SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. **N:o 428.**

ÅRSBOK 33 (1939) N:o 8.

LÖNNFALLET

SOUTHERNMOST PART OF THE EXPORT FIELD AT GRÄNGESBERG

BY

RAGNAR LOOSTRÖM

WITH 3 PLATES

Pris 2 kr.

STOCKHOLM 1939
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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Fig. 1. The stripped glaciated surface of ore and rocks. Lönnfallet, Grängesberg (looking SSE).

Fig. 2. The stripped glaciated surface of ore and rocks. Lönnfallet, Grängesberg (looking SSW).

Contents.

Introduction.

In the summers of 1928—1930, the author was charged by »Grängesbergs Gemensamma Förvaltning» (The Grängesberg Common Administration) to arrange a museum at Grängesberg, for the purpose of illustrating the mineralogy and geology of the Grängesberg ore fields. The first thing then to be done was to obtain such a clear idea of the genesis of the ores and rocks, and of the relations between them, that the museum could offer a systematic and surveyable illustration thereof. Certainly the Grängesberg fields had long been the object of geological interest, but no satisfactory starting point for the author's work was at hand. Dr. H. Johansson's detailed examination and description of the Grängesberg District[1] had led him to the conclusion that the various rocks, as well as the ores, were formed by »*differentiation in situ*». When collecting and arranging the material for a permanent museum, however, the author could apply neither Mr. Johansson's theory, nor any earlier theories, as studies of the district showed that all current theories were too general. First and foremost, little attention had been paid to the fact that the different kinds of ore: *Apatite ore*, the so-called »*segmalmer*» (ores with a low apatite percentage), and *quartz-banded ore*, did not all have the same genesis.

Through Geijer's exhaustive descriptions of the Lapland fields[2] and on the basis of experience from earlier field studies in the Kiruna and Gällivare ore fields (Malmberget), including work for geological museums in both these places, the author instead soon found resemblances with the said two ore fields in Lapland. These late observations have been demonstrated by the author in

[1] H. Johansson, Die eisenerzführende Formation in der Gegend von Grängesberg. G. F. F. Bd 32 (1910).

[2] P. Geijer, Igneous rocks and iron ores of Kiirunavaara, Luossavaara and Tuolluvaara. Stockholm (1910).
» Recent developments at Kiruna. S. G. U. Ser. C, Nr 288 (1918).
» Tuolluvaara malmfälts geologi. S. G. U. Ser. C Nr 296.
» Gällivare malmfält. S. G. U. Ser. Ca. Nr 22.

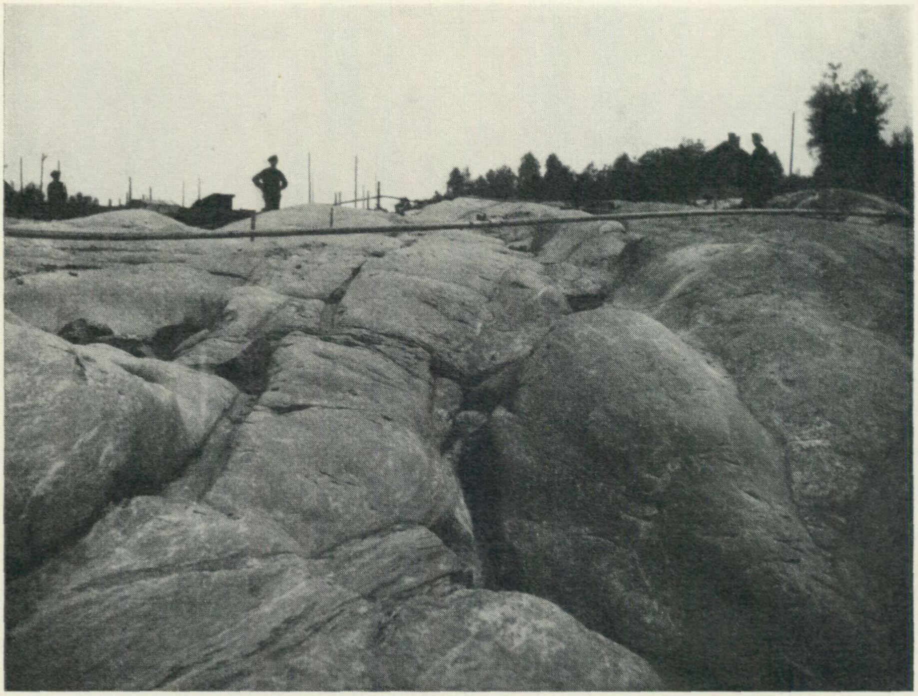

Fig. 3. The stripped glaciated surface of ore and rocks. Lönnfallet, Grängesberg (looking SSE).

series of specimens in the Geological Museum of Grängesberg, arranged there in 1930.

The most important observations, mentioned elsewhere by the author[1], are »ore breccias» and ore dikes — in some places together with contact metamorphosis (Fig. No. 4) — and leptites with a different metamorphic development, which show that they were originally surface beds.

These new data may be considered to prove fairly definitely that the original nature of the Grängesberg District is in much better genetic agreement with that of the Lapland fields than was formerly assumed.

Just at that time the author obtained, thanks to a lucky circumstance, an excellent opportunity of collecting some extremely typical observation material. The southernmost point of the Export District was, before mining was to be started, so well stripped that it could be mapped in detail by the author. The mining operations, etc., begun there later on, have changed the mapped district to such a degree that this illuminating example of the relations between ore and different kinds of rock is no longer accessible.

When this paper was ready in manuscript, there was published by the Geological Survey of Sweden Dr. N. H. Magnusson's preliminary report on his exten-

[1] G. F. F. Bd 51 (1929) p. 303 and 624.

Fig. 4. »Ore breccia», Karlgruvan, Grängesberg. Iron ore black, Na-leptite gray with lighter alteration zones along the ore dikes. Dark area in the upper right part of the specimen is an amphibolite dike.

sive studies of the Grängesberg Field as a whole. Since the writer's paper concerns a special detail, describing important exposures that were destroyed through mining operations before Magnusson's field work in the district started, it has been deemed most appropriate to publish it in its original form, without references to Magnusson's results. It may be sufficient to state that, on the whole, the observations here reported do not conflict with Magnusson's results. It is hoped that these observations will prove of value for the more complete monograph on the whole mining field.

Lönnfallet.

Before starting mining operations at the southernmost point of the Export Field, called Lönnfallet, the Grängesberg Co. stripped the area of all drift. This drift consisted mainly of moraine of varying coarseness, but there was also a very thin layer of clay under gravel and sand, which was sticky and completely covered the rock surface. To remove this layer, the author had to wash it off with water and in some places even to resort to regular scrubbing. Thus the field was completely bared. Ore and rocks came into sight in a beautiful glacier-polished configuration — a wavy surface with long, low ridges and clearly visible ice-striae. They showed that the inland ice had once passed southwards across the district (Fig. 1).

But not only was this attractive geological picture of the Quaternary period gained by these careful disclosures. The variations of the ore and of the associated rocks came out distinctly in the smoothly polished, extensive ore surface. Thus it was possible to study here the occurrence of the ore together with the rocks and the relation of the rocks to one another (Figs. 2 and 3). Since these disclosures would soon disappear with the beginning of the mining operations, the author mapped them in great detail with fixed points at every 5th meter.

The whole bared field was mapped on a scale of 1 : 250 (Plate 1) and in detailed maps on a scale of 1 : 20 (Plate 2).

In addition to the *apatite iron ore,* the rock ground contains

Grey Na-leptite,
Porph. Na-leptite,
Leptite-breccia with ore-skarn,
Oldest amphibolite,
Porph. amphibolite,
Youngest amphibolite with aplite,
Pegmatite.

The direction of strike at Lönnfallet is NE—SW, the dip is 70—75° SE, and the pitch 70—80° SW.

The common strike of rocks and ore is more marked on account of the fairly uniform schistosity direction. Owing to this deformation the district is so to speak rolled out or extended, so that the shapes of dikes, breccias, enclosed fragments, etc., have become still longer in the direction of the strike than they originally were. Some dikes, however, are exceptions in this respect, viz. those which cross the general strike of the district. In these dikes the planes of schistosity are not situated in the direction of the dike but cross it, and the shape of the dikes is deformed by the dynamic metamorphosis. They are pressed together, so that they have become short and wide. For this reason, the contacts with the adjacent rocks are not straight, as in those dikes that strike in the direction of schistosity, but stick out in all kinds of irregular protrusions (Fig. 5).

The regional metamorphism is strong at Lönnfallet as in the other parts of the Grängesberg District. In this case, too, its influence is rather irregular, as is shown by the fact that in some places portions of the rocks may be found, which have preserved relic structures, while in other cases the original rock character has disappeared, leaving indifferent schistose rocks.

In some places the rocks are also split by this dynamic metamorphosis. Several dikes were not only fairly irregularly thinned out by schistosity here and there, but in many cases they were found to be squeezed to fragments. The appearance of the squeezed-off fragments showed that this splitting actually took place during the development of the schistosity. In fact, in the central portions of these fragments the rock was better preserved and had more or less the same appearance as in the dike itself, which was not the case at the breaks. Towards these breaks the rock was successively deformed and became more pronouncedly schistose, so that the fragments were rolled out and drawn into tapering ends. Where they were located in the direction of the strike of

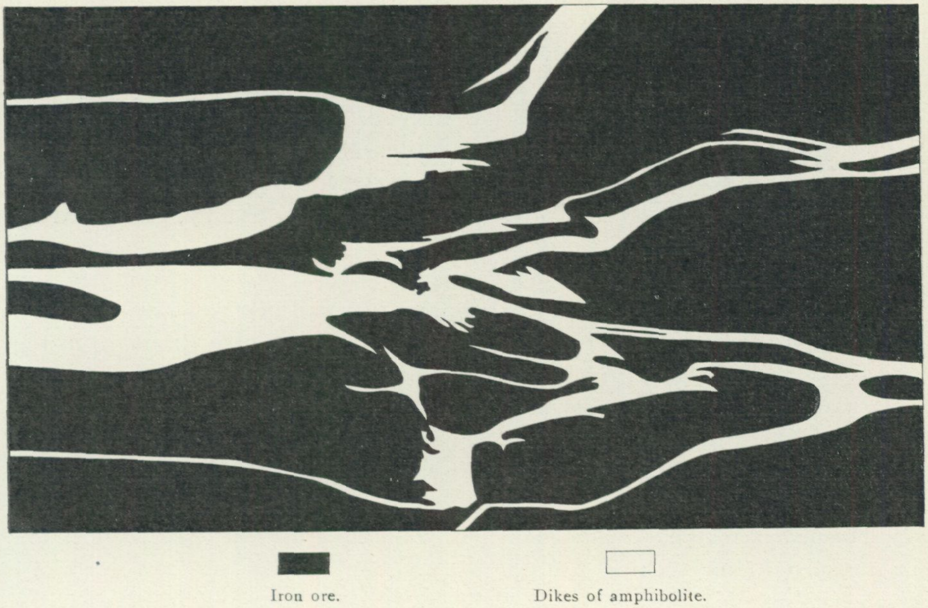

Fig. 5. Regional-metamorphosed dikes of amphibolite in the ore. 1/25 nat. size. Lönnfallet, Grängesberg.

the dike from which they were squeezed off, it was easy to ascertain their origin, i. e. the fact that they were parts of the dike. But in many places such fragments of dikes were moved aside into the schistose surroundings, while it was impossible to distinguish any trace of this movement, and in such cases it was more difficult to trace their origin. It was by no means unusual to find that some fragments of the dike rocks had been moved so far into the ore that had not the course of the process been known from other parts of the district, together with the fact that they were younger than the ore, they might have been considered as fragments of some older rock brecciated during the formation of the ore and enclosed in it.

This destructive effect of the metamorphism was observed not only in the bared horizontal surface, but was also brought out by mining operations in the vertical plane. The dynamic forces have obviously acted not only as a compressive stress in the horizontal plane, so that rocks and ore have become schistose, but the rock ground has also been extended in the vertical direction. This has led to the result that the rocks were broken to pieces also by movements in the vertical plane. These fragments are so strongly deformed by schistosity also at the breaks, that they are drawn out into sharp ends. Thus they showed the same appearance in the blasted vertical walls as the fragments squeezed off by schistosity, which were to be seen in the glacier-polished horizontal exposures.

This effect of the metamorphism has been observed not only at Lönnfallet. The author has also found rocks in other parts of the Grängesberg District,

†1—392830. *S. G. U. Ser. C. N:o 428. Looström.*

which have been split by the dynamic metamorphism in an entirely analogous manner. Such a case was observed west of the Orrlek Pond, where the bright-coloured gneiss-granite encloses numerous black amphibolite fragments of such a shape and displacement in relation to one another that they are readily taken to be older inclusions in gneiss-granite. Nevertheless, a more detailed study of the exposures made in this district showed that these amphibolites were also in this case parts of intrusive dikes in gneiss-granite, dislocated by dynamic metamorphism.

Besides, this dislocating effect does not at all appear to be unusual in Archean rocks in Sweden. The most beautiful example of this effect has been observed by the author in the shore exposures on the island of Skarp-Runmarö in the Stockholm Archipelago, and is reproduced in a paper by Holmquist dealing with that district.[1] The parallel amphibolite dikes which strike forwards through the rock-ground there and may be followed several hundred meters, have been broken within an area of gneissic granite by dynamic metamorphism in a certain part of that. The fragments have been displaced and in many cases also turned from their original position, while no traces of them were found in the surrounding rock.

Leptites.

The main mass of the rock-ground at Lönnfallet consists of leptites. Other rocks and ores are scattered and enclosed in them. At the time when this work was carried out, in the year 1930, leptite rocks were much discussed, and divergent opinions have been advanced in regard to these rocks in the field under consideration, thus H. Johansson has conceived a definite view on them in the Grängesberg District. The author, however, has gathered certain experience with regard to these rocks from his work in the Lapland mining district; he has seen how the effects of the metamorphism could be followed in these rocks, how the transformation proceeded from porphyries of a fluidal character and micro-poikilitic structure or pyroclastic formations to rocks of the same types as these leptites in the Grängesberg District[2].

The leptites at Lönnfallet are rocks metamorphosed and schistose to such a considerable extent that it would be difficult to interpret them, if the rocks of this place were not a continuation of the large leptite formation extending over the other parts of the Grängesberg District. In fact, portions of leptites are found in other parts of the district, in which the effect of the metamorphism is less pronounced, so that the original structures of the rocks may be distinguished. Moreover, the rock-ground in that place is sometimes so exposed that the transitions from these relics may be followed to such intensely metamorphosed variations as those at Lönnfallet.

The fact that the leptites of the Grängesberg District also are supercrustal

[1] G. F. F., Bd 54, p. 363.
[2] G. F. F., Bd 51, p. 303 (1929).

rocks of volcanic origin, formed by alternating beds of lavas and tuffs, may be seen e. g. from the exposed rock surface on a height at Sporrtorp near the water-tower. In the low flat surfaces which come into view there, a long stretch of the rock consists of porphyritic leptite with distinct scattered phenocrysts. This rock occurs in such a way and shows such a homogeneity in its structure that it may be inferred beyond doubt that it was originally a lava bed. But west of this porphyry, and near the grass slope, the same exposure presents a bed of pyroclastic sediment rich in rounded fragments. Here the boundary between the different rocks becomes visible, and the contact is sharp. In these exposures the pyroclastic rock is exposed to a very small extent, but the numerous excavations and blastings made about 1930 in the long adjacent slope, for building purposes, showed that this pyroclastic rock constitutes a bed of very great magnitude and that it consists practically speaking throughout of a coarse agglomerate with a mixture of different kinds of fragments. However, the boundary between the two rocks is not always so distinct as in this case. If one follows the contact between them northwards in the large exposure, the rock ground is more intensely metamorphosed, and the boundary is more difficult to distinguish. It is true that in this case the boundary is crossed by amphibolites, which contribute to concealing it, but obviously the amphibolites cannot be considered as a reason of the entirely different appearance of the rocks in this place. In fact, the porphyritic leptite loses the phenocrysts, and its grains become uniform in size, while the fragments in the pyroclastic formations assume increasingly oblong shapes under the action of the more intense metamorphism, and ultimately become so distorted that they remain only as indistinct streaks in a fine-grained leptite of uniform grain size. In the case of this most intense metamorphism the grain size of the two leptite rocks is the same, so that the boundary between them is so to speak wiped out. The variations displayed by the rocks in this case have been of great use for the interpretation of the leptite rocks in the scattered exposures of the Grängesberg District and they have proved extremely helpful in the study of the leptites at Lönnfallet.

The leptites at Lönnfallet are Na-leptites. They are all of a grey colour varying fairly irregularly in light and dark shades. In the exposed glacier-polished surface they showed the same grey colours, with the exception of the porphyritic form. In this type the colour of the rock is changed at the surface, and the grey colour takes a red hue, while the phenocrysts are coloured red and white so intensely that they stand out more distinctly in the surface than in freshly broken rock.

The schistosity is strong in the case of all leptites having a nearly vertical linear structure, which is particularly marked in all these rocks by the constituent mica. It is biotite in thin scales whose long sides are located in the direction of schistosity. In some places these mica scales accumulate into thin patches strongly elongated in the direction of the linear structure, so that the parallel structure of the rock is set off to an even greater degree.

The grain size of the leptites at Lönnfallet is fairly even both in the hanging wall and in the foot-wall. On the other hand, the leptites that occur in the interior of the ore in the shape of long bands, are predominantly porphyritic. It is doubtful, however, whether these leptites, which are so different now, were equally different before the metamorphism. In fact, larger grains are found here and there in leptites with grains of uniform size, which certainly are relics of phenocrysts, and in small areas of porphyritic leptite we find that the phenocrysts have been granulated and have disappeared, so that the rock has the character of leptite with grains of uniform size.

The porphyritic Na-leptite which runs obliquely through the ore and which showed such a distinct porphyritic structure in the glacier-polished exposure, rarely shows indubitable phenocrysts under close microscopic examination. They are partly and in many cases completely granulated. Yet they appear as relics in the rocks also in those cases where the phenocrysts are completely transformed into aggregates, because if these phenocryst relics are not of deviating colour, their grain size is in any case somewhat larger than that of the surrounding groundmass, and this holds true usually also where the schistosity has distorted them into lens-shaped streaks. The metamorphism has to reach a certain stage before the phenocryst relics disappear and the rock becomes homogeneous as regards both colour and grain structure. Feldspar phenocrysts examined under the microscope prove to be clouded by sericite. They consist of acid plagioclase ($Ab_{86}An_{14}$) in uniform individuals or antiperthitically intergrown with microcline. The feldspar formed in conjunction with the granulation of phenocrysts also consists of plagioclase ($Ab_{86}An_{14}$) or antiperthite of plagioclase and microcline, but these new formations are found in clear grains without inclusions. Apart from feldspar phenocrysts which come out in a very marked way in the leptite, the phenocrysts are of quartz. They are visible in the rock as small light specks and consist of small fairly rounded quartz grains which are more or less undulated and granulated. Some of these quartz grains have possibly been small amygdales in the original lava rock, but their appearance in the rock, recrystallized in this manner, does not furnish any closer information as to that origin. The groundmass consists of an aggregate having allotriomorphous, fairly clear grains of more or less uniform size. It is built up of oligoclase-albitic plagioclase ($Ab_{86}An_{14}$), potassium feldspar, many grains of which have a pronounced microclinic structure, quartz, and biotite, which is irregularly scattered in thin scales among the other minerals, but is always located in such a way that the length of the grains follows the linear structure of the rock. The biotite (somewhat chloritized) in many places encloses accessory grains of zircon which are always surrounded by a strong pleochroitic halo.

The chemical analysis in respect of alkalies and lime, carried out by Dr. Naima Sahlbom, showed that this porphyritic leptite contained Na_2O—4.97, K_2O—1.40, and CaO—1.01 per cent.

The grey soda leptite which forms the foot-wall, does not vary in colour like the porphyritic leptite. Here and there, however, its grey shade becomes slightly lighter towards the outer surface exposed. Its grains are fine and of very uniform size. A closer examination of the glacier-polished rocks, however, here and there discloses small white specks in the grey aggregate of fine crystalline structure. These specks consist of quartz or feldspar grains accumulated in bodies more or less extended in the direction of the linear structure. The grain size in these specks is usually somewhat larger than in the surrounding leptite mass. These small specks, especially where they are densely scattered, as they are in some places, are so strikingly analogous to the above-described phenocryst relics in porphyritic leptites, that they must also in this case obviously be considered as phenocryst relics. Thus, there are some reasons to suppose that a large portion of these grey leptites in the foot-wall which have a uniform grain size were originally porphyritic lava rocks which have obtained their present appearance through metamorphism.

Microscopic examination shows that this grey leptite is built up of an aggregate of quartz, plagioclase ($Ab_{86}An_{14}$), microcline, and biotite, having a pavement structure. In addition, it contains isolated grains of magnetite, apatite, and zircon.

Magnetite and apatite are usually found in very small grains which are not only wedged in between other grains, but also are enclosed in quartz and biotite grains, as is usual in such metamorphic rocks. Zircon in microscopic grains occurs in biotite and is always surrounded by a strong pleochroitic halo.

Biotite occurs very irregularly also in this leptite, and, as is usual in these rocks, in the shape of isolated scales, or else accumulated in more or less plane aggregates extended in the steep direction of the schistosity. The biotite content of the rock increases with the schistosity. In those places where the leptite is less distorted and where its relic structure is distinguishable, the biotite content is rather low and fairly little pronounced, but the amount of biotite increases with the degree in which the rock has become schistose. When, finally the distorting forces have acted to the highest degree, the biotite content increases to such an extent that the rock is transformed into mica schists. This transformation was observed and followed with particular distinctness in the glacier-polished slopes in the SW-part of Lönnfallet.

As may be seen from the map (Plate 1), the grey leptite is split into fragments by the ore in that place. The leptite is either cleft, so that it protrudes here and there into the ore in the shape of more or less long points, or it is broken into fragments enclosed in the ore. In addition to the useful information as to the age relation between ore and leptite, provided by this place, the rock surface furnished a survey of the different leptite variations. It was thus possible to follow the schistosity of the rock step by step, and to examine the transformations resulting therefrom. It was noticed that in the wider parts of the ramifications and protrusions of leptite into the ore, the rock had the same general appearance as in the foot-wall. It is grey and has grains of uniform size, relic structures are sparse, and the biotite content is so low that it is not particularly marked. It has a similar appearance in the wider parts of leptite fragments situated in the ore. At extreme points, on the other hand, i. e. in protrusions which thrust forth long tongues, the rock is subject to changes.

These parts have apparently been more exposed to the action of dynamic metamorphism, because they are, as it were, rolled out by schistosity, and the outermost points are drawn out in the direction of schistosity into long tongues shooting like spears into the ore. The biotite content of the leptite increases with this deformation of the rock. The number of mica scales located parallel to the direction of schistosity increases, they combine into streaks, and finally their amount increases to such an extent that at the extreme points the rock is transformed into more or less coarse-scaled biotite schist. The amount of feldspar in the leptite decreases with this deformation, and hornblende, etc., is formed.

In some places in the ore, in front of such schist points in leptite, biotite schist is found, extended in the direction of schistosity. These are apparently the outermost parts of schistose leptite points which have not only been metamorphosed into mica schist, but have also been isolated and removed into the ore by the dynamic metamorphism.

This transformation of leptite into mica schist is obviously an ordinary phenomenon in this district. In fact, mica schist is often found in the shape of inclusions, and frequently at a considerable depth in the ore. By analogy with the observations made, we have every reason to believe that these, too, are fragments of leptite which has been split out and mixed with the ore during its penetration forwards, and which has been transformed into mica schist by metamorphism.

From the various leptites at Lönnfallet ramifications of leptite shoot out into the ore, from the hanging wall and from the foot-wall as well as from the wide leptite belt in the middle of the district. As may be seen from the map, these ramifications may sometimes peter out fairly soon, while they sometimes reach a considerable extension, and many of them have a shape which is deceptively similar to the dikes in the ore. The longest of these leptite ramifications form long, narrow links connecting the leptite inside the ore with the outside leptites. All these leptite ramifications, whether long or short, extend in a direction which deviates but little from the general strike of the field.

By blasting these ramifications of leptite in the ore it was found that they all, even the thinnest band-shaped ramifications, have a considerable, persistent extension downwards and that they have the shape of steeply dipping slabs. They consist of more or less thin, split-off parts of leptite, which have been pushed aside by the ore from the leptite mass, without being broken. Only in a few cases have I found that these peculiar leptite formations constitute real thin layers in the leptite series, which have been dislocated by the ore from their original position in the leptite series. In most cases they evidently are parts of leptite beds, split off in quite an arbitrary manner. The marked extensive system of fissures, along which the ore has moved forwards, has obviously not followed the borders of the rocks, but the formation of cracks in the rock-ground has also more or less penetrated into the rocks. Therefore, the ore appears in the shape of dikes in leptite, unless it has split the rocks into ore-breccias. In some cases these ore-dikes were only long, thin fissure fillings, but they usually reached a considerable width and in such cases caused notable dislocations in the split-up leptite formation. The multiform ramifications of leptite, created in this manner, have apparently not absorbed any material from the ore, even though they have been long and thin. The leptite is more or less strongly schistose in them, but its mineralogical composition does not change down to the contacts to the ore.

The leptite ramifications that may be taken to be whole beds displaced and moved into the ore, protrude in the middle of the field from the wide porphyritic leptite belt in two branches directed north and southwards respectively. They have in fact followed tuff-layers in leptite. Such pyroclastic formations as occur very frequently in some parts of the Grängesberg District, could not be easily detected in the metamorphosed rock-ground at Lönnfallet, but it may nevertheless be assumed that such formations exist there. This may be inferred from the fact that in the glacially polished slopes in the middle of the exposed part of the field, there appeared two thin parallel inclusions in the light-red porphyritic leptite, which distinguished themselves from the surrounding rock by their grey colour and fine grains of uniform size. Both were up to 2 decimeters in width and parallel to each other in the steep dip typical of the field. As two bands separated and surrounded by porphyritic leptite, they ran in the horizontal surface of the exposure, striking obliquely through the belt of porphyritic leptite in a north-south direction. In some places they thinned out considerably and partly disappeared in the surrounding rock, but these interruptions might have been due to the strong deformation of the field, if they had ever been present there. They were likewise faulted by amphibolite dikes, and in the place where the amphibolites came into view in such an amount that they formed networks in the older rocks, they were difficult to distinguish. But after all these interruptions they proceeded in the direction of the strike through the porphyritic leptite, and where they met the ore, they continued into it along the split-off leptite branches as border-zones.

It is hardly likely that these grey bands in the porphyritic leptite might be due to dynamic actions on this rock. It seems to me more probable that their character was originally different from that of the surrounding leptite and that they formed original pyroclastic inclusions in leptite. It is found, in fact, that they have absorbed a great deal of material from the ore, in contradistinction to porphyritic leptite. In addition to aggregates of quartz and feldspar with grains of uniform size, they contain magnetite, apatite, and hornblende, in large quantities.

When they occur as border-zones on the leptite ramifications, they have fairly distinct contacts towards the inner parts of the branches, which consist of porphyritic leptite. As they contain ore and skarn-minerals, these border-zones are slightly darker in colour than the porphyritic leptite, which has the composition typical of this rock also in these long ramifications.

In spite of the fact that the ore has so greatly split the leptite in the above-described parts of the exposure, no notable metamorphism of the leptite rock is observed. The contacts are as sharp as knife-edges, irrespective of the strike of the borders, and no mineralogical changes caused by the ore were found in the leptite. It borders directly upon the ore, apparently unchanged.

However, a breccia was found in a small area northwards in the foot-wall, where the conditions have obviously been different. It was not far away from the ore border in an isolated situation at a considerable distance from the large ore-breccias shown on the map (Plate 1). The ore in this small breccia was very rich in apatite and consisted in part of pure apatite. All these forms were accompanied by large amounts of hornblende-skarn which occurred with particular frequency in the border of the leptite fragments. As the degree of schistosity was very high in this place, the breccia was much distorted and pressed together. For this reason, it had the peculiar appearance that is found in some parts of the skarn-breccia in the hanging wall described below. It was obviously formed in a manner analogous to these breccias.

While the leptite in the foot-wall of the ore was mainly brecciated by iron ore which, on the whole, is skarn-free, this was not the case with the leptite forming the hanging wall. In this leptite the injected iron ore was accompanied by very large amounts of green skarn, and the skarn was mostly intergrown with leptite in such a dense network of branches that the rock in the glacier-polished exposure appeared as a skarn-breccia. The ore occurred only here and there in the skarn and was accumulated in lumps which in most cases were very small, as is shown in the special map (Plate 2). Some of these brecciating ore-bodies mixed with skarn were nevertheless so large that it was possible to indicate them on the survey map (Plate 1).

The rock-ground in the hanging wall of the ore had a very variegated appearance on account of this skarn brecciation, which was, moreover, crossed by amphibolite dikes in some places. Between these dark green dikes and veins, the leptite appeared in grey or light-red colours also in those cases where the breccia was so strongly distorted by schistosity that it looked as if it had been strongly rolled out.

The leptite was brecciated along a system of cracks which obviously has been influenced by the general north-south strike, and this brecciation was so complete that only small portions of the rock had remained unbrecciated. These untouched portions lay within a certain level in the hanging wall and were always of an oblong shape which followed the general strike of the other rocks in the district. This might easily convey the impression that these parts of leptite, which proved entirely immune from brecciation, were special beds in the rock series, but this was impossible to ascertain in the rock-ground which was strongly distorted by dynamic metamorphism. Yet this conception is contradicted by the observations made in other places in the Grängesberg District, where skarn-brecciated leptite was found and where the rock-ground is more or less untouched by later metamorphism. In the foot-wall of the Export Field, north of Lönnfallet, both in the region of the Ormberg Field and that of the Risberg Field including the Norra Hammar Mine, the rock-ground showed that skarn-brecciation proceeds in leptite in a very arbitrary way and apparently in such rocks as have originally been pyroclastic sediments, as well as in homogeneous lavas.

In the glacier-polished exposure at Lönnfallet, porphyritic structure came into view very distinctly in the parts of leptite in the hanging wall which were not brecciated. Light-red feldspar phenocrysts were conspicuously visible in the greyish white mass of fine crystalline structure. In some places where the leptite in the breccia was not too strongly distorted by metamorphism, it had the same appearance and the same porphyritic structure. Where schistosity increased in the breccia, these relic structures disappeared more and more and were not at all observed at the points where the distorting forces have reached their maximum intensity and where the leptite appeared in the shape of streaks and stripes in green skarn.

The best-preserved portions of this leptite in the hanging wall bore very great resemblance to the above-mentioned porphyritic leptite in the large belt in the middle of the ore. Phenocrysts consist of plagioclase ($Ab_{86}An_{14}$) and are in most cases partly or wholly granulated. They are enclosed in an aggregate of plagioclase ($Ab_{86}An_{14}$) and microcline, quartz, and scattered grains of biotite more or less changed into chlorite, and accessory grains of magnetite in small quantities. The structure is of the pavement type.

Amphibolites and pegmatites.

Amphibolites are green in colour and appear in numerous dikes at Lönnfallet.

All the amphibolites are feldspar-amphibolites. They are fine-grained, and the main mass consists of hornblende in prismatical grains between which occurs andesine-feldspar (35—40 per cent An) in clear grains of more or less zonary structure. Furthermore, there is titanite in very small quantities. All amphibolites are schistose with a pronounced linear element. In many places these rocks also contain biotite which may sometimes occur in considerable quantities, especially in the oldest amphibolite and there particularly in contacts. In such cases the schistosity of the rock is not only linear but also plane-parallel.

Amphibolite dikes cut through leptite as well as ore and their clear contacts show everywhere that they are younger than these. The longest and widest amphibolite dikes stretch through the field in the north-south direction and follow the length of the field. From these dikes smaller branches ramify in all directions, and in some places in the field the dikes crossing each other were so numerous that they formed networks.

The system of fissures in which these amphibolites appear, has obviously experienced the influence of the geological structure of the district, as the rocks and the ore have mainly been broken by the injection of these rocks in the direction of the length of the field. The fissures that cross that direction nearly always show a tendency to follow it. Later on, this direction was still more accentuated by the effects of regional metamorphism. Ramifying dikes have been pressed nearer to one another (Fig. 5). The fact that the metamorphism in the whole rock-ground has not produced stronger distortion shows that these dikes have most certainly had similar directions from the very outset.

In the glacier-polished surface of the field the amphibolite dikes stood forth very distinctly. Their blackish green colour contrasted strongly with the leptites, and they were always clearly visible in the ore. In depressions they frequently were more deeply eroded than their surroundings, while in the horizontal surfaces they did not interrupt the surface configuration, but appeared in the leptite and the ore as mosaic-like inlaid patterns. Thanks to these excellent exposures, 3 different systems of dikes crossing over one another were distinguished. Since they are so different from one another down to the clear, sharp contacts, 3 different age groups were distinguished.

The oldest group consists of strongly schistose amphibolite. The original structures are lost practically everywhere in this rock on account of the metamorphism, but in some isolated points light specks, some millimeters in size, were observed, which were interpreted as strongly granulated feldspar phenocrysts. This seems to indicate that the rock originally was some kind of porphyrite. This amphibolite occurs most frequently and may be found throughout the whole field. In broader and narrower dikes it strikes through leptite and ore, ramifies, and in some places forms networks of veins crossing each other.

Younger than this amphibolite system is a porphyritic amphibolite. It has as a rule a splendid appearance. Large white phenocrysts of andesine-feldspar (30—40 per cent An), some millimeters in size, are amply scattered in the blackish green amphibolite mass. These andesine phenocrysts distingusih themselves from the andesine of the surroundings located in the hornblende mass by being clouded with epidote, sericite, and some variety of calcite. In many cases they are largely granulated into newly-formed andesine. This amphibolite occurs in the middle of Lönnfallet, where it strikes in the longitudinal direction of the field as a distinct dike. In the horizontal exposures it could be seen how it crossed over the ore and leptite as well as even the oldest amphibolite veins. The contacts to these were also clear and sharp. The difference in formation between the various amphibolites was clearly visible down to the contacts. On one side of the sharp border-line there was the even blackish green amphibolite without phenocrysts, and on the other side there was amphibolite with excellently visible plagioclase phenocrysts. If, however, this porphyritic amphibolite dike is followed northwards in the district up to the boundary of the exposures of Lönnfallet, it is found that the metamorphism was so strong in these parts that it blurred the porphyritic structure also in this rock. There it would be almost impossible to distinguish the various amphibolites if they occurred together.

It could not only be seen at Lönnfallet that there is a difference in age between these two amphibolites. In the north of the Export Field there was, in the year 1929, a small exposure in the hanging wall of the ore where the same observation could be made. The rocks in this place were a leptite, brecciated by skarn which was intruded by amphibolite. The exposure was small but the horizontal surface clearly showed that the amphibolite contained two different

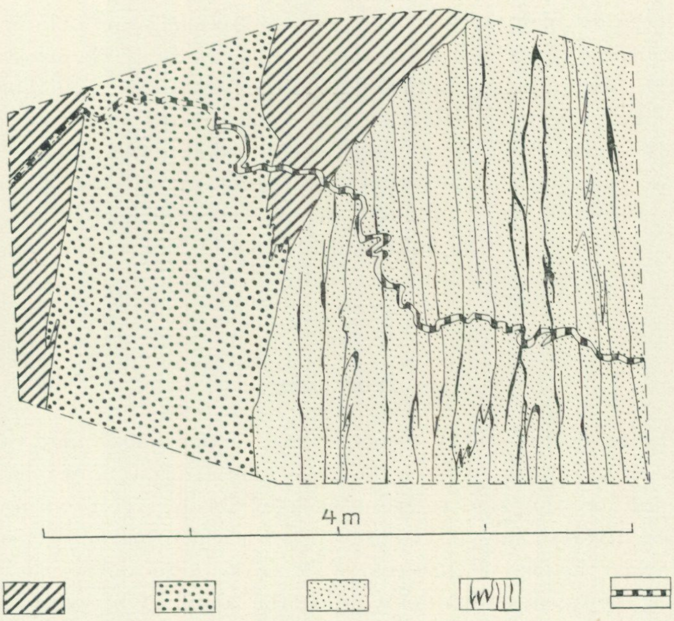

Fig. 6. Skarn-breccia with dikes of amphibolites and pegmatite from the hanging wall in the north of the Export Field, Grängesberg.

parts (Fig. 6). One was strongly metamorphosed, without any relic structure and formed an ordinary homogeneous green amphibolite. In this was enclosed, in the shape of a dike, another amphibolite which was porphyritic, with well preserved relic white feldspar phenocrysts. The contact was clear and sharp and the difference in formation between the various amphibolites was clearly visible down to the borders. There is thus also reason to believe that these two, so different as regards the stage of metamorphosis, are not of the same age. A dike of pegmatite was also to be seen in this little exposure. As is usual in Grängesberg fields, it crossed all the metamorphic rocks.

The youngest amphibolite occurs in the eastern parts of Lönnfallet. It differs from the other amphibolites in this district in that it contains oblong parts of aplite. Thus it bears a resemblance to the mixed dikes occurring in some other parts of the Grängesberg District. Aplite does not show any transitions to amphibolite, but is separated from the latter by a distinct border, while having a similar marked parallel structure. The amphibolite is fine-grained and contains no phenocrysts. This dike-formation cuts through both ore and leptite with a system of broader and narrower dikes. In the southernmost exposure it was moreover observed how an arm of amphibolite has broken its way through the two older amphibolites, showing clear, sharp contacts towards them.

Pegmatite occurs in long, narrow dikes which strike into the field from SE and cut over all other rocks and ores at Lönnfallet. They appear in a certain system of fissures which extends over the field crossing at an oblique angle the strike of leptites and ores as well as that of amphibolites. They show in particular that they do not belong to the aplite in the mixed dike, as it is faulted by a pegmatite dike. The pegmatite is red in colour owing to feldspar which is combined with quartz and some mica. In contradistinction to the other rocks and ores at Lönnfallet, it is entirely free from any effect of regional metamorphism. Therefore, they probably are apophyses from the granites that occur in a massif outside the Grängesberg District and which came up after the effects of regional metamorphism had ceased.

Iron ore.

The iron ore at Lönnfallet forms several oblong lenses and veins which are combined into an extended breccia-like system. In respect of their character these ores may be compared to eruptive dikes which have been injected into the leptite formation along a system of fissures which had in a fairly parallel manner followed the general direction of strike of the rocks. As has been mentioned above, the fissures do not only follow the boundary between leptite beds, but they have in most cases also broken right through the rocks.

When filling a given fissure, the ore has the shape of slabs having a very long extension downwards. If, on the other hand, it appears in a system of fissures, it ramifies into this system cementing together the fragments and forming ordinary ore breccia. In all probability the various parts of the ore had oblong shapes already at the time of their formation, but these shapes were further accentuated through the dynamic metamorphism. In fact, the ore is very strongly linear, and this structure extends steeply downwards.

In the glacier-polished surfaces of the exposures the ore is of a dull black colour and consists of magnetite. Hematite occurs only in exceptional cases in very small quantities and is secondary. The gangue is everywhere apatite, in some places there are also biotite and hornblende.

The magnetite has a finely crystalline structure. The grains are in all probability of a secondary nature, produced by regional metamorphism as in the neighbouring leptites and amphibolites. Although the ore is less hard than the leptites, it stands forth in the glacier-polished surface at the same height as these and forms long slopes of a pronounced *roche moutonnée* shape.

The apatite is of a white and reddish white colour and forms part of the ore everywhere. It is intimately mixed with the ore grains and, in the majority of cases, it cannot be seen with the naked eye. Apatite occurs also in an accumulated form, in small specks which contrast with the black ore by their light colour. They usually have the shape of streaks which dip steeply downwards in the direction of the linear structure. In most cases they certainly are fluidal veins, formed during the ore eruption, and have obtained their oblong shape solely through the linear structure, but their extension has in all probability been further stressed by the process of schistosity. No apatite crystals of any considerable size have been found in the ore but only in the green skarn described below. On the other hand, in the continuation of these ores at Lönnfallet, northwards in the Export Field, apatite has been found in one place in oblong granular accumulations in shape of grains, some centimeters in length, which were located radially to the inclusions in the ore (Fig. 7). These have exactly the same appearance and configuration as the apatite in some places in the ore at Painirova, Algarrobo, Cachiyuito, Iron Mountain Missouri etc., which has been illustrated and described at length before.[1]

Fig. 7. Granular accumulations in shape of oblong apatite grains (white), hematite (gray), magnetite (black). 2/3 nat. size. Export Field, Grängesberg.

The distribution of biotite in the ore is very irregular. Here and there it occurs accumulated and forms schist-like inclusions and streaks. Part of these accumulations in all probability have their origin in leptite fragments in the ore. As has been mentioned in the above, it was possible to follow this transformation of leptite into mica-schist in the field.

In a couple of places pyrite and fluorite have been found in small accumulated inclusions in the ore. However, they always occur near pegmatite-dikes and in such a manner that it may be concluded that they have been brought into the ore in conjunction with the injection of pegmatite.

Hornblende occurs in many places in the ore at Lönnfallet and is of particular interest in this connection. As a rule, large portions of the ore are free from this mineral, or it only occurs sporadically. In several projecting parts as well as in small ore lenses, on the other hand, it occurs in large quantities. The

[1] W. Petersson, Jukkasjärvi malmtrakt. S. G. U. Ser. C. Nr 183.
O. Stutzer, Geologie u. Genesis der lappländischen Erzlagerstätten. N. Jahrbuch f. Min. Bd 24. Taf. XLIV.
P. Geijer, The iron ores of the Kiruna type. S. G. U. Ser. C. Nr 367, p. 23, Fig 5.
C. Linnemann, Los yacimientos de fierro en el Sur de Atacama. Bol. Soc. Nac. Min (Chile) 1920, p. 10, Fig. 3.

hornblende varies in structure, it occurs either in isolated prismatic grains among apatite and magnetite grains, or in lump-shaped masses and streaks, in many places accumulated into vein-like formations extending far down in the same directions as the apatite streaks.

In ore breccias, hornblende is sometimes found in large quantities and sometimes it is lacking. Its occurrence is typical of minerals known under the name of skarn minerals in ores. Some information as to the origin of the hornblende in this district was obtained from the extensive exposures at Lönnfallet, so that it will be dealt with at some length, especially in the following chapter.

The borders of the ore are, as a rule, clear and sharp. No transitions of any kind to leptites or amphibolites were discovered.

The survey map of Lönnfallet (Plate 1) shows the spread of the ore in the leptites. It occurs in a great number of fissures in these rocks. It has penetrated them as an eruptive magma and has filled them. Some fissures have been long and have opened themselves so much that the ore was allowed to flow forth over a great width, others have been shorter and only permitted the ore to form narrow injected dikes. Furthermore, the leptite was broken up, so that the ore has formed breccias, and such a breccia was particularly well developed in the leptite of the foot-wall, large rock fragments being present in the ore. In spite of the fact that these fragments were slightly distorted by dynamic metamorphism, as has been mentioned in the above, still it is doubtless that they originally formed part of the leptite of the foot-wall. The leptite of the hanging wall is split by the ore accompanied by skarn and has formed breccias of a peculiar, oblong shape. Yet this may be explained by the formation of the whole ore deposit. In other words, the leptite formation has, as it were, been distended during the movement of the ore towards the surface of the earth and broken, thus forming a certain system of fissures and leaving room for the ore and the accompanying skarn.

The ore at Lönnfallet, which forms the southernmost end of the extensive apatite iron ore deposit of Grängesberg, the whole of which is known under the name of the Export Field, appears as an intrusive body with dikes and breccias, as has been mentioned above. This confirms the result at which I arrived in 1928 after my field investigations in the Grängesberg District, namely that *the apatite ore is eruptive.* All field observations contradict the assumption that the ore has some kind of immediate consanguinity with the leptites. The leptites, whether they had been lava streams or pyroclastic sediments, show all symptoms of having been solid rocks at the time of the formation of the ore. In all cases where the ore occurs in the leptites, they are split, and the ore fills the interstices formed in this manner, while having clear, sharp contacts to leptite.

It appears that the genesis of the ore at Lönnfallet is the same as that of the apatite ores in the Lapland Districts, dealt with at great length by Geijer. The Grängesberg ore not only has an analogous origin, but, as is seen from this description, there is not a single detail in this ore, which is not also found in the Lapland Districts. In many cases the peculiarities which seem to be difficult to explain at Lönnfallet, could be interpreted owing to the fact that analogous phenomena were known from Lapland and have been described. As an example we may mention the occurrence of leptite in very thin continuous slabs between the wide, table-shaped ores. This is similar to the form of inclusion of the rocks in the Gällivare Field. The occurrence of skarn together with the ore is likewise more distinct at Tuolluvaara and Kiirunavaara where it has not been subjected to so strong a distortion as at Lönnfallet.

Skarn and skarn-breccias.

Like all apatite ores, the iron ore at Lönnfallet is in most cases free from skarn. Only in some cases does green skarn occur as an admixture to the ore, where it mostly consists of hornblende. In the glacier-polished surface of the exposure, where everything was so completely exposed, it was observed throughout the field how the skarn was distributed and what relation its occurrence bore to the ore and the rocks. These observations showed first and foremost that skarn does not generally occur in the ore, but that it is found in some places in an extremely irregular manner. Large ore breccias are quite free from skarn, whereas some other likewise extensive breccias are very rich in green skarn. Vast ore bodies are not mixed with skarn, while others with quite a similar mode of occurrence contain large quantities of it.

Skarn was seen in the ore bodies proper in some places where it has accumulated in blackish green lumps entirely surrounded by the ore. Such a skarn inclusion was found in the middle of the ore in a part of the foot-wall, not far from the large ore breccia. This skarn mass consisted mainly of hornblende, it had an oblong shape and formed a continuous skarn accumulation, although it had ramifying tongues which followed the general direction of the strike of the field. Equally inexplicable was the occurrence in the ore of a similar lump-shaped skarn-mass in the northernmost parts of Lönnfallet where it merges into the ores of the Export Field northwards. In this case, too, the skarn consisted of fine-grained hornblende, and although ramifying in the field's direction of strike, it formed a mass confined within the ore.

Towards the breccias of the hanging wall rich in skarn, the large ore body of the field is for the most part free from skarn. Only within a limited district did skarn occur, and there in large quantities. This skarn did not follow the ore boundary, but extended approximately from the middle of the hanging wall straight out into the ore and appeared as an inclusion in it. In this case, again, the skarn consisted of hornblende in dense masses, but in this place it was in some parts mixed with considerable amounts of apatite. In the glacier-polished surface beautifully shaped idiomorphic crystals of white apatite were seen, which were scattered in the dense greenish-black skarn, and many of these crystals were about one centimeter in size. In this green skarn, accumulation lumps of fine-grained, fairly skarn-free iron ore were enclosed. In the surfaces of the exposure the ore came into view very distinctly in the shape of fine-grained accumulations with distinct borders towards the green skarn (Plate 3). Most of these ore lumps were small and lens-shaped. They extended in the field's direction of strike, but near the hanging wall there was a large ore inclusion in the skarn of a very irregular shape. It was not only surrounded by skarn, but also brecciated by it. The ore was split into pieces somewhat separated from one another, and the interstices were filled with green skarn. Skarn and ore have apparently alternated in this place during the eruption, and the last-formed skarn masses must have come forth after so long an interruption in the eruption that the ore had crystallised to such an extent that it could be brecciated.

An amphibolite-aplite dike strikes right through this intricate skarn and ore complex. Its contacts were distinctly visible in the exposure. They contrasted sharply against skarn and ore, thus showing that this dike was a later formation which appeared in the field after the formation of ore and skarn was completed. Consequently, it has not partaken in the formation of skarn.

Skarn does not only occur in this manner, that is in the shape of isolated patches in the middle of the ore. In many places skarn was also found in the contacts of the ore. This was however not the case in the long, straight borders to leptites along which skarn was very rare. On the other hand, it was found in many cases that the ore merged into green skarn in the pointed tongues shooting out into the leptite rocks and in some parts of the field these skarn aggregates were so extensive that it was possible to indicate them on the survey map (Plate 1). These skarn aggregates, too, consisted almost exclusively of dense hornblende masses. Here and there ore was found in the skarn. In these cases the ore was always accumulated in smaller and larger fine-grained, skarn-free black lumps.

As has been mentioned in the above, the leptite which forms the hanging wall of the big ore body is so intensely brecciated by skarn that it has been designated as skarn-breccia. Skarn penetrates the rock to such an extent, with dikes and streaks, that it is completely intergrown with it. This brecciated skarn network had in this case a peculiar oblong shape. The breaking-up of leptite has in fact followed the general direction of strike of the ore and of the rocks in the field. The rock was split into more or less thin fragments which were ranged in a row. This parallel arrangement was later accentuated by the schistosity of the field. For this reason, the breccia looked as if it were pressed together. In some places it was squeezed together so hard by the distortion due to metamorphism that the leptite fragments as well as the intermediate skarn were rolled to thin streaks which were worn off here and there, as shown in fig. 8.

The attached map (Plate 2) shows a typical example of this breccia and represents an exact copy of what was visible in the glacier-polished exposure. When we examine the small detail map, we find that iron ore occurs here and there in small accumulations, together with brecciated skarn. These accumulations are mostly located in the places where the skarn dikes slightly increase in width; where the brecciated dikes are largest, the ore occurs in such quantities that it forms the main part. These ores are everywhere lens-shaped and practically always show a distinct border towards the skarn, whether they be large or small. They consist of separate black lumps of a fairly homogeneous fine-grained mixture of magnetite, apatite, and insignificant quantities of hornblende. Green skarn occurs outside these ore accumulations and encloses them in most cases.

This extensive skarn-breccia in the hanging wall is injected with amphibolite dikes. These dikes, however, cross the skarn-breccia and follow fissures

Fig. 8. Strongly metamorphosed skarnbreccia. 1/4 nat. size. Lönnfallet, Grängesberg.

which were broken up in the field after the formation of the skarn-breccia was completed. Thus, the amphibolites show also in this case, as in the other parts of Lönnfallet, that they are rocks which have not at all caused skarn formations in the ore.

The observation that green skarn appears in the shape of accumulations when it occurs in the apatite ore, was made at all points at Lönnfallet, and was specially mentioned in connection with the skarn-inclusions in the large ore bodies referred to above. In one of these, namely in that which is situated not far from the hanging wall, the ore was found to be in such a separate position, too, in regard to skarn, that it was brecciated by the latter.

As has been mentioned in several places, skarn does not generally occur together with ore. The ores are for the most part free from skarn, and in the numerous contacts to leptites skarn only occurs at some points. In the large breccia which the ore has broken up near the foot-wall, the leptite fragments likewise occur directly in the ore, without any notable skarn formation in the contacts.

Thus, these distinct exposures at Lönnfallet show that skarn only occurs in some parts of the ore. This cannot be due to variations in the rocks through which the ore has broken, since the leptites are markedly uniform. And considering that the ore does not show any variations in composition that might account for this skarn formation, we are bound to assume that it still has had a different composition in those places where skarn was formed, and that it has contained some substance which is no longer present.

The most probable assumption would then be that the ore had contained gases and solutions in addition to the magma which may now be seen in a crystallised form. It is known that water vapour solves silicic acid at high pressure and moderately high temperature[1]. The other constituents required for green skarn, except iron which might have been furnished by the ore, could have been obtained from the brecciated leptites.

The border which is practically always found between skarn and ore, could probably be explained by the fact that the silicates formed had been in a state which was more easily movable than the iron ore. This is particularly conspicuous in the large skarn breccia in the hanging wall, shown in part on Plate 2. In this case the skarn appears to have prepared the way for the ore flowing forth immediately afterwards.

The same applies also to the skarn-breccia in the foot-wall. The skarn has penetrated farthest into leptite fissures, and the ore, which in this place mostly consists of apatite, is accumulated at the points where the angular fragments are located further apart. Thus it seems that in this place, too, it was not so easy for the ore to penetrate into the broken-up rocks as it was for the skarn. It is to be noted that this small breccia in the foot-wall bears a striking resemblance to the apatite breccias occurring in the Gällivare Ore Mountain. The apatite which is otherwise white in iron ore, assumes a bright greenish white colour in this breccia consisting of hornblende-skarn, in exactly the same manner as pointed out by Geijer in respect of the apatite breccias in the Gällivare Ore Mountain.

Skarn-breccias in the Grängesberg District have also been found in other parts and not only at Lönnfallet. In many places they occurred in leptites near the big apatite ores which form a continuation of the Lönnfallet ore northwards. In that place, too, they occur spotwise in the rocks in hanging and in foot-walls.

Such breccias have been known from a long time but they were not considered to be skarn-breccias, which is probably due to the fact that the analogous formations in the Lapland Districts had not been studied, where they can be more easily interpreted.

These skarn-breccias usually occur in leptite together with the ore, so that it was possible to see, as at Lönnfallet, that they were connected with the ore. But there are other skarn-breccias, e. g. east of the Strandberg District, where they occur at such a distance from the ore that their connection with it may be doubted.

Like ore-breccias, the skarn-breccias possess some peculiarities which are known from the Lapland Districts. In this case it was also found e. g. that skarn-veins of very small proportions could likewise extend remarkably far into the leptite rocks; they could be notably persistent although measuring only a few millimeters in width.

In the Lapland Districts the rocks are transformed by skarn-brecciation in widely varying degrees, and this is also found at Grängesberg, perhaps in an even larger measure. In some cases the leptite fragments are equally well

[1] Campbell, T. M., The ore minerals of Tavoy district. Min. jour. Feb. 8, 1919.

preserved in the skarn as in the skarn-breccias of the Kiruna District. In other cases, again, but mainly in the northernmost parts of the field round the Hammar Mine, the leptite in the breccia is changed into skarn to such a degree that the original character of the rock is lost. Then they form skarn masses of the types known from the Gällivare Field.

It has been pointed out here that the skarn seems to originate from gases at high pressure and moderately high temperature, present in the ore during the eruption. The solutions, probably for the most part aqueous solutions, which accompanied the ore during its progress, appear, on the other hand, not to have been directly active in the formation of skarn. It appears rather that they have produced other results. Geijer has shown that there are hydrothermally formed Hauki-ores in the Kiruna District, besides the eruptive ores. In the same way analogous hydrothermal ores, namely the so-called »segmalmer», are found in the Grängesberg District. They occur in a broad belt west of the apatite ores, enclosed in the leptite formation, where they form a great number of ore lenses. Many of these are large and go down to a considerable depth, others are small and insignificant. Their ore content is varying, not only in the different lenses, but also in one and the same lens. As in Haukivaara, the predominant ore mineral of these lenses is hematite, but at Grängesberg they also contain considerable quantities of magnetite which occurs mixed with hematite in larger and smaller accumulations. The apatite content of these ores is low. These »segmalm» ores at Grängesberg have therefore been suitable for the manufacture of iron and have been worked since olden times.

In the Kiruna District the intimate connection was emphasised between the Hauki-ores and the apatite ores, when it was found, in the extensive exposures round the Rektor Mine, that parts of apatite ore occurred quite near the ore impregnations in the Hauki series. Similar observations have also been made in the Grängesberg District. In fact, the rock-ground round the ore pits in the Risberg Field was stripped in 1927 before starting the extensive mining operations. These operations exposed a very variegated rock-ground mixed with ore. Iron ore occurred in the shape of grains incrusted in an agglomerate leptite rock, but also in the shape of ore-veins passing through this leptite (see figs. 9 and 10). The ore in these ore-veins were fine-grained and had the usual appearance of the apatite ore. Chemical analysis showed that the apatite content of these ore-dikes was very high. This confirmed the assumption that they were apophyses from the eruptive apatite ore, extending up to these districts.

The rock injected with these dikes was leptite. It was obviously of pyroclastic origin because it was not more metamorphosed than to show the agglomerate structure very distinctly, even if in a slightly distorted shape. It was rich in rounded fragments which were rolled out and stretched downwards by schistosity. These fragments were free from ore grains, but the matrix between them was more or less rich in such grains, and in some places the ore grains increased in number, so that fairly pure ore was formed. Green skarn was not found here. Since the ore was mixed with various other silicate minerals — quartz,

Fig. 9. Ore-bearing agglomeratic leptite with veins of apatite ore. Horizontal surface. Mossgruvan, Risbergsfältet, Grängesberg.

feldspar, mica — it was obvious that these ore formations in the leptite differed in nature from the above-described ore-skarn breccias.

In this place we have obviously to deal with two types of iron ores. Firstly, eruptive iron ore in the dikes, and secondly, an iron ore formed through metasomatic transformation of the leptite rock. These ores, though entirely different in nature, may yet be supposed to have the same origin. The most probable assumption is that in connection with the magma eruptions which have created the ore-veins, hydrothermal solutions appeared in this place, which furnished the ore material for the surrounding pyroclastic rock-ground. As has been mentioned in the above description of Lönnfallet, the skarn formations produced during the ore eruptions seem to have been created by the accompanied gases at high pressure and moderately high temperature. From the fact that skarn is lacking here, it may be inferred that the temperature was fairly low during the formation of ore at this place.

Like the Hauki-ores, these ores do not only occur accumulated in pure masses, but the ore mineral appears also in the adjacent leptites in such a manner that the ore masses, so to speak, fade in them. Round the mines in the Ormberg Field[1] and the Risberg Field there were many exposures about

[1] R. Looström. G. F. F., Vol. 51, 1929.

Fig. 10. Ore-bearing agglomeratic leptite. Vertical surface. Mossgruvan, Risbergsfältet, Grängesberg.

1920 which are now covered. These exposures demonstrated this very convincingly. It was seen how the ore occurred in the leptite, first as scattered grains, then the number of grains increased, and the ore content gradually grew higher to such an extent that it was clearly visible how it developed step by step into a pure ore mass.

Where the leptite had relic agglomerate structures, the rock fragments were in most cases not influenced by the penetrating ore. Also in those cases where the matrix in which they were located completely merged into ore, they remained free from ore. In these cases they had the appearance of bright leptite patches in the ore. A notable circumstance worthy of special mention here is

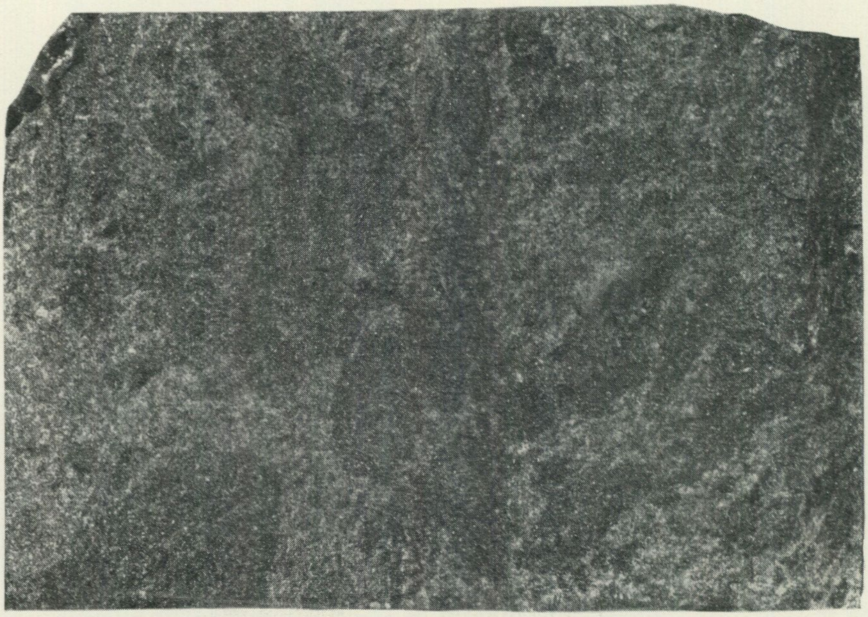

Fig. 11. Agglomeratic leptite. 2/3 nat. size. Risbergsfältet, Grängesberg.

Fig. 12. Ore-bearing agglomeratic leptite. 2/3 nat. size. Risbergsfältet, Grängesberg.

that these agglomeratic ores by dynamic metamorphism could obtain a deceptive resemblance to the distorted genuine ore breccias at Lönnfallet and in other parts of the Grängesberg District[1]. The blocks on the waste tips which have now been removed, furnished many proofs to this effect.

The fact that such hydrothermal ores can assume an appearance closely resembling that of ore-breccias, was shown in several places in the Risberg Field in the large exposures made in 1927 prior to the extensive modifications

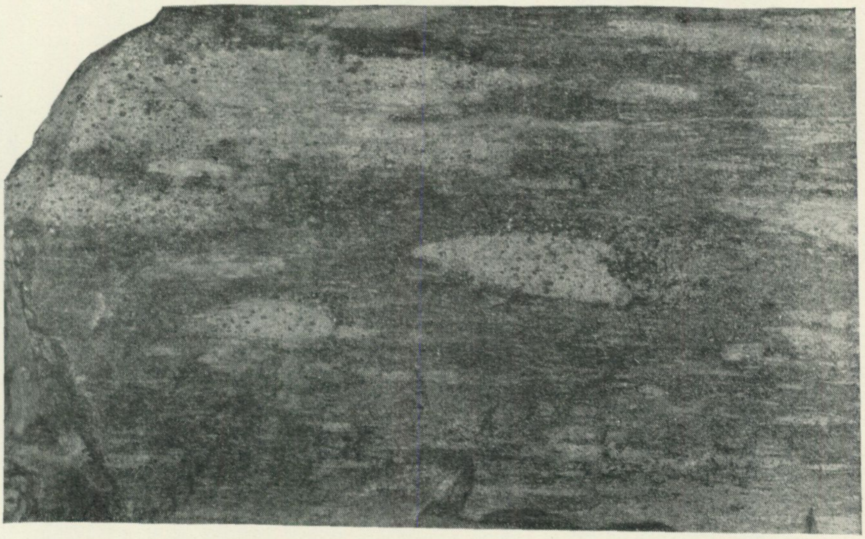

Fig. 13. Ore-bearing agglomeratic leptite, deformed. 1/3 nat. size. Risbergsfältet, Grängesberg.

in view of the development of mining operations. Along the western border of the field, above the mines, there were poor ores in agglomeratic leptite. In these ores it was possible to follow, not only the development into the variations due to the dynamic metamorphism, but also the impregnation of the leptite rock by the ore. The place where the original structures of the leptite were best preserved, was located in the exposures made at the southernmost end, round the dams, and in the slopes below a plant for water-purification for ore-separation. Here the pyroclastic structure of the leptite rock is preserved. It has an agglomeratic texture, as shown in fig. 11, and is entirely free from ore. But in the same exposure the rock contains ore. Iron minerals occur between the relic fragments, at first in very small quantities, but their amount increases successively, so that the matrix of the rock merges into ore, whereas the rock fragments are free from ore. They occur in the shape of leptite spots also in those places where the ore content is at the highest, as shown in fig. 12. Thus, the occurrence of iron ore is quite analogous to the manner observed in Haukivaara, where it is considered by Geijer to have been hydrothermally formed.

[1] R. Looström. G. F. F., Vol. 51, 1029.

By following the extension of this leptite layer northwards in the Risberg Field, the changes produced in it by dynamic metamorphism may be followed. It is to be seen here that as the schistosity increases, the relic fragments are distorted and assume the shape of flat lenses, and even thin plates. Yet they never contain ore, but appear as bright spots differing from the surroundings

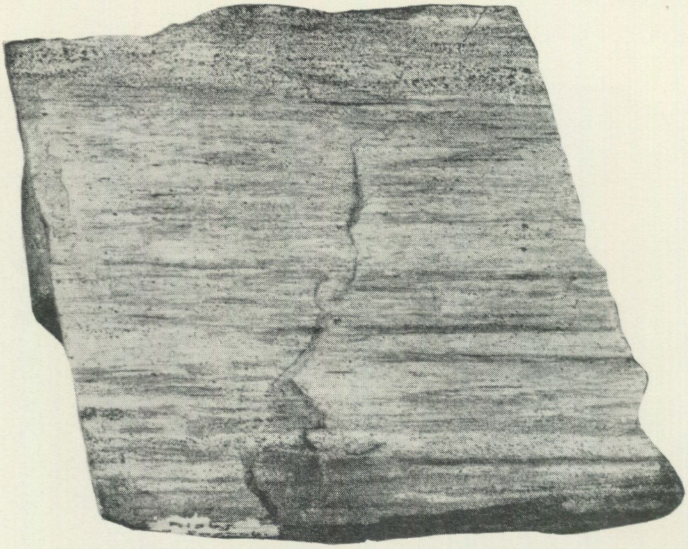

Fig. 14. Ore-bearing agglomeratic leptite, very strongly deformed. 1/2 nat. size. Risbergsfältet, Grängesberg.

which are more or less mixed with ore, as shown in fig. 13. If, however, the schistosity attains its maximum degree, the agglomerate structure is completely lost. The rock is transformed into masses with parallel streaks, but the original heterogeneous character still remains visible, as the ore occurs separated in threads or extremely thin continuous planes, as shown in fig. 14. These deformations of the agglomeratic ore-form are also found at Haukivaara.

Royal Technical University, Stockholm, July 1938.

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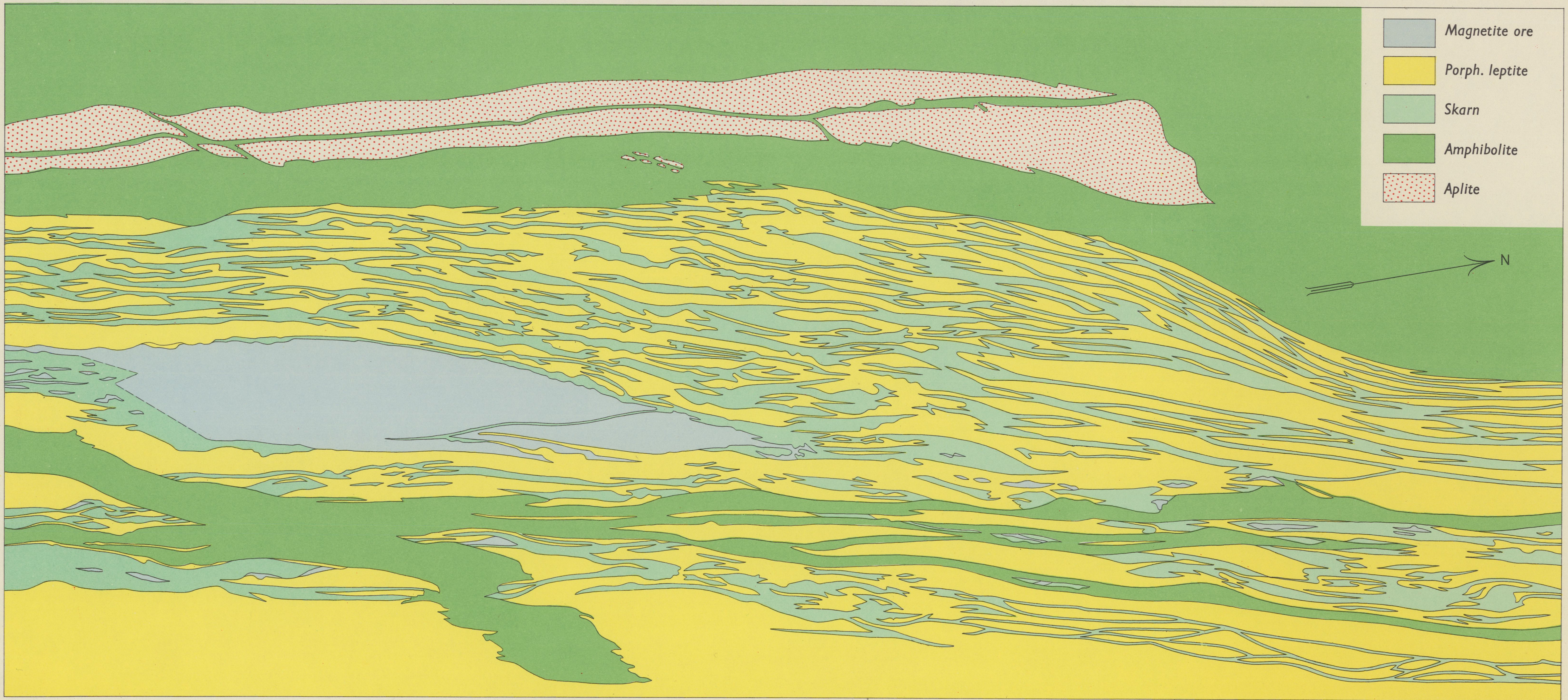
DETAIL FROM THE HANGING WALL OF THE ORE IN LÖNNFALLET, GRÄNGESBERG

By Ragnar Looström 1929

SVERIGES GEOLOGISKA UNDERSÖKNING SER. C N:O 428



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SCALE 1:20 0 1 2 m

PLATE 3

DETAIL FROM THE ORE IN LÖNNFALLET, GRÄNGESBERG

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