this rock.



Diagrammatic section through Kiirunavaara, illustrating stages in its early geological history. North is to the left.

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