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SER. C. Avhandlingar och uppsatser. N:o 515.

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GEOLOGY OF THE SULPHIDE DEPOSITS AT MENSTRÄSK AND A COMPARISON WITH OTHER DEPOSITS IN THE SKELLEFTE DISTRICT

BY

ERLAND GRIP

WITH 4 PLATES

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STOCKHOLM 1951
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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†1—501845. *S. G. U., Ser. C, N:o 515. Grip.*

Introduction.

The Mensträsk ores are situated at latitude 65° 4′ N and 19° 22′ E, near Mensträsk, a village in the parish of Norsjö in the province of Västerbotten. They lie in a zone 3 km long and strike NW—SE. All the ores, with the exception of the two most easterly ones, are situated underneath Lake Mensträsk, and none of them outcrop. The names and positions of the ore-bodies are shown on the map, fig. 1. All the deposits were found by the Boliden Mining Co. and the majority are owned by this Company.

The district around Lake Mensträsk to be dealt with here, is situated between the valleys of the Skellefte and the Malå Rivers and constitutes a very flat terrain where the outcrops are but sparse. Lakes, swamps, and moraine cover the greater portion of the district. In the ore-bearing zone and its immediate surroundings there are no outcrops. The rocks, however, are very well exposed along the stream which flows from Lake Mensträsk due S to join the Malå River.

As early as 1921, during the Boliden Mining Co's first ore-prospecting campaign, a boulder of pyrite ore was found in the neighbourhood of Mensträsk. In the two following years there was an intensive search for boulders in an area that was almost entirely covered with morains and lakes, and a large number of new boulders were found, mainly composed of finegrained pyrite. In order to locate the source of the ore boulders, new methods of electrical prospecting were used, to a large extent elaborated here. They are described in detail by Lundberg and Sundberg (18). The electrical indications in the direction of the ice-flow above the ore boulders were investigated by diamond drilling. During the investigations, in the winter of 1924, the so-called Lake Ores were located and during the following years some further ore-bodies were disclosed. The Mensträsk prospecting has been described in a paper by O. Baeckström (1), who was the Company's chief geologist at that time, and by A. Högbom in papers on the Skellefte District. (12, 13.)

Geological investigations in the Mensträsk Area have subsequently been carried out by E. Dahlström in 1937 and G. Kautsky 1946—48. F. Kautsky spent many years studying the distribution of boulders.

A geophysical revision of the district with improved electrical and gravimetric methods was undertaken during 1945—47 under the direction of B. Öhrn and diamond drillings were carried out in connection with them.

In 1945 underground development of the Lake Ores was begun. Before the sinking of the shaft a headframe was built according to a new method described by S. E. Karlén (14). A concrete cylinder was moulded at the surface and as the moraine was removed from the base of the cylinder and as the cylinder sunk, further concrete was moulded to the top. The cylinder was allowed to sink to the rock surface 10 m below ground level and was moulded upwards as high as was convenient. A shaft was then sunk into the bedrock in the usual manner; it has now reached the 260 m level. Levels have been opened up at 150 m and 250 m, and from these horizontal diamond drill-holes have been drilled through the ore zone. On the 100 m and 200 m levels, horizontal bore-holes have been drilled from small cross-cuts in the shaft. All drifts and bore-holes on the main levels are shown on the maps Pl. 1—3. The underground development of the deposit was carried out under the direction of K. Johansson and later by B. Israelsson.

The underground workings have been followed by detailed geological mapping in the scale 1 : 200. This has been done by Å. Wirstam and coworkers under my supervision.

The underground development work was completed in the autumn of 1948. As no mining will be started in the near future and it is uncertain when the mine will be accessible again, I shall now give an account of the results of the geological investigation of the desposit. In that connection, I shall also present a survey of the geology of the area and short descriptions of the ore-bodies which were exposed by diamond drilling.

Since the first ore boulder was found in 1921, many geologists, geophysicists, and engineers have been working with the problems of the Mensträsk Area. I have had the privilege of meeting most of them and I wish to thank them for many inspiring discussions. To the Maganing Directors of the Boliden Mining Co, I wish to express my gratitude for the permission to publish this report. I also thank Professor P. A. Geijer for allowing the paper to be published in the Series of the Geological Survey.

The Geology of the Mensträsk Area and the Appearance of the Ores.

The bedrock in the Mensträsk Area consists of volcanic and sedimentary rocks and, to a small extent, granite-porphyry. The supercrustal rocks belong to the upper part of what has been called the porphyry series of the Skellefte District and the lower parts of its phyllite series. On account of the paucity of outcrops, it was originally difficult to get a clear picture of the geology of the area. During the investigations, however, a great many drill-holes and — later — shafts and drifts have been made. The entire area has been geophysically investigated and in the last few years it has been re-investigated with the new electrical "loop-frame" method. The indications thus obtained, to a great extent caused by impregnations of graphite and pyrrhotite in slates, are valuable when constructing the geological map.

In the summer of 1946, G. Kautsky was commissioned by the Boliden Mining Co. to make a detailed geological survey and stratigraphic-tectonic investigation of a part of the Skellefte District which comprised, inter alia, the Mensträsk Area. His survey continued in several stages during the following summers, and he has been able to give a new picture, rich in details, of the stratigraphy and tectonic features of this part of the Skellefte District.

The following description of the geology of the area is founded on G. Kautsky's reports, on my own observations during our joint excursions and on surveys made of the Mensträsk mine and its neighbourhood. For the construction of the map, fig. 1, I have used cores from all drill-holes, mine plans, electrical indications, and, to some extent, local boulders in the moraine. The most important result of G. Kautsky's investigations is the discovery of a large unconformity between the lower series, mainly corresponding to that which was previously called the porphyry series, and the overlying phyllite series. This unconformity forms a very important index horizon, which can be followed over large parts of the Skellefte District. As rocks rich in lime accompany it, the horizon can often be traced, even over drift-covered areas, by the observation of the rich vegetation which it develops. The various sedimentary horizons can be followed for considerable distances even though they may vary in facies. The lavas are, however, much less continuous in their horizons and rapidly peter out, sometimes being replaced by tuffs and agglomerates.

In the literature, the upper series of the Skellefte District, generally consisting of pelitic sediments, has been called the phyllite series. In the Mensträsk area, however, the metamorphism is so slight that I prefer to call the sediments, slates. The psammitic sediments generally have distinct sandstone textures although they are quartzitic and therefore may be called quartzitic sandstones. The acid lavas forming the foot-wall in the Mensträsk mine are so fresh and unaltered, that they should be called rhyolites or possibly metarhyolites. Since these rocks have been called quartz-porphyries in the Skellefte District, independent of their grade of metamorphism, the old name will be retained.

The stratigraphy of the area as disclosed by the new investigations is shown in the following table (from younger to older).

Intrusive granite-porphyry.

Black and grey slates with intercalated black quartzites.

Knotty, banded grey slates and black quartzitic sandstones, in the lower parts containing slatey conglomerate and conglomerate with a coarse, green groundmass.

Black slates, not very thick but horizontally continuous.

Weathering breccia, rich in lime grading upwards into calcareous conglomerates, which higher up become polymict. Interstratified beds of andesitic and dacitic lavas, tuffs, and agglomerates. A thin bed of black slate is sometimes found at the bottom.

Great unconformity.

"Felsites" with quartzite, quartz-porphyry and probably tuffs of the same rock.

Grey and black, often banded slates with intercalations of quartzitic sandstones and conglomerates. Sandstones of different types and with thin layers of slate occur in the upper portions. Sometimes beds of quartz-porphyry and andesitic lavas occur.

The angular unconformity between the two series shows that the lower one must have been folded and denudated before the deposition of the upper series upon the old weathering breccia. Sporadic granite pebbles, found by G. Kautsky in the polymict conglomerate above the weathering breccia, also indicate a deep weathering, during which the granite has been exposed and has been able to contribute material to the sediment. This granite was probably formed during the folding of the lower series and so corresponds to what, in an earlier paper (10), I have called the first phase in the folding of the Skellefte District. In the areas mapped by myself, I did not observe the great unconformity; but I considered that the folding did not begin till the end of the sedimentation of the upper series, and that the oldest granite was formed during the first folding phase. Later, there followed a denudation of an area in the N, raised during the folding phase, whereby the granite became consolidated and some phyllite conglomerates were formed to the S. Then followed the second folding phase, the stress having about the same direction but being much more intense. The sediments must have been sub ect to granitization when the whole complex was folded. The granite was then intruded and formed the massives of Revsund granite, occurring for instance along the southern boundary of the Skellefte District. I considered, as did Gavelin and Ödman (17), that the principal ore formation in the Skellefte District took place in that connection.

G. Kautsky's recent discoveries have demonstrated that the two foldings are more widely separated than was formerly supposed. The older granite has been exposed to the N and has produced material for the sediments above the weathering breccia and is thus older than these. At least a great part of what was earlier considered to belong to the Vargfors conglomerates and supposed to be younger than the phyllite series and the Revsund granite, must be assigned to the conglomerate lying above the weathering breccia but below the slates. The interpretation of the second, more intense folding phase, during which the Revsund granite was formed, has not changed as a result of the latest investigations. Through the strengthening of the northern ridge by the granite, the folding up could take place against a strong area of resistance, the existence of which has been further confirmed by the latest investigations.

It is this second folding that sets its mark on the Mensträsk Area. The folding-axes lie flat and strike about NW—SE. The rock series are mainly flat and the folds shallow, but a characteristic feature is that some usually narrow folds have very steep sides, forming isoclinic folds. Such folds can often be followed for long distances (cf. fig. 1). Another remarkable feature is a steeply dipping schistosity cutting over the bedding, where this is flat. — The narrow isoclinal folds lying along flat fold-axes are, however, secondarily folded along steep axes, and sharp drag-folds have sometimes been formed, for example W out of the Outer Lake Ore.

In this heavily drift-covered area, faults have only been noticed in the mine, where they are very small (see Pl. 3 and fig. 3). The direction of the fault plane is N—S, dipping E, in one case flat, in another steep. Grooves and drag structures show that an upward movement has occurred towards the NW.

South of Lake Mensträsk and the Malå River, G. Kautsky found several faults almost perpendicular to the direction of the strike.

The granite-porphyry is exposed only in the mine and in a drill-hole 3 km further to the SE. In boulders, it has been observed in the direction of the ice-flow from that drill-hole and in an area a few km north of the mine. It appears as dykes in the sediments and at least in the mine shows preference in following their steep parallel structures. As the granite-porphyry, according to our present knowledge, is connected with the second phase of the folding, it could probably be correlated with the Revsund granite, which may have a similar development as for instance east of Renström.

The geological map of the ore-bearing area at Mensträsk, fig. 1, shows some remarkable structural features. S of Lake Mensträsk the rocks, which here are well exposed, lie flat, but have a more or less pronounced steep schistosity. S of the lake this schistosity is especially well developed in the slates, which belong to the deepest stratigraphical horizon known in the district. The geological picture in the NE part of the map, fig. 1, is founded on exposures in the mine, in drill-holes, and on electrical indications and boulders in the moraine. Wherever it has been possible to determine the dip of the beds in this part, it has been found to be much steeper than in the SW part. The flattest dip was found in some drill-holes in the SE corner of the map, where it was about 40° NW (bedding at right angles to the drill-core). This direction of dip is parallel with the direction of strike in the isoclinally folded, steep dipping zone, which runs from here towards NW to the mine and therefore also indicates the approximate dip of the fold-axis in this place.

The dip of the Lomvik Ore is 72° NNE, having been determined with the aid of drill-holes cutting the ore-body at two levels. Drill-cores from other parts of the zone also indicate steep dips to the NE. In the Mensträsk mine, the dip is 70° NNE and the pitch of the ore-body 45° NNW. At the Outer Lake Ore, the dip is 70—75° N, according to observations in several drill-holes.

The observations of strike and dip within the zone thus indicate that in the SE the fold-axis dips about 40° NW, but in the NW it bends towards NNW with no change of dip. A vertical section at right angles to the anticline with this 45° dip of the fold-axis would thus appear approximately as on the map, i. e. the narrow fold zone would be about 4 km deep. This cannot very well be the case, however, as the rocks show a comparatively weak schistosity and the brittle layers seem to follow the ductile beds very well and without interruptions. According to the geological map the widths of the various layers in

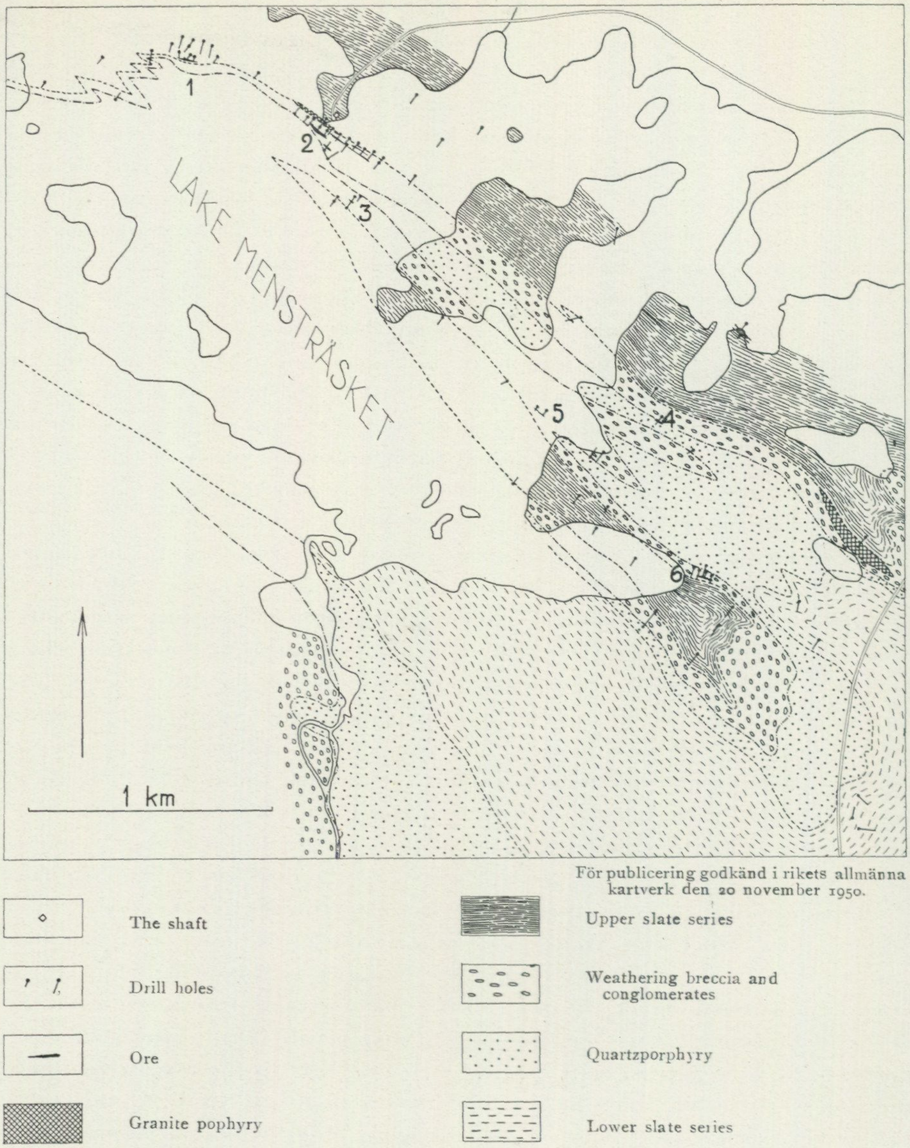

Fig. 1. Scetch-map showing the geology of the Mensträsk area. Scale 1 : 31.000. The ores: 1 Outer Lake Ore, 2 Inner Lake Ore, 3 Rundklumpen, 4 Lomviken, 5 Rågången, 6 Långviken.

the curves of the sharp folds are too large to correspond to a dip of the fold axis of 40°—45°. A dip of 10°—15° would agree better with picture of the map. Even with such a flat fold axis the zone must be very strongly folded. An occasional flattening out of the fold axis between the Lomvik Ore and the mine may be possible and then the fold amplitude is smaller.

Repeated faults across the anticlinal zone resulting in a depression of the

SE part compared with NW part might also give an appearance of length to what is really a short isoclinal fold dipping 45° NW. It is, however, very uncertain if such fault lines really occur.

In the eastern part of the Skellefte District a secondary, steep linear structure and folding is very common, as I have shown earlier (10), and seems to have been developed by lateral movements within the folded beds in the final stage of the folding. Especially in the lowest part of the slate series there sometimes occur steep drag folds, as for instance around the Boliden deposit (17). Similar structures have also been described by Gavelin from the Malånäs and the Vindelgransele Districts (3, 6). It is remarkable that these steep linear structures are mostly found in the lowest part of the upper series, directly above the great unconformity. The cause of this seems to be a considerable difference in resistance between the lower, earlier folded series and the upper more ductile sediments, which were able to form gentle folds during block-dislocations in the lower series (10).

In the Mensträsk Area too, this structure with secondary axes gives the most likely explanation of the structural features related above. The fold at the Outer Lake Ore must then be regarded as a drag-fold, to which structure the area of the Inner Lake Ore also contributed. The system of faults found there, in which the SE parts have moved over the NW parts, is then the result of the same lateral movement as formed the drag-fold (cf. p. 14 and fig. 3).

Under the stress, the younger sediments have been compressed as shown by the conglomerate pebbles, and this degree of compression is certainly greater than in the case of the older competent layers. An expansion occurred also in a horizontal direction, but where space was lacking a secondary folding or linear structure along steep axes may sometimes have been the result. This secondary folding, like the schistosity and the linear structure is considered to be simultaneous with the principal folding but it developed mainly towards the end of that folding process in connection with a change in the direction of stress.

The ores of the Mensträsk Area are composed of more or less compact sulphides and are all connected with the zone of the coarse sediments and weathering breccia between the felsites and the upper slates. A slight sulphide mineralization is also found in the felsites, where they are brecciated. All the ores occur in steeply dipping layers in the two limbs of an anticlinorium. Sulphide mineralization is also found in the flat, weathering breccia S of Mensträsk, where, however, it does not form compact ore.

The Outer Lake Ore is orientated along the middle steep fold-axis of the drag-fold, where it was evidently deposited on account of the favourable structure thus presented. The Inner Lake Ores pitch 45° NNW and lie in a conglomerate which peters out towards the NW against what seems to be a primary hill on the old land surface. The pitch of the ores corresponds to the direction in which the pebbles of the conglomerate are elongated.

In the other ores of the Mensträsk Area the number of drill holes is too scanty to allow a determination of the direction of pitch.

The metamorphism is weak in the Mensträsk area. The boundaries of the metamorphic zones in the Malånäs District and its surrounding as given by Gavelin (3 p. 52), have been verified in my area. It thus falls entirely within Gavelin's chlorite facies of acid volcanics and calcite-chlorite facies of greenstones. Towards the S, however, the metamorphic grade is higher, so that Elvaberget, S of the Malå River, lies in a transitional zone to biotite and amphibole facies, respectively, which also appears on Gavelin's sketch map.

The inner Lake Ores (Inre sjömalmerna).

Stratigraphy.

In the Mensträsk mine and its drill holes the rocks around the great unconformity described in the previous chapter, are exposed to a total thickness of about 300 m. Within the mine area the strike of the often well-banded sediments is N 55° W and the dip 70° NE. A section almost perpendicular to the bedding is well exposed in the shaft, drifts and drill-holes (see pl. 4). The system of rocks within the mine, ranging from younger to older, is as follows:

Sulphide ore.
Intrusive coarse granite-porphyry.
Dark slate and quartzites.
Polymict conglomerate.
Quartz-porphyry conglomerate and quartzitic sandstone.
Weathering breccia of the quartz-porphyry.
Quartz-porphyry.

A continuous section was best studied on the 150 m level and Table 1 shows in detail a horizontal section through all the rock layers there. (Compare Pl. 2 and 4). In this cross-section every rock type in the mine is represented with the exception of a calcareous sandstone at the western end of the A-orebody and the slates higher up in the series, which, however, are placed at the head of the table.

A more detailed description of the rocks and their contact relations is given under the heading "Rocks", so that I shall here mention only the general features. As is shown on the maps, fig. 1. Pl. 1, 2, 3, the sediments do not form a layer of uniform thickness on the quartz-porphyry over the whole mine area, but instead form a wedge which peters out towards the NW. Neither does the weathering breccia reach the most westerly parts, the conglomerates here lying directly upon the quartz-porphyry. The tectonic structures do not completely explain this fact; it seems to be a primary structural feature, formed at the time of sedimentation. The western quartz-porphyry area formed a hill, which, during a transgression, rose as an island out of the water, and from which loose material was washed down. We do not know the size of this hill district, but it extends at least half way to the Outer Lake Ore, as demonstrated by drill-holes, in which the weathering breccia is lacking and

Table 1.

Horizontal cross-section on the 150 m level from the NE wall of the shaft towards the SW through cross-cuts and drill holes.

The hanging wall in the N with grey and black, often graphite- and pyrrhotite-bearing slates and quartzites (according to the shaft section at least 45 m).

0 — 9 m	Grey slate with thin sandy bands.
9 — 21 m	Coarse granite-porphyry.
21 — 28 m	Grey slate, somewhat quartzitic.
28 — 29 m	Banded, partly gritty quartzitic sandstone.
29 — 30.7 m	Polymict, gritty conglomerate with solitary larger quartz-porphyry pebbles.
30.7— 31.0 m	Banded quartzitic sandstone.
31.0— 34.7 m	Polymict conglomerate rich in pebbles < 5 cm, of felsite and quartz-porphyry (fig. 8).
34.7— 38.2 m	Quartzitic sandstone and sandy slate with sericitic alteration.
38.2— 41.3 m	Dense pyrite ore.
41.3— 42.5 m	Quartzitic sandstone, sericitized, with pyrite-sphalerite impregnation.
42.5— 53.0 m	Pyrite ore with breccia structure and scattered small felsite pebbles (cf. p. 29).
53.0— 57.0 m	Quartzitic sandstone with scattered felsite pebbles richly impregnated with mottled pyrite and sericitized.
57.0— 59.7 m	Dense pyrite ore with scattered felsite pebbles.
59.7— 68.0 m	Coarse conglomerate with pebbles of felsite becoming more frequent towards the bottom. Sericitized and richly impregnated with sulphides.
68.0— 69.3 m	Quartzitic sandstone, sericitized.
69.3— 69.8 m	Conglomerate with felsite pebbles, sericitized.
69.8— 81.0 m	Quartzitic sandstone, sericitized.
81.0— 81.2 m	Conglomerate with felsite pebbles, sericitized.
81.2— 86.5 m	Quartzitic sandstone, sericitized.
86.5— 90.5 m	Conglomerate with felsite pebbles, sericitized.
80.5—103.7 m	Quartzitic sandstone, downwards more and more altered into sericite-chlorite.
103.7—105.9 m	Ore with chalcopyrite, pyrrhotite and arsenopyrite. (C-ore).
105.9—115.9 m	Conglomerate, gritty and uneven with angular pebbles, altered into chlorite-sericite.
105.9—125.5 m	Quartz-porphyry weathering breccia, sericitized.
125.5—140.6 m	Quartz-porphyry with phenocrysts of quartz and feldspar 1 mm.
140.6—148.6 m	do — weak sericite-chlorite alteration.

The foot-wall in the S.

the conglomerate zone is not very thick. This island, and probably others too, was apparently of some influence during a considerable period of sedimentation and supplied quartz-porphyry material for the formation of pebbles right up to the polymict conglomerate. A petering out to the NW is also in evidence here. Conglomerate pebbles in the polymict conglomerate on the 250 m level further indicate that parts of the already cemented conglomerate were situated above sea-level towards the end of the deposition of the polymict conglomerate and supplied this with material.

The age relations between the granite-porphyry and the ore are not quite clear as there is no direct contact between them. The granite-porphyry in the mine is strongly chloritized, however, and it is probable that this alteration occurred in connection with the forming of the ore. This is also indicated by the fact that further towards the E and outside the ore-bearing area, the same granite-porphyry is completely unaltered, and thus the chloritization cannot be of a regional character.

Tectonics.

As mentioned before the ores of the Mensträsk Area appear in the steep limbs of an anticline striking NW—SE. The Inner Lake Ores occur in the NE limb, which here dips about 70° towards the NNE (cf. fig. 1). In the mine, the bedding planes and the planes of schistosity mainly coincide and no real linear structure can be seen in the rocks. The pebbles of the conglomerate however, are somewhat elongated in the direction of the pitch, 45° NNW, a direction which coincides with the pitch of the ore lenses.

In the quartz-porphyry and sometimes in the weathering breccia as well as the conglomerate occurs a dense system of fine quartz veins with the direction N 30° E, 75° E, which system is older than the ore formation.

A measurement of the fissures in the quartz-porphyry conglomerate at the crossing of the drifts on the 150 m level has yielded the frequency diagram seen in fig. 2 a. Among the steep fissure systems here, the direction N 10° E dominates. Another pronounced, but more dispersed system is about N 60° E. The system N 55° W is approximately parallel with the schistosity, which in the conglomeratic rock is somewhat variable. The two first-mentioned fissure systems lie as Mohr's planes around the schistosity. One third of the fissures measured in the direction N 10° E, are filled with pyrite, which is not true of fissures in other directions (with the exception of one lying N 27° W).

From the stereogram fig. 2 b it is evident that there are many flat-lying fissures, especially around N 60° E, 15° S. They thus form an angle of about 60° with the pitch. Most of these fissures are filled with calcite.

The ores occur in distinct zones of brecciation and schistosity, cutting through the coarse sediments that form a wedge tapering towards NW between the quartz-porphyry and the slate. As shown by the mine maps Pl. 1, 2, 3, these zones are mainly parallel with the underlying plane of unconformity against the porphyry and form a small angle with the overlying slate. The slate contact, which has been determined almost only from drill-holes, forms very irregular lines on the different levels of the mine, but in the light of the zones of fracture, those lines are explicable. Compression of a number of blocks has here taken place along a series of shearing faults at an acute angle with the slate contact. The faults that caused the irregular slate contact, appearing especially well on the 250 m level, Pl. 3, occurred along the shearing zones in which the ores now lie, but probably also along several other parallel planes, e. g. E of the S ore in the 250 m level. The faults occurring in the brittle por-

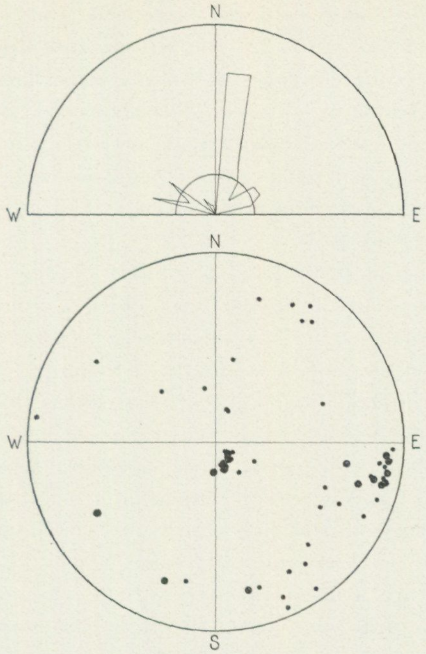

Fig. 2 a. Diagram showing frequency of the steep fissures around the crossing of the drifts at 150 m level in the Mensträsk mine. The inner circle marks the middle frequency.

b. Stereographic projection of all the fissures at the same place as 2 a. Fissures more than 2 m in length are marked with large dots and smaller ones with small dots.

phyry on the NW part of the 250 m level also coincide with this tectonic structure. Fig. 3 is a sketch map of the 250 m level and the movements there recorded. In horizontal section the planes along which the faults cocurred lie almost parallel to one of the slopes of the old quartz-porphyry land surface. As is shown by Pl. 4, in vertical section this land surface is very irregular but a

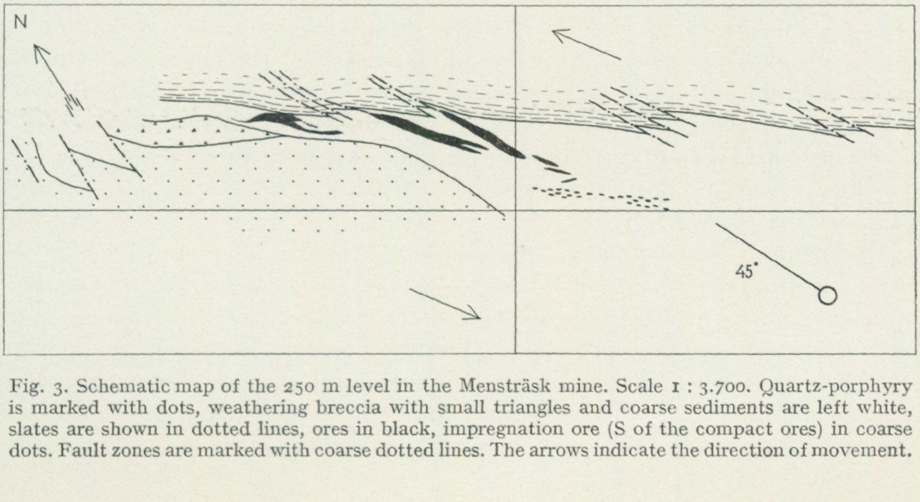

Fig. 3. Schematic map of the 250 m level in the Mensträsk mine. Scale 1 : 3.700. Quartz-porphyry is marked with dots, weathering breccia with small triangles and coarse sediments are left white, slates are shown in dotted lines, ores in black, impregnation ore (S of the compact ores) in coarse dots. Fault zones are marked with coarse dotted lines. The arrows indicate the direction of movement.

connection between the planes can here be traced, and it is evident that the fault planes have been governed by the tilted land surface which towards NW rises through the conglomerates up to the slate horizon.

It has not been possible to directly determine the direction of the axis around which the movements of deformation occurred, but it is probable that it coincides with the axis of length of the elongated conglomerate pebbles and with the direction of the ores. Around this axis and dipping 45° NNW an anti-clockwise rotation then occurred.

In the S ore body on the 250 m level, angular rock fragments in the sulphide breccia passes rotation-structure indicating a clock-wise movement during the ore formation and similar features have been observed in some of the other ore lenses. The ore solutions cannot have migrated through the compressed rocks, space having been supplied only by a relief of stress occasioned by a small movement in the opposite direction. Space was thus supplied in the most strongly sheared zones for the penetrating solutions, which subsequently received additional space through replacement of the wallrock.

The pyrite-filled fissures in the direction N 10° E also indicate a relief of the E—W pressure during the ore mineralization.

The tectonic structure around the Inner Lake Ore along with the compressed blocks agrees quite well with the drag-fold formation at the Outer Lake Ore, since the compression of the blocks and the formation of the drag-fold are results of the same anti-clockwise movement (that is a dislocation of the SW block towards SE in relation to the NE block).

Rocks.

The quartz-porphyry and its weathering breccia.

The quartz-porphyry, which forms the footwall of the rock sequence in the mine area, is a dark grey, brittle rock with phenocrysts of quartz and albite, generally about 1 mm in size but sometimes reaching a size of 3 mm. The quartz phenocrysts are often in the form of sharp idiomorphic bipyramids, but are at times also present in a splinter-like condition. Corrosion cavities and reaction zones with the ground mass are common. Most of the albite phenocrysts are idiomorphic with twin lamell-formed texture and showing a good state of preservation. The ground mass has a microgranoblastic texture and is composed of quartz and albite and a fine powder of opaque minerals. Occasional lamellae of chlorite and sericite also occur. Fig. 4 shows the microscopic appearance of the rock.

The chemical composition of the quartz-porphyry is given in Table 2. Col. A.

The now steeply raised old surface of the quartz-porphyry forms a weathering breccia. As mentioned before (p. 4), this weathering breccia has a large regional distribution and indicates a great unconformity. It is generally developed as a lime-cemented breccia with angular fragments of underlying felsites which sometimes have a porphyritic texture. In the good exposures found in the mine one is able to study the weathering breccia in detail. The photo,

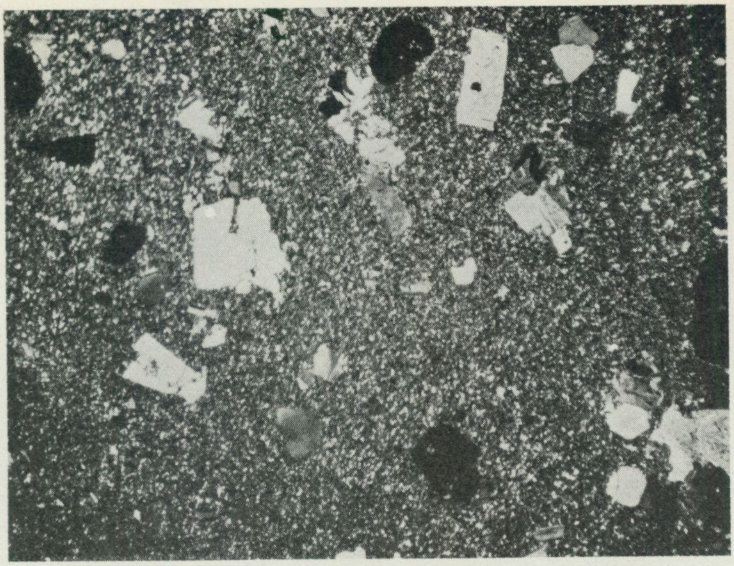

Fig. 4. Quartz-porphyry. 250 m level in the Mensträsk mine. × nicols. Scale 8 : 1. The same sample as analysis B in table 2. (Cf fig. 6.)

fig. 5, is from the 150 m level and shows the quartz-porphyry, traversed by quartz veins and fissures, from which fissures alteration has continued inwards. Fig. 6 is a sketch illustrating the same feature at a place nearby. The fresh grey quartz-porphyry occurs as rounded relicts surrounded by a bleached

Table 2.

Quartz-porphyry weathering breccia,

Mensträsk Mine, 150 m level, drift No. 301 ca 10 m W of Tp 11

Analyst: Th. Berggren

	A	B	C
	%	%	%
SiO_2	80,96	78,76	70,04
Al_2O_3	11,15	11,08	19,04
Fe_2O_3	0,00	0,00	0,08
FeO	1,38	1,45	0,69
MgO	0,02	0,16	0,72
CaO	0,62	1,56	0,45
Na_2O	5,0	4,7	2,4
K_2O	< 0,01	0,45	3,3
TiO_2	0,18	0,21	0,46
$H_2O < 105°$	0,04	0,02	0,05
$H_2O > 105°$	0,12	0,31	2,08
CO_2	0,25	1,14	0,19
	99,73	99,84	99,50

A. Dark, fresh quartz-porphyry
B. Leached »
C. Sericitized »

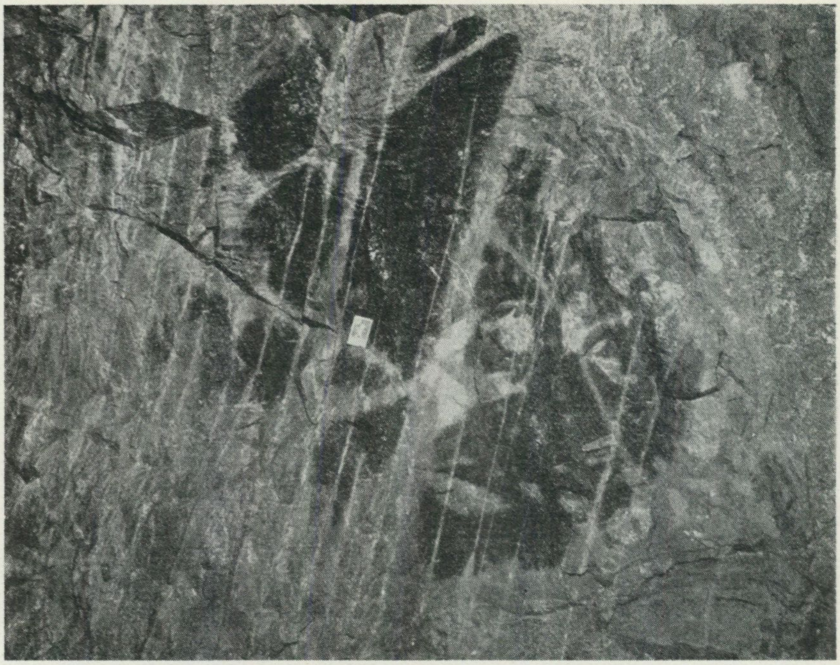

Fig. 5. Weathering breccia in a wall at 250 m level in the Mensträsk mine. Fresh dark coloured quartz-porphyry surrounded by bleached quartz-porphyry which is sericitized along irregular fissures. The white, parallel, narrow strings are quartz veins older than the weathering. Scale 1 : 15.

zone. Microscopically this zone differs from the fresh rock only by the presence of small calcite spots and a less pronounced pigmentation. Its chemical composition, however, compared with that of the fresh quartz-porphyry (Tab. 2 A—B) shows a somewhat lower percentage of SiO_2 and higher percentages of K_2O, CaO, and CO_2. Around the fissures, the rock is altered further in the same direction, forming a sericite quartzite. The phenocrysts there are fresh, but the ground mass is altered, the feldspar to a great extent being transformed into a very fine lamelliferous sericite and some chlorite. The percentage of SiO_2, and also of Na_2O, is considerably lower while Al_2O_3, MgO and K_2O show higher values. The content of calcite, however, has diminished.

Higher up in the bed the dark quartz-porphyry is completely bleached and the yellowish-white sericite quartzite becomes more frequent. Further up, the quartz-porphyry is completely broken up into angular fragments contained in a sandy matrix, above which follows a conglomerate with more or less rounded pebbles of quartz-porphyry, which, however, do not show any tendency to more than a rough rounding.

The weathering breccia in the neighbourhood of the mine has usually a calcareous or aluminous matrix. That is not the case in the mine, when the content of lime in the weathering breccia is negligible, a rich sericitization occurring instead. It thus seems as if the lime migrated during the metamorphism

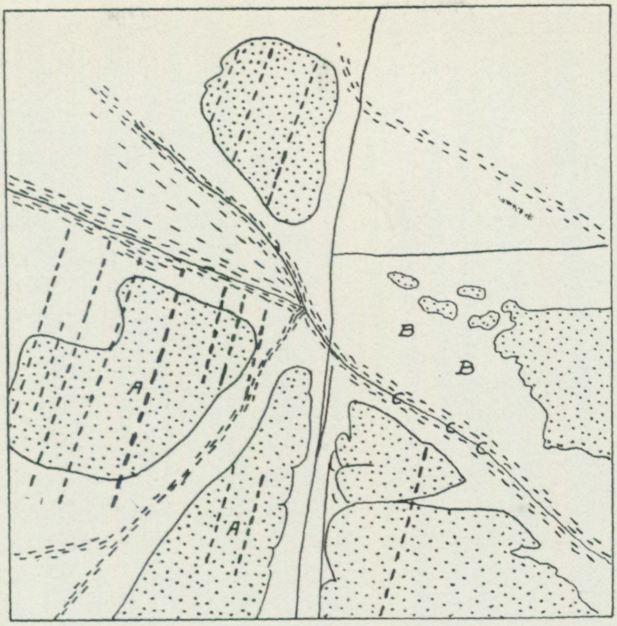

Fig. 6. Scetch of the weathering breccia in the same wall as fig. 5. A fresh, B bleached and C sericitized quartz-porphyry. The letters mark the samples taken for the analyses in table 2. Coarse dotted lines mark quartz veins, full lines fissures. Scale 1 : 10.

that overtook the rocks while the ore was forming. The rich sericitization in and around the old weathering breccia is then explained by the fact that these parts were richer in alumina and also looser and more easily affected than the fresh quartz-porphyry.

Quartz-porphyry conglomerate and quartzitic sandstone.

The weathering breccia of the quartz-porphyry grades upward successively into conglomerate, where the pebbles consist of quartz-porphyry and the sandy matrix of the same rock, together with quartz, chlorite aud sericite. At the bottom the pebbles are large (up to 1 m) and not very rounded, but towards the top they become smaller and rounder. Splinter-like fragments are frequently found, however, even high up in coarser as well as in finer material. Occasionally, pebbles of other rocks with darker colours occur (fig. 7). Boundaries between the pebbles and the matrix are very sharp, except in places where they have become veiled through alteration into sericite and chlorite and impregnation with sulphides in shearing and brecciated zones. (Fig. 8.) Due to tectonic influence, however, the pebbles have been affected, so that even in the parts that are least altered there is a certain elongation of the pebbles in the direction of pitch.

As is shown in the cross-section in Tab. 1, intercalations of sandstone occur at several levels in the conglomerate. However, it is not always possible to

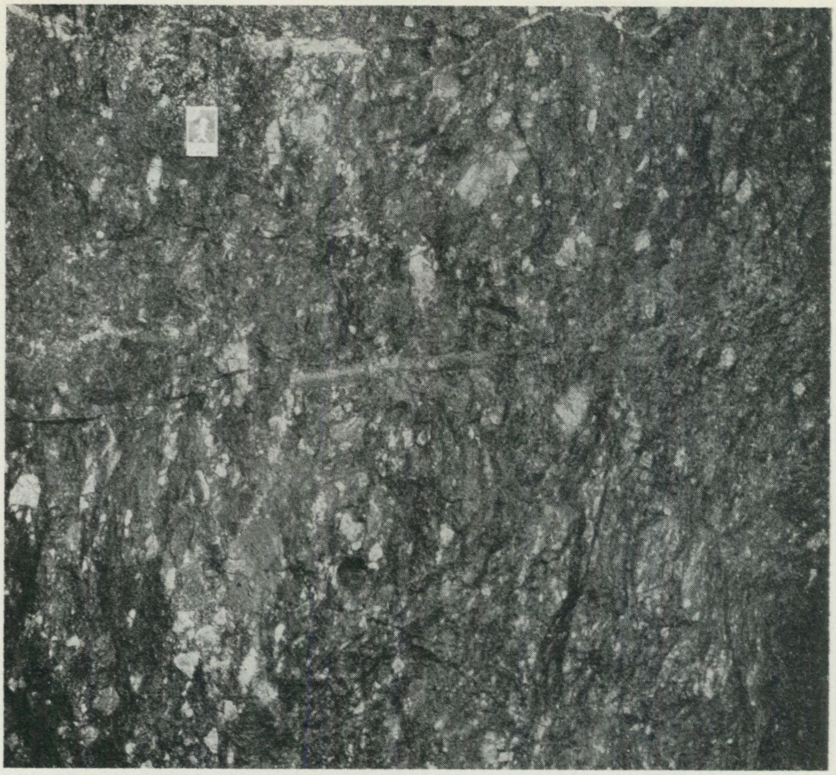

Fig. 7. Conglomerate with felsite pebbles and occasional small dark coloured pebbles. Wall at 150 m level in the Mensträsk mine. Scale 1 : 9.

follow them from drill-hole to drill-hole owing to the fact that there is a great variation in facies and a petering out of the beds. The thickest sandstone bed in the cross-section, Tab. 1, is, disregarding a thin conglomerate layer, about 16 m. The rock there to a great extent has a peculiar appearance with occasional larger grains (5 mm) in a sandstone with a grain size of about 0.1 mm (fig. 9). The small grains of sand, which are quite well rounded, consist of quartz in one or more individual grains, crystallized together, and these lie in a fine-grained mass rich in chlorite and sericite and with a little calcite. The large grains consist of quartz, often to a greater or lesser degree replaced by calcite, and together with this form graphic textures. The calcite also occurs as occasional, probably secondary grains. The large quartz grains have grown considerably in their present place at the expense of the fine-grained quartz surrounding them. It is possible at times to detect in the quartz the contours of the primary grain, which was about half as large as the present one.

The sedimentary rocks in this series are throughout of a very light colour. The material of the pebbles, as well as of the sandstone, is mainly of the same type as the underlying quartz-porphyry. Towards NW and downwards in the mine the bed of conglomerate-sandstone becomes considerably thinner, in-

Fig. 8. Quartz-porphyry conglomerate, sericitized and richly impregnated with pyrite replacing the groundmass of the conglomerate. Roof of a drift at 150 m level in the Mensträsk mine. Scale 1 : 10.

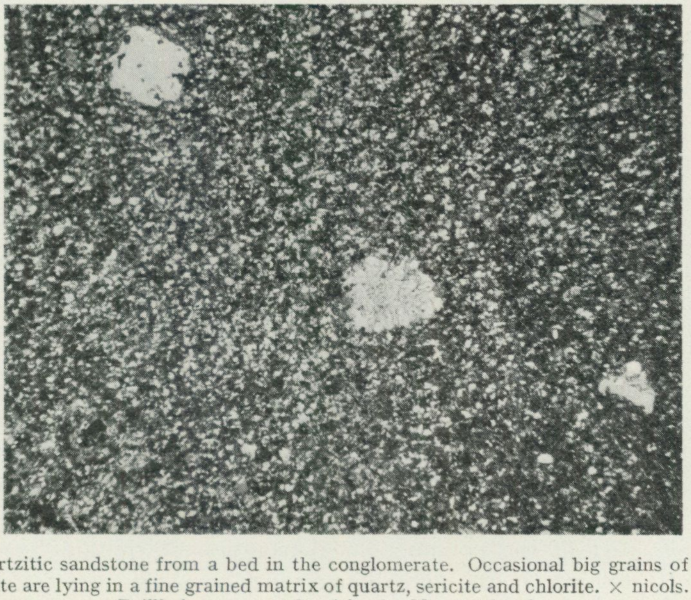

Fig. 9. Quartzitic sandstone from a bed in the conglomerate. Occasional big grains of quartz and quartz-calcite are lying in a fine grained matrix of quartz, sericite and chlorite. × nicols. Scale 8 : 1. Drillhole at 150 m level in the Mensträsk mine.

dicating that there was a primary hill here on the bottom of the sea which rose above sea-level and thus produced material for the conglomerate and sandstone. A further proof of this statement is that the weathering breccia, mighty in the E, completely disappears towards the NW.

A weak pyrite impregnation is common even in the freshest conglomerates and quartzitic sandstones while richer impregnations appear in those parts which are more strongly tectonized and altered into sericite-chlorite. First and foremost the sulphides replace the matrix in the conglomerate, while even in richly sulphidized parts the quartz-porphyry pebbles can be almost free from sulphide; on the whole they are very little influenced by the metamorphism.

Polymict conglomerate.

Above the quartz-porphyry conglomerate follows a polymict conglomerate. The contact between the bed rock is only on occasions sharp and in the drill-cores it is often difficult to determine it exactly. Towards NW the conglomerate peters out, indicating that even at the time of its sedimentation, a hill or a shoal existed in that part of the sea where the sedimentation occurred. The thickness of the polymict conglomerate is maximum 20—30 m.

The pebbles in the polymict conglomerate are as a rule well rounded and generally only a few centimeters in size (fig. 10). The coarsest conglomerate is found at the bottom while the size of the pebbles as a rule becomes smaller towards the top. Uppermost there are interlayers of finer sediments, varying from psammite to pelite. The contact between the conglomerate and the slate series is more dictinct in some drillholes, while in others a successive transition occurs, caused by thin alternating layers. The contact then becomes somewhat variable especially as there is a strong alteration of facies in a horizontal direction. It is therefore often difficult to trace the layers from drill-hole to drill-hole even if the holes lie close to each other. Another cause seems to have been that the pelitic beds were flattened out and torn apart during the tectonic movements.

On the mine map, the upper part of what must be called polymict conglomerate is marked as slate, since the pelitic sediments which dominate here are from the ore-geological point of view, of great significance, having impounded the ore solutions and concentrated them into the conglomerate zone.

The E-ores lie wholly within the polymict conglomerate, which is strongly affected and partly replaced in and around them. The primary structures are consequently not so well preserved in this otherwise well exposed part. The sedimentary layers NE of the E-ores are, on the contrary, very well preserved particularly as they have been protected from sulphide solutions by dense pelitic beds. The microscopic investigations of the primary textures have therefore generally been made on slides taken from here.

The lower part of the polymict conglomerate still contains considerable amounts of pebbles from the underlying quartz-porphyry (fig. 10), but these decrease upwards where there is a mixed material, e. g. containing pebbles of

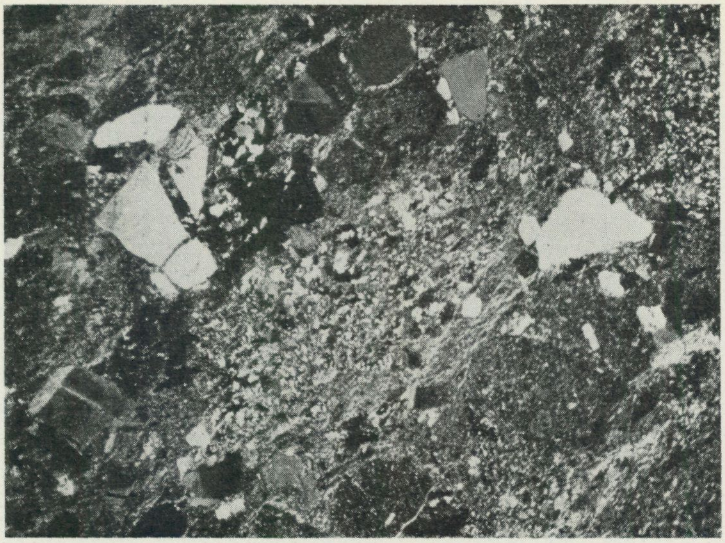

Fig. 10. Polymict gravel-like conglomerate with grains of sedimentary rocks and lavas, quartz and felspar. × nicols. Scale 8 : 1. Drillhole at 150 m level in the Mensträsk mine.

intermediate acid volcanic rocks. Thus in the upper part of the conglomerate NE of the E-ore group, the following rock-types occur in the pebbles: Felsitic quartz-porphyry, felsitic keratophyre, dacite, andesite, quartzitic sandstones, conglomerate quartzites with and without lime, quartz, plagioclase, alkalifelspar and myrmekitic quartz-alkalifelspar. The felsitic quartz-porphyry probably originated from the quartz-porphyry below the weathering breccia, while the other volcanic rocks all seem to have originated from a volcanic activity roughly contemporaneous with the sedimentation of the conglomerate. The volcanic rocks in the pebbles are all more or less strongly chloritized and their felspars have lost all their lime, so that they now everywhere consist of albite. As the original mineral composition has been so strongly changed, it has only been possible to determine these rocks by means of their texture, general features and chlorite content. Keratophyre, dacite and andesite do not occur in the bedrocks of the conglomerate, but in other parts of the Mensträsk area occur a certain number of these lavas or their pyroclastic products, and further to the E in the Skellefte District they play an important part. There they are found in the corresponding stratigraphic horizon (e. g. in the Renström area, around Boliden and Långdal and in the Kågedal cupola). The volcanic pebbles in Mensträsk thus seem to originate from volcanic areas in the neighbourhood, probably E of the mine, while the thickness of the volcanic beds is considerably greater in that direction. Tuffaceous agglomerate is especially abundant there, and it is probable that the pebbles of the polymict conglomerate consist partly of erosion products from such soft beds.

Those quartzites, with or without lime, and sandstones which form the pebbles in the conglomerate are of types occurring in the bedrock. The several mm large fragments of felspar and myrmekitic quartz-felspar, however, do not seem to originate from rocks known in the immediate neighbourhood. Most probably they originate from a granite and this may also be true of the larger quartz grains as far as they do not originate from quartz veins. The most likely contributer granite in this case is the one occurring in the large Jörn massive, the nearest boundary of which is now 12 km ENE of Mensträsk.

The quartzitic sandstones intercalated in the polymict conglomerate generally consist of the same material as the conglomerate. Splinter-like grains are common and the sand is not well assorted, either as regards size or grain-material. The sand grains consist of quartz and alkalifelspar and fragments of lavas and sedimentary rocks. The abundant quartz and felspar in grains, which are several mm in size, as well as occasional myrmekitic grains indicates that a granite contributed much of the material for the sandstone. Conglomerates as well as sandstones contain, especially in the finely granular matrix between larger fragments, varying quantities of chlorite, sericite, and calcite. Occasionally the calcite partly replaces the quartz grains in the sandstone. Sericite and chlorite are especially confined to shearing zones in the sediments. A sulphide impregnation, particularly pyrite, is common even in the freshest and best-preserved conglomerates and quartzitic sandstones, but it is most richly found where the sericite and chlorite alterations are stronger.

The polymict conglomerate is a transgressive conglomerate and represents the transition into a thick series with dominating pelitic sediments: the extensive phyllite series of the Skellefte District. The large transgression occurred after or at the end of a period of volcanic activity which can be traced over the whole of the Skellefte District and which, judging from pillow structures in the lavas in the Mensträsk area as well as in the area east of it, extruded streams of lava which partly solidified under sea-level.

Slates.

The sedimentary rocks which overlay the polymict conglomerate and belong to the lower part of the extensive phyllite series in the Skellefte District, generally consist of pelitic sediments, which often show a beautiful banding. (Compare p. 7 "black slate".) The rocks of this series were named phyllites by Högbom, Gavelin and other workers, but the rocks in the Mensträsk area are generally in a low metamorphic condition and are so fresh and so little altered that the term, slate, may be more appropriate. The abundance of graphite and pyrrhotite impregnations is a characteristic feature of especially the finest sediments. These impregnations make the rocks good conductors of electricity and with electrical ore-prospecting methods is has been possible to follow the horizons for long distances. Abrupt breaks are common, however; these seem to be due to the fact that the conductive slate beds were torn apart as a result of tectonic movements.

The colour of the slates varies from grey to black sometimes with a touch

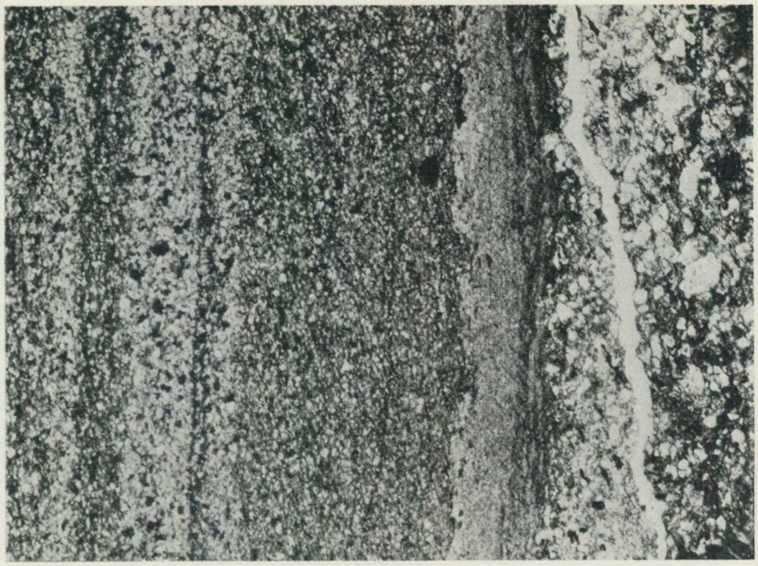

Fig. 11. Banded slate. 1 nicol. Scale 8 : 1. The shaft at the Mensträsk mine.

of green. The banding appears partly from the varying colours of the layers and partly from the varying sizes of the grains within them (fig. 11). Samples of grey slate from the 55 m level in the shaft and from the 150 m level have a grain size of about 0.01 mm and consist of quartz, sericite, and chlorite and a little calcite especially along the fissures. Pyrrhotite occurs as occasional larger grains, which are mostly enriched along fissures. Sericite and chlorite are well arranged in the plane of schistosity.

A black slate in the upper part of the shaft has very pronounced bedding. (Fig. 11.) The grain size is about 0.01—0.2 mm. The large grains always consist of quartz, but there are also occasional grains of albite, quartzite and slate. Some layers are rich in calcite. Sericite, fine-grained quartz, small amounts of light coloured biotite, powdered graphite and occasional grains of pyrrhotite represent the other slate minerals. The occurrence of biotite in the slate is remarkable since this rock is the only one amongst the sediments where biotite has been found. The biotite seems to be older than the chlorite-sericite alteration, for some of the biotite lamellae show absorption textures. — In the adjoining Malånäs District, Gavelin (3) found a metamorphic zoning around a massive of the Revsund granite in the S. Nearest to the granite is a zone where acid volcanics have complete biotite facies. Towards the NE follows a transitional zone and after that a zone with a complete calcite-chloritefacies. In certain graphitic phyllites he has found small amounts of biotite even outside the zone of biotite facies, and he considers this to be due to the fact that biotite is more easily formed under a heavy stress than otherwise (3 p. 64). Gavelin has drawn the boundaries of the metamorphic zone on the basis of his scanty observations and makes the zone include the whole of the Mensträsk Area; the whole of the mine area is thus situated within the calcite-chlorite zone (3 p. 52), which fact is only confirmed by my investigation.

Granite-porphyry.

A coarse-grained granite-porphyry is found to be intruded as a sill in the sediments of the slate series. The sill has a thickness of 10 m and the porphyry contains plenty of material from the wall-rock. The intrusive character of the porphyry is shown up better in a drill-hole a few km E of the mine, where from the N contact and south-wards it is exposed to a breadth of more than 30 m.

The granite-porphyry in the mine contains phenocrysts of quartz and felspar up to 10 mm in size in a dark groundmass. The quartz grains possess traces of bipyramidal forms but they are generally very rounded and sometimes have ragged edges. They have many inclusions consisting of fine-grained quartz and an isotropic mass, which seems to consist at least partly of chlorite. The inclusions have a more or less pronounced rhombohedral habitus, but rounded contours of fine-grained quartz within the rhombohedron, sometimes several within one another, suggest that the inclusions at first were vesicular but later attained a rhombohedral habitus owing to corrosion from within. Small amounts of calcite are also found there.

The felspar is a plagioclase, present as slightly rounded plates. It shows traces of zonal structure and its present albite composition is evidently a secondary one. The abundance of interspersed calcite indicates that the plagioclase has yielded its lime content to this mineral. Chlorite is plentiful along fissures.

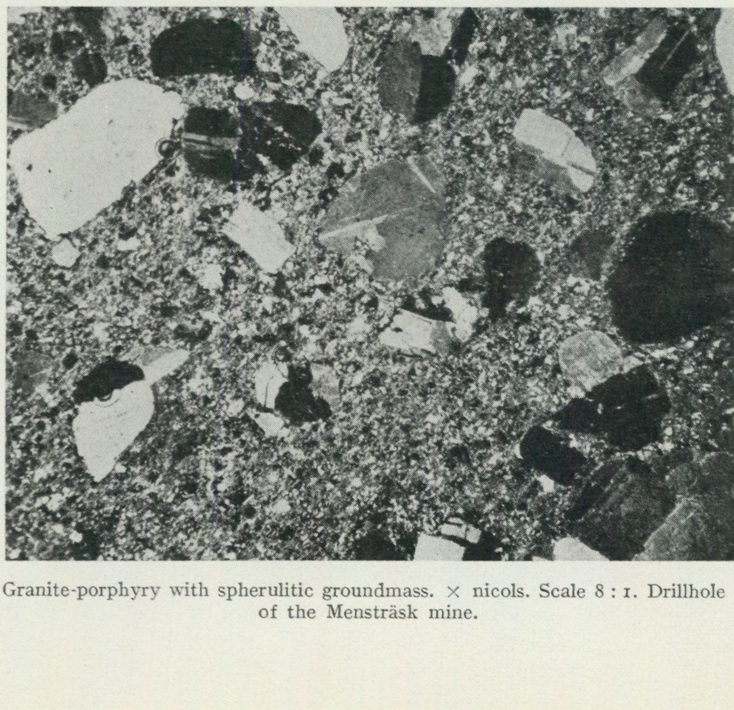

Fig. 12. Granite-porphyry with spherulitic groundmass. × nicols. Scale 8 : 1. Drillhole 3 km SE of the Mensträsk mine.

The fine-grained groundmass contains quartz and albite with plenty of chlorite and calcite. Sulphide grains have crystallized sparsely in connection with the chloritization.

The granite-porphyry E of the mine is fresher (fig. 12). The phenocrysts here are largest in the neighbourhood of the slate contact and around fragments of slate, while further into the sill they become smaller (< 6 mm). The plagioclase is an acid oligoclase. The groundmass has a spherulitic texture indicating that it solidified as glass. Between the spherulites, which are about 0.2 mm in size, occurs a mass rich in sericite, chlorite and sometimes a little biotite, usually together with sulphide. The scattered, but relatively abundant and pronouncedly idiomorphic arsenopyrite needles in the porphyry are remarkable. In two drill-core sections, the content of arsenic was thus 0.19 and 0.07 % respectively. The sulphide impregnations are richest in the parts most altered into sericite and chlorite and evidently belong to a secondary mineralization.

The age of the granite-porphyry in relation to the ore formation has not been established through direct contacts. The relatively strong alteration of the groundmass and the impregnation of pyrite indicates, however, that the porphyry is older than the ore formation.

The Ore Bodies.

As mentioned before, the ore bodies are almost completely confined to the conglomerate series, where they form several lenses. Generally speaking, they follow the bedding planes of the sediments but on the 250 m level occur also crossing structures forming acute angles with the bedding plane (about 20—30°).

The richest parts of the ore consist almost entirely of sulphides and at several places the contact between compact ore and wall-rock is very sharply defined. In other places, however, especially along the contact between the ores and the footwall, the ores attain the character of impregnations. The conglomerate on the footwall side is more or less richly impregnated with sulphide for quite a distance from the compact ore bodies. The contours of the ore bodies drawn on the maps show the boundaries of what, from an economic and technical point of view, can be called ore. Especially on the SW side of the ore bodies, drawn on the maps, the rich impregnations mentioned above often occur.

The ore group in the Mensträsk mine called the Inner Lake Ores consists of several lenses which, however, especially to the E, are connected with one another by parts containing smaller amounts of sulphide minerals. Broadly speaking, the ore bodies have been followed from level to level, but their contours vary considerably, especially in the eastern group. In the following discussion, the various ore bodies in the western group are indicated with the letters A—D, the whole of the eastern group with E, and an ore body furthest south and at the 250 m level, with S. Their situations are shown on the maps, pl. 1—3.

Lenses A, B, and C lie in the lower part of the conglomerate zone beneath the contact against the quartz-porphyry or its weathering breccia. The D-lens lies within the weathering breccia and the remaining ore lenses, which form the E-group, are situated higher up in the conglomerates, near the boundary with the slate series.

The A-lens on the 30 m level is 100 m in length and has a maximum breadth of 28 m. It consists of fine-grained pyrite ore with bands of sphalerite and contains on an average about 64 % pyrite, 8 % sphalerite, 4 % pyrrhotite and small amounts of sulpho-minerals, chalcopyrite, gudmundite, arsenopyrite, and tetrahedrite. Quartz and calcite are the essential gangue minerals and, in addition some sericite, chlorite, sporadic felspar and tourmaline occur. The average size of the pyrite grains is 0.05 mm. To a varying extent they are replaced by sphalerite, pyrrhotite, chalcopyrite, and sulpho-minerals. When the sphalerite occurs plentifully it has a grain size of about 0.01 mm. Here, as in the whole mine, the sphalerite has a dark colour.

An average sample taken from drill cores through the A- and B-lenses shows a chemical composition as depicted in Tab. 3. The approximate average mineral composition, calculated from the analyses, is also given.

Table 3.

Average sample of ore from the B and C lenses taken from drill-cores

Analyst: Th. Berggren and co-workers

	%	Mol. prop. × 1000		%
SiO_2	11,64	1938	Fe total	34,45
Al_2O_3	1,40	137	Cu	0,34
MnO	0,07		Co	0,01
MgO	0,64	159	Zn	5,29
CaO	2,60	464	Pb	0,57
BaO	<0,01		Cd	0,001
Na_2O	0,22	36	Hg	0,0010
K_2O	0,24	26	Bi	< 0,001
Li_2O	<0,04		Au	0,00008
TiO_2	0,14	18	Ag	0,0052
CO_2	1,90	432	Sb	0,106
$H_2O < 105°$	0,12		As	0,98
$H_2O > 105°$	1,09		Se	0,002
			S	37,75
	20,06			79,51
				20,06
				99,57

Calculated mineral composition

Quartz	9	FeS_2	57,0
Calcite	4	FeS	10,7
Sericite	4	$CuFeS_2$	1,0
Chlorite	2	ZnS	7,9
Titanite	1	PbS	0,7
		FeSAs	2,1
	20		79,4

On the 150 m level the A-lens is of about the same length as on the 30 m level, but its breadth is much less. Here is found a zone, rich in chalcopyrite, within the eastern part of the ore lens. The content of sulphide on this level is considerably lower than on the 30 m level, whilst the zinc content has diminished considerably. The average copper content, however, is higher.

On the 250 m level the A-lens has not been re-encountered, and so it must peter out between the 150 and 250 m levels.

The B-lens is known only on the 30 m level and subsequently peters out above the 150 m level. It consists of a fine-grained pyrite ore of the same type as the A-lens, but somewhat poorer in sulphides.

The C-lens is situated in the direction of strike to the south of the A-lens and is only known on the 150 m level. The ore is not very large. It consists of a fine-grained pyrite-copper ore containing about 35 % pyrite, 7 % chalcopyrite and small amounts of sphalerite. Locally there is a considerable enrichment of arsenopyrite.

The D-lens lies in the weathering breccia of the quartz-porphyry and is known only from a drill-hole on the 150 m level. It is a small copper ore of the impregnated type and consists of about 6 % chalcopyrite with the same amount of pyrite.

The ore lenses of the E-group on the 30 m level consist of an ore-body 210 m long and 3—17 m wide and another 65 m wide to the E of this; between these two is an insignificant ore lens in an impregnation zone. The long ore-body consists of a moderately rich pyrite ore in the NW part and an impregnation ore with copper and zinc in the SE part. The ore lenses in this group on the 30 m level consist on an average of about 45 % pyrite, 4 % sphalerite, 3 % pyrrhotite, 1 % chalcopyrite and small amounts of sulpho-minerals, gudmundite and arsenopyrite. Occasionally tetrahedrite and galena occur. Quartz is plentiful while calcite plays a subordinate part. Both chlorite and sericite are common. — The grain size of the pyrite is about 0.04 mm. The long lens in its western part contains a distinct banding of zinc ore which seemingly mirrors the structure of the sediments.

The lenses of the E-group are again found on the 150 m level but with the contours of the ore considerably changed. In the 180 m long drifts on this level the NE lens is dominant while the SW ore is more insignificant. There is a continual alternation between the richer areas and impregnations. The average pyrite content on this level is a little higher than on the 130 m level but the sphalerite and chalcopyrite contents are lower.

The ores are well exposed in a cross-cut where the structures may be well studied. To the N the pyrite-ore is dense and even-grained, it being followed by a pyrite and sphalerite impregnated area of sericite-altered sandstone. To the S of these ores follows a 10 m thick pyrite ore with occasionally small felsite pebbles. Judging from relict structures the ore has here replaced a gravelly conglomerate. The ore itself possesses a gravelly structure, since rounded pebbles of dense pyrite ore, up to a size of 1 cm, occur lying in a somewhat coarser matrix of pyrrhotite, sphalerite and the other ore minerals previously mentioned, along with quartz, chlorite and sericite. Further southwards follows a quartzitic sandstone, brecciated and richly impregnated with sulphides. After this 4 m thick bed there occurs again a compact 3 m thick ore bank where sparse felsite pebbles indicate that it has replaced a conglomerate. Such a body also forms the footwall of the ore and is there often richly impregnated with sulphide.

On the 250 m level the E-group reappears as three small ore lenses, of which the two easterly ones cross the strike at an angle of 20°—30°. On the 150 m level this feature is less pronounced, but a preliminary trace is detectable as early as on the 30 m level. The ore lens closest to the west of the shaft makes a very sharp contact with the wall-rock to the E while in consequence of smallscale folding and impregnation in the wall-rock the western lens is not sharp.

The mineral composition of the eastern group is of the usual type: pyrite dominates, and some amounts of sphalerite, chalcopyrite, etc., occur.

The S-ore. On the 250 m level S of the shaft and S of the other ore lenses an ore-body has been discovered which is unknown at higher levels. It is 60 m long and maximum 6 m wide and consists of pyrite and pyrrhotite, estimated to be in equal amounts, besides sphalerite and small amounts of chalcopyrite. The total amount of sulphur here is only 19 %.

The S-ore lies in a quartz-porphyry conglomerate directly beneath the polymict conglomerate. The conglomerate structures are visible within the ore but in particular outside it in the direction of strike towards the S. The ore there grades into a coarse breccia where the fissures are filled with pyrite, considerably coarser than within the ore, and sphalerite. The ore-filled fissures generally coincide with the direction of strike but often may cross over these in various directions. The positions of sharp-angled fragments indicate a clockwise-movement during the sulphide mineralization. Where the ore does not directly follow the fissures, the resultant replacement in the mine is in the first place of the groundmass in the conglomerate, preferably along shearing zones. Outside the previously mentioned ore breccia there is a very wide zone with scattered pyrite crystals of more or less distinct hexahedral habitus, with a size of about 10 mm, sometimes, however, up to 15 mm.

Around the S-ore there are short quartz veins striking N 30° E and dipping steeply W, which are older than the ore, as well as veins parallel with the ore-body present in its contact with the wall-rock. The latter were probably formed at the end of the ore-genesis.

In the hanging wall of the S point of the S-ore occurs a quartz vein about 10 cm in thickness and containing pyrrhotite, sphalerite and a considerable amount of boulangerite in radiating clusters as well as smaller amounts of jamesonite and arsenopyrite. There is also a veinlet of dense arsenopyrite. Further towards the SSE in the direction of strike there are some parallel quartz veins in a chlorite-rich zone, where quartz as well as the surrounding chlorite schists contain an abundance of arsenopyrite needles, a few mm in length.

The Ore Genesis.

Tectonic relations and nature of the ore solution channels.

As indicated in the description of the ore-bodies most of them occur in the conglomerates and are connected with fissures, crushing and shearing structures in them. The rocks of the surrounding area are, as mentioned before (p. 9), folded along flat fold axes and lie alternately flat and steep. The schistosity, however, is at all times steep and has a strike of about 55° W over the whole area. It therefore crosses the bedding plane, forming varying angles with it between 0° and 90°. The development of the schistosity can be directly connected with the folding process and evidently increased towards the end of this.

A tectonic analysis of the mine area has revealed (p. 14) that after the formation of the NW—SE anticline and anti-clockwise rotation around an axis occurred which probably coincided with the present ore axis. In connection with this, movements have been released along a series of small faults roughly parallel with the surface of unconformity beneath the conglomerate zone, which towards NW approaches the slate contact above the conglomerate zone, forming a small angle with the slate. During these movements a series of blocks was driven up, one over the other, and the conglomerate zone was brecciated around the fault planes. Simultaneously, the dragfold at the Outer Lake Ore was formed. During a decrease of pressure and a small movement in the opposite direction (clockwise) the fractured and brecciated zones were opened up and the ore solutions were able to penetrate. The ore formation then proceeded, the movement still being clockwise.

The deposition of the Inner Lake Ores is explained by several co-operating tectonic factors. The ore-bearing conglomerate zone lies between two rock complexes of widely differing competence, the older series containing brittle quartz-porphyry and the younger slate series of ductile rocks. By virtue of their exposed position during the folding the easily crushable conglomerates were especially strongly tectonized through fissure-forming and brecciating, and particularly so just in this place on account of the underlying, uneven old land surface with its considerable rise to the NW, which causes the conglomerate to peter out in this direction (comp. p. 15). The crushed conglomerate must have been easily permeable to the solutions, while the slates on the side of the hanging-wall, being compact, were practically impermeable as was also, to a certain degree, the porphyry of the footwall. The permeable, crushed zone is thus well limited to the thinnest edge of the wedge, which is made up of acid conglomerates and sandstones, since it is surrounded by rocks which offer difficulties for permeating solutions. The importance of the impounding slate which in the N nearly contacts underlying quartz-porphyry, must be especially emphasized, because together with the quartz-porphyry, the slate forms a cover, difficult to permeate, around the crushed zone, which pitches 45° NNW and leaves only the SE side open. The crushing here seems to be less, however and the conglomerate more difficult to permeate. The upper part of the crushed zone with accompanying ores was situated above the present earth surface. Over it, however, the slate of the hanging wall must have arched itself and formed the upper anticlinal part. Here, too, the slate must have impounded the ore solutions and it is probable that the ores petered out against the slate.

The metamorphism and its relation to the ore formation.

The rocks in and around the ores are as mentioned before (p. 12) altered in varying degrees. Sericite, chlorite, and calcite are the minerals formed by this alteration, which is unusually weak compared with the alteration of other sulphide deposits in the Skellefte District. To some degree this may be explained by the fact that the original rocks were very acid and could not contribute much material to conversions and by the fact that the shearing movements during the metamorphism were not as intense as in the other areas. Fragments of sericite-chlorite quartzite within the sulphide ore show that the metamorphism occurred to a large extent before the general ore deposition took place, and that during the deposition the altered rocks were partly broken up and replaced. The metamorphism with its formation of sericite and chlorite has required an addition of K_2O, MgO, and Al_2O_3, while SiO_2, Na_2O, and probably CaO must have been carried away. To a certain degree, Tab. 2 is an illustration of this fact and col. A shows the composition of a fresh quartz-porphyry and col. C of sericite quartzite. The original material for the rock in col. C, however, seems probably to have been a calcareous weathering product of A. Sericite quartzite of a similar character, however, is also found outside the weathering breccia as well as in conglomerate and sandstone horizons.

The mineralization.

During the ore formation itself, which must be regarded as a direct continuation of the process of metamorphism as described above, there has been an addition of S, Fe, Zn, As, Pb, Cu, and smaller amounts of other elements (see Tab. 3).

The ore solutions penetrated by way of the existing tectonic structures but also replaced the wall-rock, consisting mostly of conglomerate, but in some cases of sandstone, weathering breccia (D-lens), or quartz-porphyry (C-lens). In the case of the conglomerate, the matrix was quite easily replaced, whereas the quartz-porphyry pebbles resisted the attack to a remarkable degree. (See fig. 8.)

Judging from conditions in the neighbourhood of the mine the matrix of the conglomerates was rich in lime. This seems to have been a contributive cause to the fact that the matrix was replaced more easily than the acid pebbles, but this is also due to the greater porosity and lesser strength of the matrix, which allowed fissures to be formed more easily there than in the pebbles.

At the replacement of gangue minerals during the ore deposition a loss especially of SiO_2 and CaO but also of Al_2O_3, K_2O and MgO must have oc-

Fig. 13. Pyrite ore with schlieren (light coloured) of sphalerite, chalcopyrite and pyrrhotite. The dark minerals between the pyrite grains are quartz, calcite and sericite. Scale 13 : 1.

curred. Intensive sericite-chlorite-formations around certain parts of the ore, e. g. the E-ore, may have taken place due to re-arrangements, when the gangue minerals were replaced.

The ore mineral first to crystallize seems to have been arsenopyrite. The arsenopyrite forms schlieren of varying size in the ore bodies and sometimes

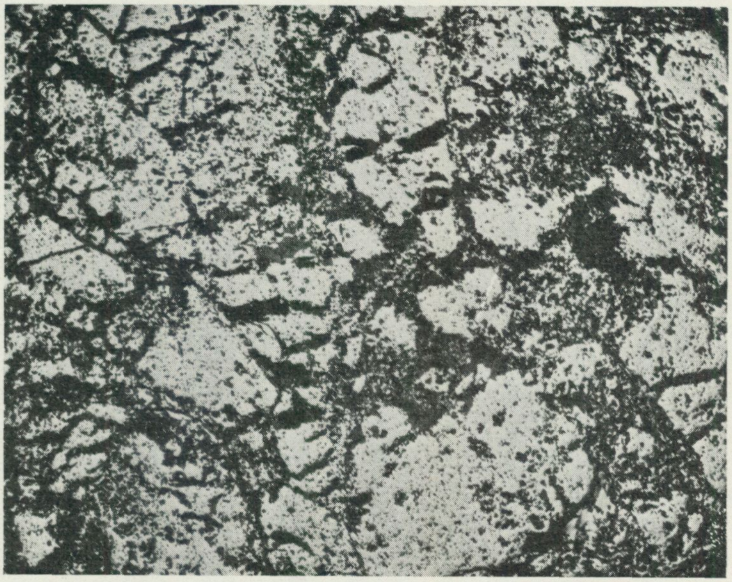

Fig. 14. Pyrite ore with breccia texture. Some quartz and chlorite between the pyrite grains. Scale 13 : 1.

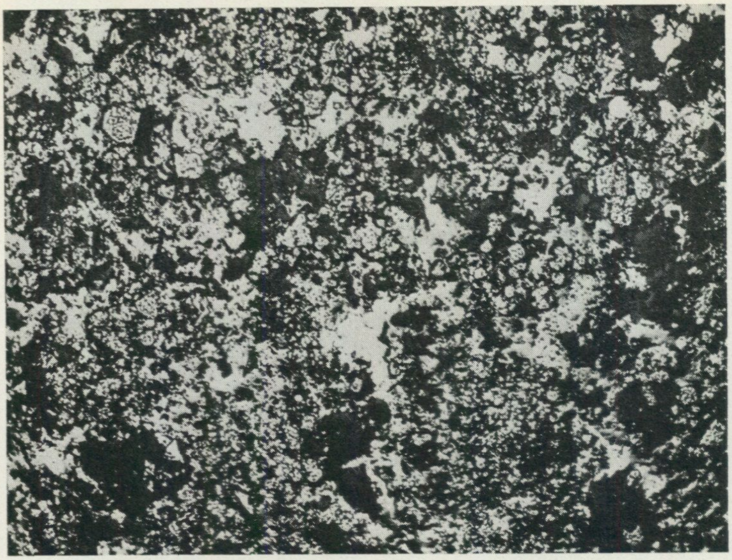

Fig. 15. Complex ore with pyrite as more or less rounded crystals $\leqslant$ 0,5 mm in a matrix of sphalerite and pyrrhotite (white), quartz and sericite (dark). Scale 13 : 1.

in richly sulphide-impregnated wall-rock. The schlieren commonly consist of very fine-grained arsenopyrite, forming idiomorphic crystals about 0.02 mm in size. Since the arsenopyrite constantly occurs in schlieren in which it follows the schistosity of the rock, it is probable that it crystallized at an early stage and probably earlier than the pyrite, which impregnates the sericite and chlorite quartzites throughout. Schlieren of arsenopyrite are often found wholly surrounded by pyritic masses, which, judging from the structures in polished samples, crystallized later.

The pyrite, which is the dominating ore mineral, began to crystallize in order after the arsenopyrite, but the crystallization seems to have taken some length of time. The grain size of the pyrite varies from 10 mm to a size hardly detectable under the microscope. In general, the fine-grained type — which forms a more or less compact ore — seems to be the oldest formation, while the coarse-grained type is later.

In the E-ore group there is an ore-body possessing a gritty structure and occasional small felsite pebbles, showing that the sulphide has replaced a gritty conglomerate. The sulphide ore itself also has a gritty structure with globules of dense pyrite ore 1 cm or less in size, lying in a coarser mass of quartz, chlorite sericite and pyrrhotite, sphalerite and sulpho-minerals. Here the pure, dense pyrite ore was formed first. — Arsenopyrite does not occur here and so the age relation cannot be determined in this ore-body. — The fine-grained pyrite ore was subsequently broken up during the movements which continued throughout the ore formation, fragments were rounded and were then partly resorbed in later sulphide solutions richer in zinc.

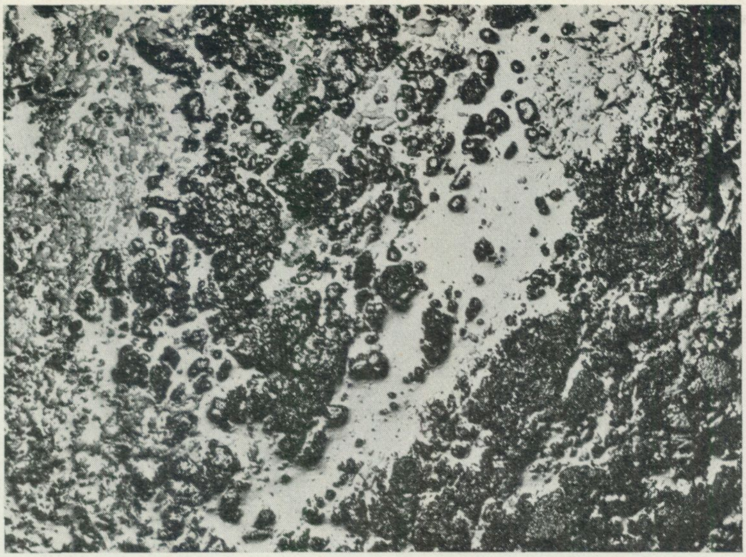

Fig. 16. Complex ore. Pyrite (high relief) as partly replaced grains in sphalerite (grey), pyrrhotite (light grey e. g. in the NE corner of the fig.) and chalcopyrite (white). Some boulangerite occurs together with chalcopyrite in zinc-rich parts. Scale 13 : 1.

The pyrite, which in the main section of the ores is well crystallized but fine-grained, has been more or less replaced by the sphalerite, pyrrhotite, chalcopyrite, and sulpho-minerals which crystallized later (fig. 13, 15, 16, 17). These minerals occur in crystals of about the same size as the pyrite and form,

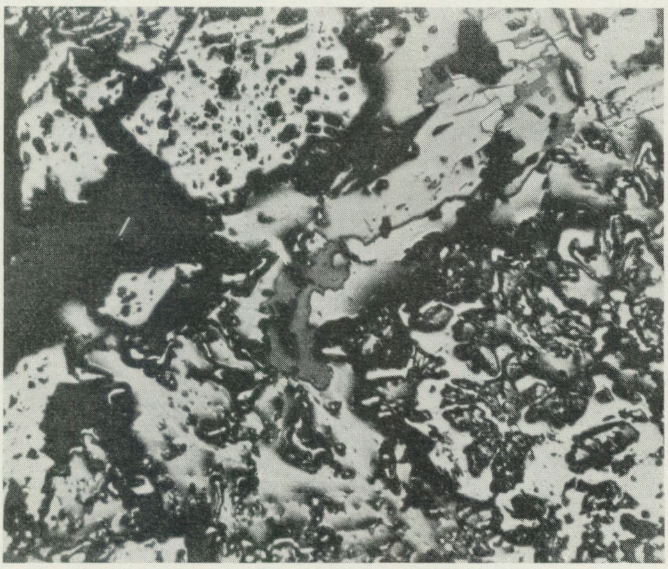

Fig. 17. Complex ore. Pyrite crystals in a mass of quartz (dark), sphalerite (dark grey), pyrrhotite (grey) and chalcopyrite (light grey) the latter replacing the pyrite. Scale 72 : 1.

together with the gangue minerals, a groundmass to the pyrite grains. They often lie in schlieren and nearly always together. This schlieren structure, parallel with the schistosity of the replaced rock, is found everywhere. In the exposed sections through the ores we thus find bands of almost pure pyrite, alternating with others rich in sphalerite, pyrrhotite, chalcopyrite and sometimes sulpho-minerals. On a smaller scale a similar structure is noticeable under the microscope. The bands of sulpho-minerals contain, in dominating quantity, boulangerite, commonly accompanied by jamesonite, bournonite, tetrahedrite, and galena. The boulangerite is fibrous but not especially so pronounced. Together with the sulpho-minerals there is often some gudmundite in more or less skeleton-like crystals. Rare finds of small grains of native gold have been recorded. Some of these have a lighter colour, indicating the gold to be amalgamated with silver or mercury (compare Tab. 3, where the mercury content in the ore is 10 g/t).

The Outer Lake Ore.

On the same stratigraphical horizon as the Inner Lake Ores (investigated in the mine) but 600 m NW of these, is another ore lens, the Outer Lake Ore. This also lies under Lake Mensträsk and has been drilled in wintertime from the ice.

The rock series around the ore is about the same as in the mine, the few dissimilarities being explainable as variations in facies and petering out of the layers. The rocks have been altered into sericite and chlorite to the same low degree as in the mine. In general, the ore consists of a compact sulphide ore-body, in the western part branching into small ore bands and attaining the character of an impregnation. The ore-body is 90 m long and maximum 14 m wide and peters out downwards. It lies beneath a steeply dipping weak fold in the sedimentary beds, which structure has apparently offered a favourable side for the deposition of the ore. (Cf. p. 16.)

The mineral composition of the ore is about the same as in the ores of the mine but chalcopyrite and arsenopyrite occur a little more plentifully while the content of sphalerite is lower. Several schlieren within the ore are enriched in arsenopyrite. It is very fine-grained and sometimes occurs as dense masses. Gold values occurring in the ore are usually connected with the parts rich in arsenopyrite.

The pyrite has a grain size of about 0.05 mm and is more or less replaced by pyrrhotite, sphalerite, and chalcopyrite, sometimes in the shape of a network.

T. Du Rietz, who investigated the ore microscopically for possibilities of flotation, found that besides the minerals mentioned above, bournonite, jamesonite, tetrahedrite, galena, gudmundite, and possibly glaucodote were present.

300 m W of the Outer Lake Ore there is a small ore lens, situated in a part of the sediments which is probably very strongly isoclinally folded and stratigraphically a little higher up than the Outer Lake Ore. The ore principally consists of pyrite, which in a sponge-like way replaces quartz and other gangue minerals. The pyrite in its turn is replaced by pyrrhotite. The sphalerite, occurring abundantly, forms large grains containing many inclusions of idiomorphic pyrite crystals and grains of pyrrhotite in varying forms. Sometimes the sphalerite grains contain a network of later pyrite.

The Rundklumpen Ore.

200 m S of the E-ore zone of the Inner Lake Ore and about parallel with this, a small ore-body occurs beneath the lake, called Rundklumpen. It has the same stratigraphical position as the ores found in the mine, but it lies in the S flank of an anticline, whereas the former are situated in its N flank. The Rundklumpen Ore is known only from two drill-holes, drilled from the ice of the lake.

The wall-rock of the ore is somewhat limy and shows the same weak sericite-chlorite alteration as in the mine area. The ore is of the same character but contains slightly lower percentages. Pyrite is the dominating ore mineral, but there is plenty of pyrrhotite besides. Sphalerite occurs also, besides small amounts of chalcopyrite, arsenopyrite, and sulpho-minerals.

The Lomviken Ore.

About 2 km SE of the Mensträsk mine and arranged around the eastern shore of Lake Mensträsk there are three ores. The Lomviken Ore is situated on the same N flank of the anticline as the Lake Ores, while the Rågången and Långviken Ores, in common with the Rundklumpen Ore, lie in the S flank of the same anticline. (Cf. map fig. 1.) These ores have only been exposed by drillings.

The Lomviken Ore has only been examined by means of two drillholes. It has a maximum breadth of about 5 m and consists of pyrrhotite, blended with pyrite, sphalerite, chalcopyrite, arsenopyrite, and some galena. The arsenopyrite shows very distinct replacement structures forming networks and is replaced by chalcopyrite. The ore has a parallel structure with the same orientation as the schistosity of the wall-rock and has bands alternately richer and poorer in ore minerals. There are thus some sections which are rich in chalcopyrite while the percentage of the other sulphide minerals is relatively low. The grain size of the sulphide minerals is about 1 mm.

The sandy and conglomeratic rocks around the ore are only slightly altered into chlorite-sericite.

The Rågången Ore.

The Rågången Ore is situated under Lake Mensträsk and is exposed only in two diamond drill-holes. The ore, which is fairly narrow, lies in conglomerate or breccia which it has replaced to a great extent, whereas the wall-rock is very little altered.

The ore consists for the most part of pyrrhotite, occurring in sponge-like grains which have replaced quartz and other gangue minerals. In the pyrrhotite there are small pyrite grains more or less replaced by pyrrhotite. The chalcopyrite occurs unevenly distributed in the ore but is sometimes plentiful. The sphalerite, which is sparse in occurrence, contains small inclusions of chalcopyrite.

The Långviken Ore.

The Långviken Ore is the largest ore in the group around the eastern shore of Lake Mensträsk. It is known from four drill-holes, three of which cut the ore at a depth of 20—30 m and one at 60 m. The ore is maximum 7.5 m wide and consists chiefly of pyrite replaced by abundant pyrrhotite, often banded. There is plenty of chalcopyrite together with pyrrhotite, while sphalerite and arsenopyrite are found only in small amounts. The grain size of the ore minerals is about 0.5 mm. Schlieren of calcite often occur in the ore. The wall-rock, consisting of gritty and conglomeratic sediments, evinces only slight alteration into chlorite and sericite.

Comparison with Other Deposits in the Skellefte District.

Elvaberget.

At Elvaberget 4 km S of the Mensträsk mine and immediately S of the Malå River there is a sulphide deposit, discovered in 1944. It consists of an ore-body 300 m long and maximum 9 m wide, the dominating mineral being pyrite, besides which sphalerite, chalcopyrite and accessory arsenopyrite and galena are present. The chalcopyrite is especially enriched along a zone in the middle part of the ore, where the percentage of zinc is lower than in the remaining parts. The ore is fine-grained.

In the direction of strike 100 m NW of the main ore there is a small disseminated ore-body with chalcopyrite as the dominating ore mineral.

The ore-bodies are situated in the same stratigraphical position as the Mensträsk ores. Its foot-wall is composed of a felsitic quartz-porphyry with a calcareous weathering breccia and conglomerate, while sediments belonging to the upper slate series form the hanging wall. G. Kautsky's stratigraphical scheme for the Mensträsk Area (p. 7) is to a large extent based on a section through Elvaberget. The strike of the ore-bearing area is NW—SE and the dip 65° SW.

The compact sulphide ore and the small disseminated copper ore are very similar to the Mensträsk ores in both composition and texture, the percentages of zinc, lead, and arsenic, however, being lower. The wall-rock, however, shows some dissimilarities, as regards metamorphism. Thus in Elvaberget an association of high-temperature minerals is more frequently found than in Mensträsk, biotite appearing richly in association with chlorite. The original sedimentary structures of the wall-rock are also far less well preserved than in Mensträsk and the schistosity in connection with the formation of sericite, chlorite, and biotite was more intense. Elvaberget lies within Gavelin's transitional zone between chlorite and biotite facies (3 p. 52).

Rakkejaur.

Rakkejaur, the largest area of ore in the Skellefte District (comp. 12, p. 89), is situated 12 km NW of the Mensträsk mine. The ore body, which is 550 m long and maximum 65 m wide, is known from outcrops, diamond drillings from the surface, a stope on the 10 m level, drifts into the ore on the 160, 240 and 320 m levels, and from a net of horizontal drill holes from these drifts. The underground investigation of the ore was performed during the years 1939—42, when the geological mapping of drifts and drill-cores was carried out by me.

The Rakkejaur ore appears in the same geological position as the Mensträsk ores (fig. 18). The foot-wall in the W consists of quartz-porphyry or its

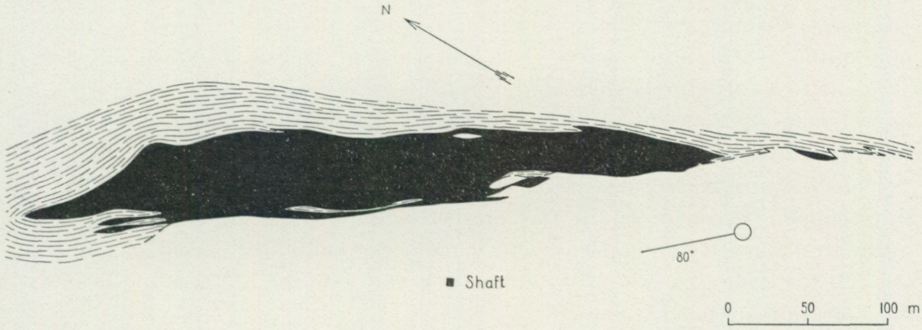

Fig. 18. The Rakkejaur ore. Scale 1 : 4800. The ore is shown black and the slates by striations. The ore pitches at 80° NW.

tuffaceous equivalent altered to sericite schist and more or less schistose. A calcareous weathering breccia and a polymict conglomerate, with occasional granite pebbles, follow next in order in the upper part of the mine. These beds with coarse clastic rocks peter out in a downward direction. Above these beds on the 240 m level partly in direct contact with the quartz-porphyritic sericite schist banded slates occur, at the bottom consisting af alternating calcareous and quartzitic layers but further up in the stratigraphical column showing a greater dominance of black slate, rich in graphite. The strike is NNW, the dip vertical and the pitch of the ore about 80° NNW. The great fold axis along which the sediments were folded is flat however, as is the case throughout the Mensträsk-Rakkejaur area. In the wall-rock of the ore there is a linear structure with direction about 80° NNW, and fragments of quartzite in the pyrite ore are elongated in the same direction.

The southern part of the ore lies in coarse sediments, quartzite and slate and has to a great extent replaced these rocks. The slate contact runs roughly through the centre of the ore. In the N part, the slate forms a dragfold along the direction of pitch and patches of slate go down on the W side of the ore and also W of the northern part of the ore. However, these patches may consist to some degree of slaty intercalations in the coarse sediments. Besides in the abovementioned steep linear structure, the folding — which originated from an anti-clockwise movement — can also be traced in the shape of small S shaped drag-folds in quartzite slices within the pyrite ore, scratches on schistosity planes, and in large-scale differential movements along small fault planes lying close to one another and about perpendicular to the schistosity of the well-banded slates N of the ore and immediately N of a strong crushing zone just N of the ore on the 240 m level.

As mentioned above, the coarse sediments thin out in a downward direction and the weathering breccia is lacking at least in the S part of the ore-bearing area on the 240 m level. Immediately S of the ore on this level the quartz-porphyritic sericite quartzite is in contact with the slate series. The lack of weathering breccia and coarse sediments here indicates that this part represented a hill on the old quartz-porphyry land surface and that material was washed down from this to lower parts where the coarse clastic sediments, now found on the upper levels of the mine, were deposited. Neither here nor at Mensträsk, where the old land surface has a similar morphology (p. 12), have I found tectonic features to explain the uneven distribution of the coarse sediments and the weathering breccia.

The large ore-body consists of a lean pyrite ore with varying contents of zinc, copper, and arsenic. In this ore-body there are some lenses of arsenopyrite and some with copper ore. In general the boundary between the pyrite ore and the wall-rock is sharp, but towards the SSE the ore fans out or grades into an impregnated variety.

The arsenopyrite ore is always fine-grained or dense and is thus similar to the arsenopyrite of Boliden (17). The arsenopyrite lenses are quite extensive on the surface but peter out as the depth increases and on deeper levels only small schlieren are found, which always follow the schistosity or bedding planes. From the study of large structures in the mine as well as the microscopic examination of polished samples I have been able to establish that the arsenopyrite ore is the oldest ore formation in Rakkejaur. The large arsenopyrite lenses as well as the smaller schlieren are usually entirely surrounded by pyrite ore, which often brecciates the arsenopyrite. Sharp-edged or slightly rounded fragments of arsenopyrite are often found enclosed in the pyrite ore.

As mentioned before, the main part of the ore consists of pyrite, which is seldom compact, however, and contains considerable amounts of material from the bedrock. With the exception of the dominating pyrite there are varying amounts of sphalerite, some arsenopyrite (about 1 %), and insignificant amounts of galena, etc., all mainly enriched in schlieren. Sometimes the dense pyrite ore contains a fine impregnation of chalcopyrite, and small amounts of pyrrhotite may also occur. Compact pyrrhotite is found in a 1 m wide zone on the N boundary of the ore. The ore brecciates and replaces especially the coarse clastic rocks, the weathering breccia and the conglomerates, but also quartzites and slates, and particularly the alkaline and argillaceous minerals seem to have been replaced so that the bedrocks of the ore are very rich in quartz. Structures in the bedrock inclusions in the ore show that the mineralization during the pyrite stage occurred during or after the formation of the steeply dipping dragfold during an anti-clockwise movement. The dragfold, with the dense and ductile slate sweeping around the norther part of the ore and bounding the ore in this direction, must in the main have been formed before the pyrite ore, as its impounding effect has evidently been of the greatest importance in the concentration of the sulphides. The ore-bearing solutions must have found easily accessible channels for permeation through the crush-zone which was formed during the folding of the coarse clastic and the acid and brittle sediments in the inner part of the drag-fold. The heterogeneity of the sedimentary series, caused by the hill on the old porphyry land surface was certainly of great importance at the time of folding as it favoured the formation of passages for the solutions.

The copper ore represents the third stage of the ore formation and appears as irregular patches, somewhat elongated in the direction NW—SE and vertically fairly persistent. Within the area the pyrite ore along with the included remnants of the bedrock, is brecciated and cemented with chalcopyrite and pyrite. Furthermore, the copper ore sometimes contains pyrrhotite and small amounts of sphalerite, arsenopyrite (of about the same amount as in the pyrite ore) and tetrahedrite. The elongation of the copper ore at an acute angle to the strike indicates that here the brecciation occurred under continued anticlockwise movement as a result of which the gash vein structures were formed and the solution, rich in copper, was able to penetrate and deposite ore. The pyrite ore must have been well consolidated since the pyrite as well as the enclosed fragments of quartzite often have sharp edges in all directions with the cementing chalcopyrite. The appearance of the pyrite ore is quite different, with its gently shaped slices of quartzite. Relict pieces of slate often contain impregnations of pyrite and pyrrhotite but never of chalcopyrite, which has very little power to penetrate material that has not previously been broken up.

A fourth stage of mineralization builds the abundant carbonate veins-which often contain sulpho-minerals. The carbonate minerals consist of calcite and dolomite and they are often quite dark. The ore minerals are chalcopyrite and sulpho-minerals such as falkmanite and tetrahedrite. Particularly in the case of the copper ore, the veins are orientated at random while in the case of the pyrite ore they lie mostly parallel to the schistosity and often occur in the contact with the bedrock. The sulpho-minerals are often found in such contact zones.

The wall-rock of the ore, especially on the porphyritic and conglomeratic W side, is sericitized to varying degrees mostly to sericite-schists but sometimes to a sericitic rock. Inferior amounts of chlorite follow the sericite. Biotite and amphibole have never been observed.

The similarities between the Mensträsk and the Rakkejaur ores are both striking and numerous. They are situated on the same stratigraphic horizon along steep tectonic structures in an area which is otherwise gently folded. In both cases the ores occur in connection with hills on the old porphyry or felsite land surface. The alteration of the wall-rock is of the same weak, low-temperature type. The arsenopyrite ore was the first ore to be formed and was followed by extensive pyrite mineralization in rocks mainly consisting of psefitic sediments which were loosened by shearing and brecciation. The pyrite ore accompanied by sphalerite and pyrrhotite replaced the brecciated bedrock leaving fragments, enriched in silica, floating in the ore. The chalcopyrite at Mensträsk, where it appears in the pyrite ore, was formed later and particularly the disseminated copper ore of Mensträsk seems to be equivalent to the copper ores at Rakkejaur. — Finally, in both ores there occur veins with dark-coloured carbonate partly containing lead and antimony minerals besides iron and copper sulphides.

Ores of the Malånäs District.

The Malånäs District with many ore deposits lies SE of the Mensträsk area and was investigated and described in detail by S. Gavelin (3). The NW part of Gavelin's map area forms a direct continuation of the Mensträsk Area and the two are geologically similar. The SE part, however, is geologically different and has different tectonic features. It is bounded from the former by a sharp tectonic line which seems to mark an overthrust plane. The whole supercrustal series is intensely folded and the folds are overturned towards the N. The S part of the district is occupied by the lobe-like massive of the Revsund granite and around this Gavelin has found a pronounced metamorphic zoning in the supercrustal series. The compact ores of the Malånäs District consist of pyrite, pyrrhotite with varying amounts of chalcopyrite, sphalerite, galena, and arsenopyrite. Generally these ores have coarser textures than the Mensträsk ores and the alteration of the wall-rock is usually stronger although, in general, the alteration minerals are sericite and chlorite. High-temperature minerals, such as cordierite, andalusite, staurolite, and garnet, however, occur principally in the eastern part of the district.

Like the Mensträsk ores, most of the Malånäs ores are replacement ores (Bjurliden and Bjurträsk), whereas the zinc-rich Ö. Högkulla ore and, to a certain degree, E. Bjurfors were formed by "displacement". In general, the compact sulphide bodies are connected with areas which during the tectonic movements attained linear structures (B-tectonites), while in areas with pronounced schistosity (S-tectonites) there are usually found only more or less dispersed impregnation zones. This is also in agreement with conditions in the Mensträsk Area, where the larger ore concentrations, such as the Lake Ores, appear in connection with B-tectonites and the less important ones occur in shearing zones with S-tectonites.

The Bjurträsk ore in the E part of the Malånäs District lies in an S-folded area with a fold axis dipping 40° WSW. It does not, however, lie in the zone between slates and brittle rocks as at Mensträsk, but along the intersection between a bedding and schistosity or between two directions of schistosity (4).

The highest temperature ores lie in the E, while the thermal influence to the NW, in the displacement ore Ö. Högkulla, is considerably lower. The presence of garnet in the sericite-chlorite altered wall-rock at Ö. Högkulla, indicates, however, a higher grade of metamorphism than at Mensträsk. Although the sulphide mineralization is later than the regional metamorphism, Gavelin has found a distinct connection between the degree of metamorphism and ore formation and considers it probable that the ore solutions emanated from the same magmatic source as the Revsund granite.

In the Malånäs ores Gavelin found a continual transition from pyrite-pyrrhotite ore to ore types rich partly in copper and partly in zinc. Transitional forms between copper and zinc ore are, on the other hand, quite subordinate. A third group, arsenopyrite ore, plays a very small part quantitatively. — A division into similar differentiates is found also in the Mensträsk area. Schlieren of arsenopyrite belong to an early ore-forming stage but are quantitatively of little importance. Pyrite-copper ore or pyrite-zinc ore also occurs, but transitional forms are sparse.

Boliden.

The Boliden ore consists of two lenses of compact sulphide ore lying en échelon in an area of alteration which rapidly increases in size downwards. The ore lies in about the same stratigraphical position as the Mensträsk ores. Relict structures as well as the composition of the strongly altered rocks indicate that the foot-wall originally was quartz-porphyry and was succeeded above by coarse clastic sediments or agglomerates and dacitic lava or tuffs. A quite well preserved keratophyre occurs next and then the phyllite series. The phyllite forms a pronounced dragfold around the E end of the ore, the pitch of which is about 55° E and coincides with the axis of the dragfold.

Ödman (17) has found that the alterations occurred during three stages of the formation: first quartz-sericite schists, then the sericite rock, and finally — at the expense of these rocks — andalusite rock. During the following ore deposition, which occurred in three stages, the alteration seems to have continued. During the first ore-mineralization stage a compact arsenopyrite ore with certain other mineral associations were formed by "displacement". The following stage was initiated by the intrusion of lamprophyre and continued with a penetration of pneumotectic ore solutions, forming the rich mineral association of the quartz-tourmaline ore. The last stage is characterized by pyrite ore, forming the large main mass of the Boliden ore and surrounding the arsenopyrite lenses and to a large extent the quartz-tourmaline ore. Also the pyrite ore is considered by Ödman to be a "displacement" ore.

The Boliden ore differs from the Mensträsk ores in many ways. There are, however, several similarities, such as the stratigraphical and tectonic appearance, the sericitization before the ore formation, the formation of the arsenopyrite ore first and the pyrite ore later. On the other hand, the quartz-tourmaline stage is lacking at Mensträsk, the alterations are insignificant compared with those at Boliden, and the number of ore minerals is fairly small.

Kristineberg.

The Kristineberg mine, which at present has the largest output in the Skellefte District (about $^1/_2$ million tons a year), is situated in the western part of the district in an anticlinal area which also comprises another group of ores, including Rävliden and Rävlidmyran. The following summary is founded partly on a description of the mine by T. Du Rietz (2) and partly on my own observations of the tectonics and of the ore formation made during the last few years when I directed the geological surveys in the mine.

The Kristineberg deposit consists of a group of sulphide lenses distributed along two roughly parallel zones. These rest in the inner part of a large anticlinal which arches over a core of older granite (Jörn granite). A westerly offshoot of the granite lies just N of the ore-bearing area. The supracrustal rocks, against which the granite exhibits a clear cooling contact well exposed on the lowest levels in the mine, form deep stratigraphic layers far below the phyllite series. Throughout the whole area these are much altered and Du Rietz has shown how the degree of metamorphism strongly increases towards the Revsund granite in the S.

The ore bodies at Kristineberg lie in sericite and chlorite schists. The proportion between sericite and chlorite is very variable but usually the chlorite is most plentiful within and around the ores. The hanging-wall of the ores is rich in talc, developed as talc-chlorite rock, especially in the northern so-called A-ore zone.

The strike of the ores is about E—W with a dip of about 60° S and the pitch 40° S 60° W. Fig. 19 is a sketch map of the ores on the 170 m level. The ore bodies consist of pyrite with varying amounts of sphalerite and chalcopyrite as well as some accessory ore minerals. All transitions from compact sulphide ore via impregnations to almost barren rock exist.

It is possible to distinguish several different ore types and by studying the structures in the wallrock beneath the ores and relict parts within the ore, I have found that the ore deposition in general occurred in connection with three tectonic movements. The quartz-tourmaline veins which occur plenti-

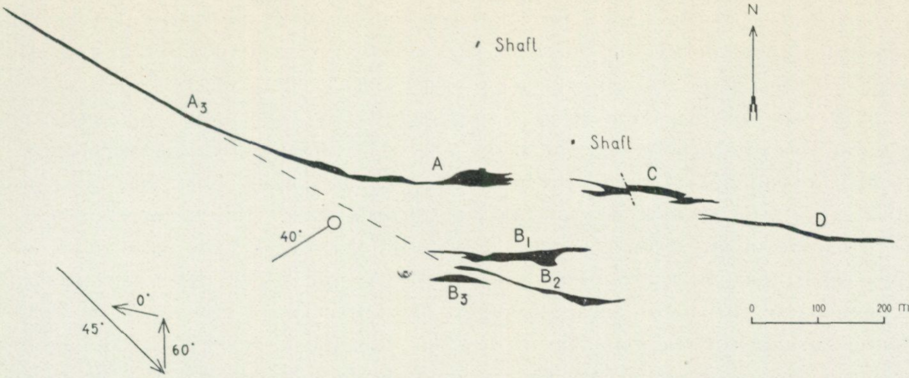

Fig. 19. The Kristineberg ores at 170 m level. Ores are shown in black. The dotted line indicates the principal sheare zone. A small dotted line at C marks a fault. The ore pitches 40° SW. The arrows in the lower, left corner indicate the tectonic movements of the southern block relative to the northern block. The first movement was 45° downwards in the direction of the arrow, the second one 60° upwards and the final movement was horisontal. Scale 1 : 11400.

fully in the mine are considered by Du Rietz to be older than the ore formation and to lie along Mohrs' planes around the pitch-direction of the ores. The veins, which do not contain sulphide minerals but scheelite, are equivalent to the second ore-formation stage at Boliden (17). During the first ore-forming stage, when the quantitatively predominant pyrite ore was deposited, the pitch direction of the ores was the axis of the movement, which is also registered in the shape of rotation structures in the ores and in their footwall. In a great many places and on various levels in the mine and at the A-ores as well as the B-ores the same direction of movement has been found; it shows that the S-block moved in a direction 45° downwards towards SE. It is evident that the dominating sulphide mineralization occurred in connection with this movement when, under the influence of decreasing stress and shearing movements, channels were opened for the solutions. The movement was most pronounced along two lines, the A_3—A-ore zone and the A_3—B_2-zone (cf. map fig. 19). Du Rietz has shown how the real sulphide mineralization was preceded by an intense magnesia metasomatism, which spread out chiefly from the above-mentioned lines, causing an extensive sericite, biotite and chlorite alteration. The metasomatism continued during the ore formation and to some extent after it. Zones with mica-rich, schistose rocks, formed during the metamorphism, were opened by release of the stress and or-bearing solutions penetrated. As a result of this, the sulphide minerals crystallized in the chlorite schists which were replaced in part by the sulphides. The dense, almost non-permeable hanging-walls impounded and collected the penetrating solutions. The largest ore deposition occurred where the most space was provided during the movement, in the A-ore area. Through the bending of the shearing plane towards the E, space must have been provided by movement along the A_3—B_2 zones, e. g. in about ESE, which space was filled with ore solutions (cf. fig. 19).

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

A second ore-formation stage is represented by the copper ore occurring around the pyrite bodies in the B-ore area. The chalcopyrite is especially enriched around quartz nodules where roll structures along horizontal axes indicate that the S-block was pushed up towards the N. The same movement is registered in soft folds in pyritic chlorite schists in the A-ore zone and in an over-thrust part of the hanging wall of the A_3 ore, which cuts off a steeper schistosity in the ore at an acute angle. This direction of movement has been found throughout the mine, even down to the 490 m level. The copper ore shows a clear connection with the compact sulphide bodies, but it is also connected with the stress directed towards the N. If the chalcopyrite which was the last mineral to crystallize in the pyrite ore, was not completely crystallized when the compression and the N stress began, the copper-rich solutions must have been squeezed out of the crystal mesh and flooded to places with less stress, e. g. fissures and the surrounding hard quartz nodules.

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

The Kristineberg and the Mensträsk ores, although quite different, have some interesting similarities. Thus the main ore bodies of the two deposits (the pyrite ore stage at Kristineberg) have a similar mineral composition and the same is true of the disseminated ores. Impounding beds have in both cases played a large part in the concentration of the ore. At Kristineberg, however, these were schists formed during metamorphism before the ore formation proper, while at Mensträsk they consist of slate and quartz-porphyry.

The position of the ores in steep anticlinal limbs with shearing structures, and their fairly steep pitch directions are also characters common to the two deposits. Among the dissimilarities between the deposits the following should be mentioned: apart from the different sizes of the deposits, the Kristineberg ores seem stratigraphically to lie considerably lower than the Mensträsk ores and the pitch follows the main fold axis of the Kristineberg area while the Mensträsk ore follows a secondary axis. Furthermore, Kristineberg lies in an area of strong regional alteration which successively increases towards the Revsund granite in the S (2), while the alteration around the Mensträsk ores is of a more local nature, even if the alteration as well as the ore formation here as well as at Kristineberg must be connected with the Revsund granite and with the processes of formation. The last ore-forming stage at Kristineberg, when zinc ore appeared in dykes, is lacking at Mensträsk as it is in all other known deposits in the Skellefte District.

Summary.

The main features of the stratigraphy of the Mensträsk area are as follows: At the bottom there are pelitic, banded sediments with coarser intercalations and above them a usually felsitic quartz-porphyry. Separated from the bedrock by a great unconformity follows a weathering breccia of the quartz-porphyry and then conglomerates (and quartzitic sandstone), upwards more and more polymict and intermixed with fairly basic vulcanites. Above these psefitic and psammitic sediments lies the so-called phyllite series composed mainly of pelitic sediments. The latter is intruded by solitary sills of granite-porphyry. The volcanics and sediments are intensely folded along flat, undulating fold-axes in a style similar to the Jurassic folding in Switzerland (11). The folding is connected with the second phase of folding in the Skellefte District during which the Revsund granite was formed. A central part of the map area, Fig. 1, is isoclinally folded and forms an anticline in the direction NW—SE. The pitch of the ores in the mine area is 45° NNW, i. e. steeper than the main fold-axis, and was formed during shearing with a movement of NE-blocks obliquely upwards as compared with SW-blocks. During this movement the conglomerate zone was brecciated and compressed along shear and fault planes at an acute angle to the overlying slate (Fig. 3, pl. 1, 2, 3). At the same time, a dragfold was formed at the Outer Lake Ore. The ore formation then occurred in the broken up zones in connection with release of stress and movement in the opposite direction.

The sulphide ore lenses in the area lie in the conglomerate zone and in its bedrock. All the ore lenses are found in steeply dipping limbs of isoclinal folds. Impounding beds played a large part in the trapping of ore-bearing solutions, from which ore minerals then crystallized in opened zones.

The compact ore lenses consist dominantly of pyrite besides varying amounts of pyrrhotite, sphalerite, chalcopyrite, and occasionally galena, tetrahedrite, arsenopyrite, boulangerite, etc. These ores sometimes peter out into impregnations, especially in the direction of strike. Some small impregnation ores consist of chalcopyrite and pyrite in about the same proportions. During the ore formation the wall-rock was partly replaced.

A weak sericite-chlorite alteration follows the ores and is partly older than these. Metamorphism has resulted in an addition of K_2O, MgO and Al_2O_3, while SiO_2, Na_2O and possibly CaO have been removed.

Four ore-forming stages can be distinguished in the Inner Lake Ores mine, causing the formation of the following ore types:

1. Arsenopyrite ore in smaller schlieren.

2. Pyrite ore with varying amounts of pyrrhotite, sphalerite, and chalcopyrite and constituting the quantitatively predominant part of the ore.

3. Chalcopyrite impregnation ore, probably younger than the pyrite stage and possibly formed from solutions rich in copper which were squeezed out from the pyrite ore during its crystallization.

4. Calcite and quartz veins with Pb—Sb—As minerals and other sulphides (ore pegmatites).

The other ores in the Mensträsk area in general correspond to the pyrite stage of the Inner Lake Ores.

The tectonics which are connected with the ore formation in Mensträsk belong to the folding of the Skellefte District during which the formation of the Revsund granite took place. This speaks in favour of a connection between the ore and the Revsund granite, which in other parts of the district has proved to be the source of the mineralization.

The ores at Elvaberget 4 km S of the Mensträsk mine, are very similar to the Mensträsk ores both in composition and structure. The main lens consists of pyrite ore with zinc and copper values underlain by a small copper ore of impregnation type. The ores thus have the same stratigraphical position as at Mensträsk and occur in a steeply dipping limb of a fold along a flat fold-axis. The wall-rock, however, is more intensely altered.

The Rakkejaur ore, situated 12 km NW of the Mensträsk mine, also appears in the same geological milieu, i. e. in the conglomerate zone which lies disconformably upon a quartz-porphyry and which in its turn is overlain by the slate series. As at Mensträsk, there are structures indicating that the old porphyry land surface was hilly and that the mine area contains an old hill. The rock layers are folded along a flat fold-axis and dip vertically. During the formation of a dragfold along a secondary axis dipping about 80° NNW — by movement towards the north of E-blocks in relation to W-blocks — especially the conglomerate zone was crushed. Here the ore was subsequently deposited and partly replaced the wall-rock.

The same ore-forming stages can be distinguished as at Mensträsk:

1. Lenses of arsenopyrite which peter out downwards.

2. Pyrite ore with varying percentages of zinc, arsenic, and copper is the predominant ore type and brecciates and replaces especially the coarse clastic rocks but also quartzites and slates. Structures in the ore show that this stage occurred in connection with the formation of the dragfold. The impounding power of the slate around the crushing zone permeable to ore solutions was evidently of great importance for the sulphide enrichment.

3. The copper ore which appears as irregular patches, though somewhat elongated in the direction NW—SE and vertically very continuous. It occurs completely enclosed in the pyrite ore, brecciating it. The brecciation occurred during a new movement in the same direction as that which formed the dragfold and after the consolidation of the ore of the pyrite stage.

4. Ore pegmatites of carbonates with sulpho-minerals and chalcopyrite.

Within the Mensträsk and Rakkejaur areas the rocks were prepared for ore deposition both through shearing and brecciation. The schistosities are generally very weakly developed, however, while the breccias play a large part. According to experience from other parts of the world (16 p. 4) schistosity structures are formed at great depths, while the rocks closer to the surface become brecciated by the corresponding movements. The tectonic structures at Mensträsk and Rakkejaur then indicate an ore formation at a relatively slight depth, a fact also suggested by the low degree of metamorphism.

The stratigraphical position of the Mensträsk and Rakkejaur ore deposits is the same as of many other deposits in the Skellefte District, e. g. Boliden, Långsele, Långdal, Åsen, Rävliden, and others. A few ore-bodies, for instance Kristineberg, have a considerably lower position and only one, Sandlidberget, is situated higher up, in the phyllite series (12, 13).

Tectonically, there are many similarities between the Mensträsk—Rakkejaur ores and many other deposits in the Skellefte District. (No comparison is here made with the ores of the Adak group, which are different in appearance and possibly in age.) (8.)

Features common to all the more important ore deposits are that they follow more or less steep shear or breccia zones, that their pitches are often steeper than those of the main fold-axes in the area, and that they are connected with linear structures or secondary fold-axes, formed by shearing movements and sometimes during the formation of dragfolds (Outer Lake Ore, Rakkejaur, Boliden).

At several ore deposits there occur dyke rocks following steeply dipping structures: greenstone at Boliden, Långsele, Åkulla, Kristineberg; granite-porphyry at Mensträsk. They indicate the persistance in depth of the fracture and shear zones.

All the ore deposits of the Skellefte District are surrounded by alteration zones but their size and degree of metamorphism varies within wide limits. Ores like the Mensträsk group where breccia, and fault structures were important at the time of the ore deposition, are surrounded by insignificant and weakly altered aureoles, while ores in pronounced shear zones, as for instance Kristineberg, have very wide alteration zones where in many cases minerals of a higher temperature than sericite and chlorite occur (andalusite, cordierite, biotite, amphiboles).

The relation of the alteration zone in a vertical direction can be well studied in the Boliden mine, and has been investigated down to about the 800 m level. The width of the alteration area at the surface is 60 m but it gradually increases and on the 570 m level it is about 200 m and on the 800 m level still wider. The compact ore-body peters out at about the 270 m level. The alteration at Boliden is generally so intense that primary structures are preserved only in certain rocks, such as quartz-porphyry and psefitic sediments or tuffs. At Mensträsk, on the other hand, the alteration has seldom obscured the primary structures so as to make them unrecognizable.

In many of the deposits of the Skellefte District it has been possible to distinguish several ore-forming stages, and generally the succession is similar. Where it was possible to determine the age relation the dense arsenopyrite ore proved to be the first to be formed (e. g. at Boliden, Malånäset, Mensträsk, Rakkejaur). At Boliden then follows the quartz-tourmaline stage with its unusual mineral association. At Kristineberg, an equivalent example, poorer in mineral, occurs. The third stage at Boliden is represented by pyrite ore, which has equivalents at most of the other deposits in the Skellefte District (Malånäset, Mensträsk, Rakkejaur, Kristineberg). The pyrite ore is generally zinc- and copper-bearing. The percentage of zinc being higher, however, the percentage of copper is lower, and vice versa. Later than the ore of the pyrite stage, at least at some deposits, is a chalcopyrite ore with varying percentages of pyrite (e. g. Rakkejaur, Kristineberg and possibly Mensträsk). This copper ore, frequently appearing as breccia, seems to have been formed from solutions squeezed out from the crystallizing pyrite ore as a result of a change of the direction of stress (Kristineberg) and deposited in newly opened structures. At Kristineberg occurs a zinc ore deposited after the copper ore and in connection with another movement direction. No equivalent to this ore is known at other deposits in the district. The latest ore-forming stage at several places is represented by "ore pegmatites", carbonate-quartz veins containing Pb—Sb—As minerals (e. g. Malånäset, Mensträsk, Rakkejaur).

The rhythm of the ore formation, the successive deposition of one ore type after the other, has been proved to be connected more or less with tectonic impulses. This is clearly discernible at Kristineberg, but also at Rakkejaur, Boliden and Malånäset, and a differentiation by squeezing of a crystallizing sulphide solution seems to be the explanation at least of the formation of the copper ore after the pyrite ore (Kristineberg, Malånäset, Rakkejaur and probably Mensträsk).

The deposits mentioned as examples may be grouped as follows with respect to increasing degree of alteration of the wall-rock and to increasing extension of the alteration areas. The ores in the upper part of the scheme are to a great extent connected with fracture and breccia structures, while shear structures dominate in the middle of the scheme and downwards become ever more important.

Mensträsk. Ö. Högkulla	↑ Increasing
Rakkejaur. Elvaberget	brecciation
Boliden. E. Malånäset	Increasing shearing
Kristineberg	↓ and alteration.

A combination of the type sections represented by the deposits in the scheme, gives the following general picture of a mineralization area in the Skellefte District and its formation.

Steeply dipping zones of fracture, at the top developed as breccias and fissures and downwards more and more intensely as shear zones, occur especially in the more or less coarse clastic sediments between the brittle, earlier folded, older series and the overlying, almost non-permeable slate series.

During pulsations in the shearing movements, which occurred in directions usually deviating less 45° from the horizontal plane, mineralizating solutions rose along the newly opened channels and reacted with and substituted the wall-rock. The zones of fracture go so deeply down that they sometimes served as channels for basic or granitic magmas. The solutions advancing through the increasingly sheared rocks seem to be connected with the formation and intrusion of the Revsund granite in the south and to emanate from a migmatite front, advancing towards the north. They are thus considered to be distillation products of the volcanics and sediments, that were granitized.

The alteration, caused by the penetrating solutions can be characterized as an alkali-magnesia metasomatism, where the alkalies seem to have reached farther than the magnesia. Only when the bedrock had been prepared by the substitution of the alkalies and magnesia of the solution did metalliferous and sulphur-bearing solutions advance through the newly formed alteration rocks, mainly sericite and chlorite schists. Under the influence of various pulsations, different fractions of the ore solutions were squeezed out. A differentiation occurred at least partly by squeezing of partially crystallized ore solution.

Boliden, August 1949.

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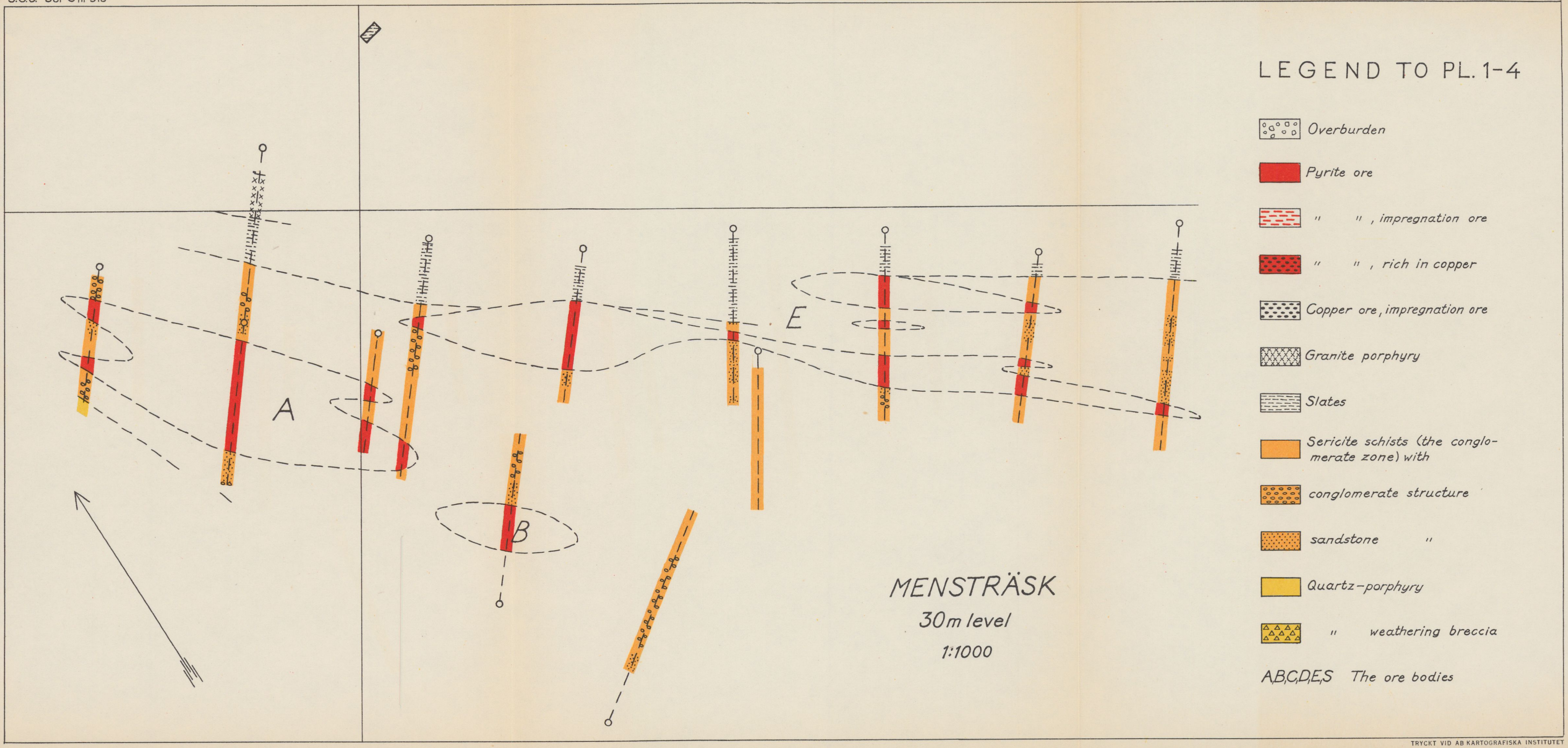

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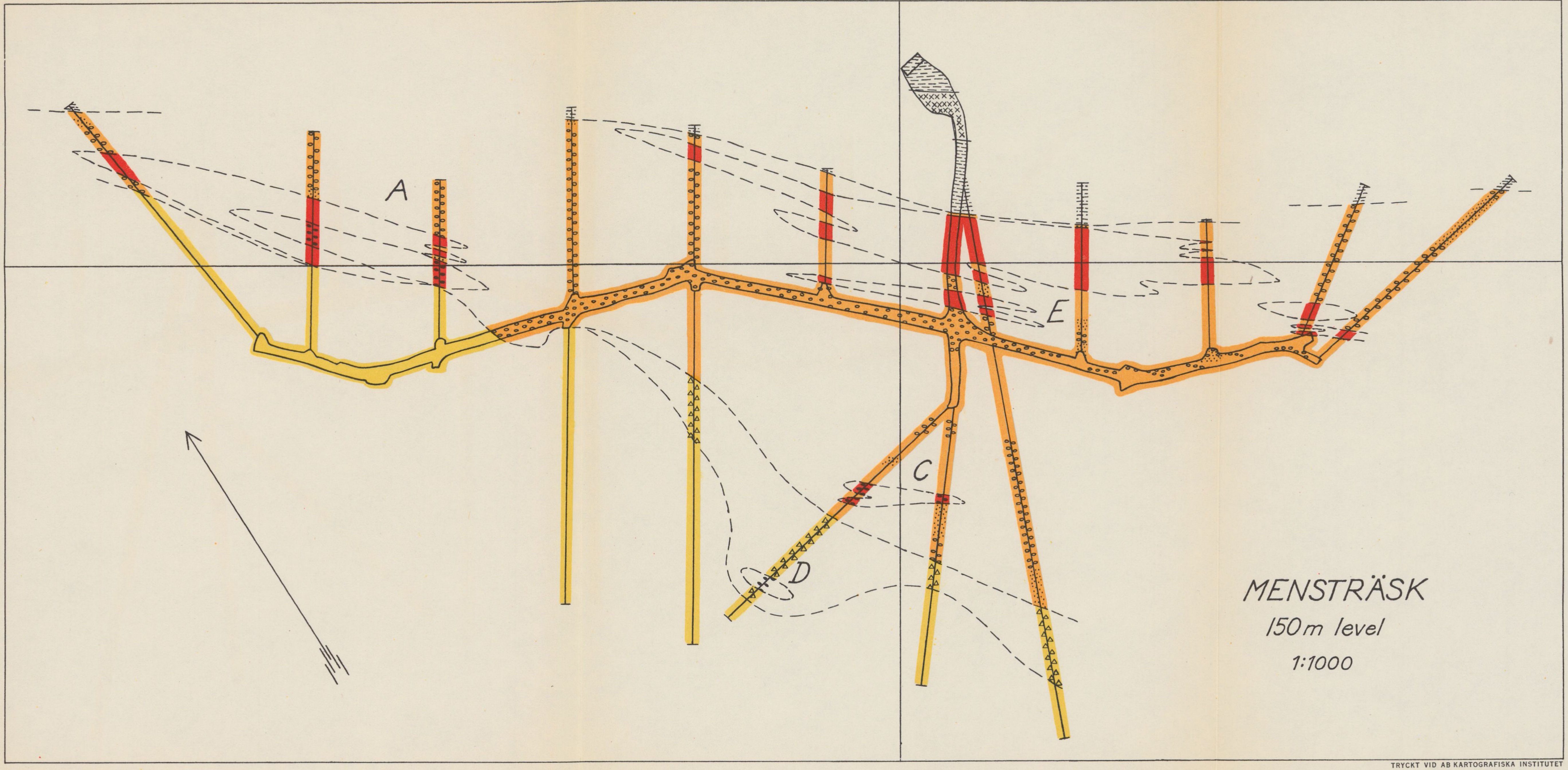

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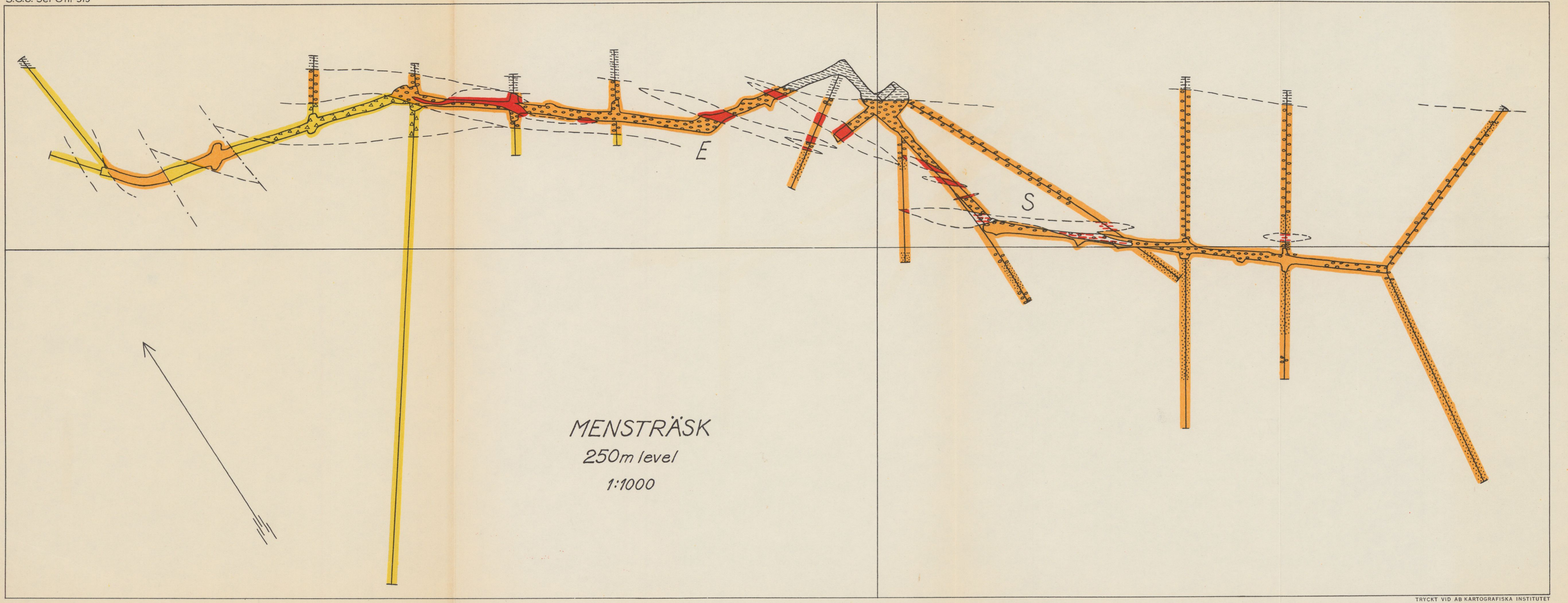

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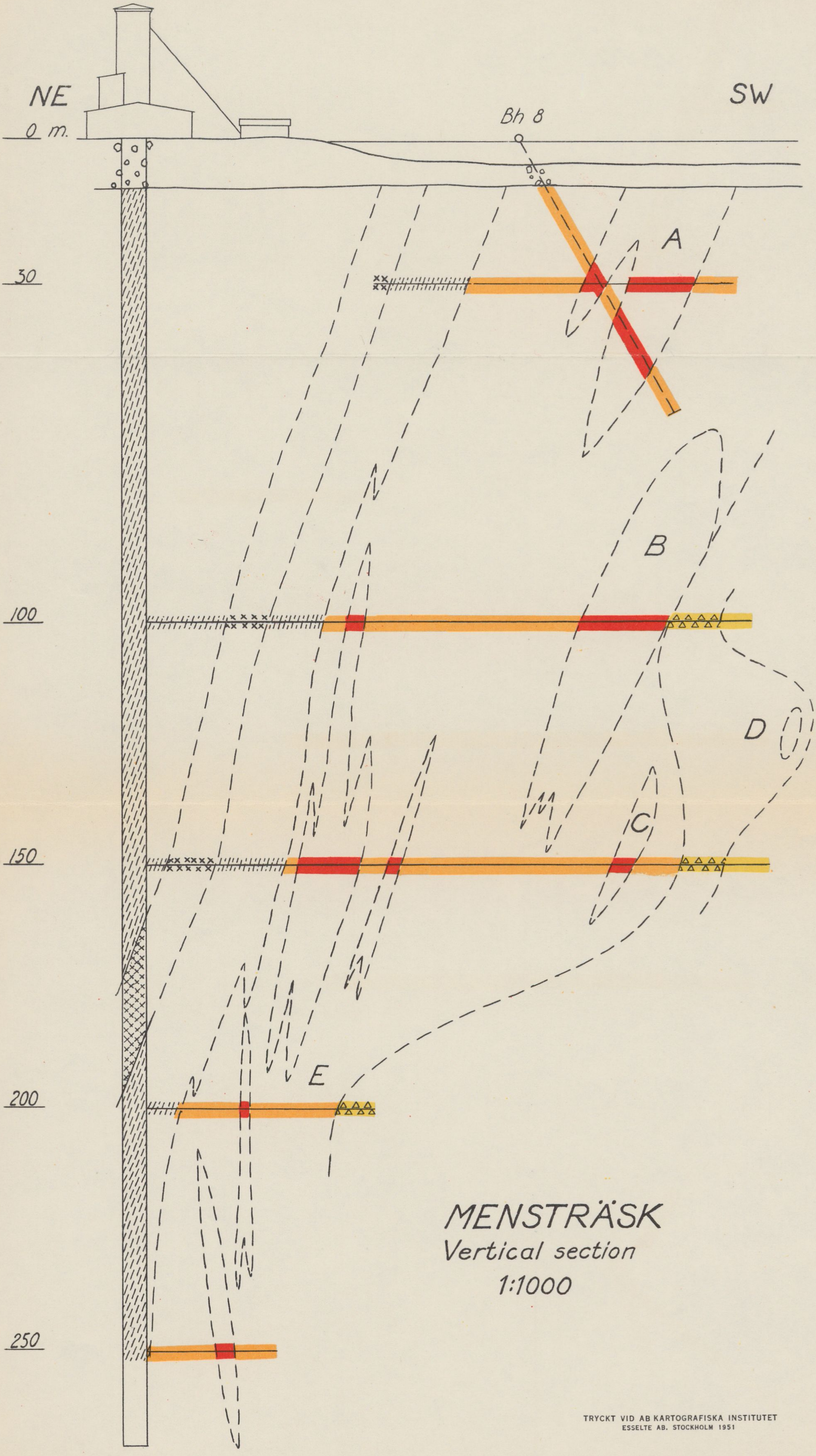

MENSTRÄSK
Vertical section
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