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ÅRSBOK 41 (1947) N:o 6.

MANGANESE MINERALIZATION IN THE ULTEVIS DISTRICT, JOKKMOKK, NORTH SWEDEN

PART I: GEOLOGY

BY

OLOF H. ÖDMAN

With Appendices by
Sture Werner and G. Lundqvist

WITH 4 PLATES

Pris 4 kronor

STOCKHOLM 1947
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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Preface.

In the field work forming the basis of the following account, a number of persons have been of great assistance to me. In particular I want to emphasize the extremely valuable help rendered by the prospectors of the Geological Survey. Thanks to their keen power of observation and excellent woodcraft it was possible to trace the manganese-bearing glacial boulders from the original find in the vicinity of Murjek the distance of 125 km through the wilderness to the outcrop of the mineralized zone on Ultevis.

Many of the problems encountered in the district were concerned with Quaternary geology, glacial transport of ore boulders, etc. On several occasions I had the great fortune to be able to call on Dr. G. Lundqvist, who freely gave valuable advice on those problems, both in the field and at home in the laboratory. In Appendix 2 Lundqvist discusses the transportation and distribution of the glacial boulders.

Mr. E. Viluksela of Helsingfors took an active part in the work in the summer of 1946 and mapped some sections of the mineralized zone and a wide area to the west of it. His work effectively contributed to the solution of some of the stratigraphic and tectonical problems.

Mr. S. Werner was in charge of the geophysical survey and it is thanks to his work that the mineralized zone could be traced all through the sometimes badly exposed district and that some of the geological details could be revealed. In Appendix 1 Werner presents an account of the geophysical work.

At an early stage of the work, in 1942, Professor B. Mason, of Bloomington, Indiana, then a temporary resident in Stockholm, undertook an X-ray study of the oxide manganese minerals found in the boulders from Murjek and which I could not identify under the microscope. As a result of Mason's work the identity of the mineral species present was established.

The analytical work has been performed by Dr. G. Assarsson, Dr. A. Bygdén, Mrs. A. M. Byström and Mr. F. Swenborg. Some analyses were made at the Boliden Laboratories and Statens Provningsanstalt. The spectrochemical work was carried out by Dr. S. Landergren and Mr. B. Gustafsson. The optical determinations are by Mr. E. Åhman, Upsala.

I am greatly indebted to the persons mentioned and I am desirous to express to them my gratitude for the valuable help they have rendered me.

It has been found convenient to divide the account into two parts, the present part dealing with the geology of the bedrock and the mineralization and the origin of the latter. Part 2 will deal in greater detail with some of the more unusual minerals found in the district and which are thought to be of special interest.

Geological Survey of Sweden
Stockholm, February, 1947.

Olof H. Ödman.

Introduction.

In 1935 when a well was dug in the glacial drift in the village of Vuotnajaure (Pl. 1), 8 km N of Murjek, a station on the railroad Luleå—Narvik, there was found a boulder of a disproportionally heavy weight, betraying a metallic content. A preliminary analysis proved that the boulder ran remarkably high in manganese (31.9 % MnO) and also in iron (36.0 % Fe_2O_3). Some barium and lead were also present. A couple of villagers made a futile search for the outcrop of the ore in the vicinity of Vuotnajaure, and the boulder was subsequently handed over to the Geological Survey in 1940. In the summer of that year geologists and prospectors of the Survey began a prospecting campaign in the district, which resulted in further finds of glacial boulders with lean manganese breccias and disseminations. The rock in the boulders consisted mainly of light-gray leptites, sometimes with phenocrysts of quartz and feldspar. The bedrock is not very well exposed in this part of the country and it is covered with thick deposits of glacial drift. Only a few outcrops were found and they consisted of a red granite.

The search for boulders was continued throughout the summers of 1941 and 1942, a considerable number of poor manganese boulders being found. Only two boulders of richer ore were discovered. A statistical examination of the boulder content of the drift, which was carried out by G. Lundqvist, indicated the possibility of an area of the same rocks as found in the boulders occurring 3—4 km NNW of Vuotnajaure. A magnetic survey, begun already during the winter of 1940—41, gave a fairly well marked anomaly zone beyond the line NNW of the village where Lundqvist's studies indicated the ore-bearing rocks to occur. Also a gravimetric survey indicated a disturbance in the same place.[1] It thus seemed probable that the ore-bearing zone had been located.

However, as early as 1941 manganese-bearing boulders of the same type as at Vuotnajaure had been located at other places, *e. g.* at the villages of Högträsk and Sarkavare, 27 and 38 km respectively NW of Murjek and on the highway 10 km SE of the latter place (Pl. 1). Solitary boulders were found spread out between the localities mentioned and were observed as far towards the northwest as at Muddusjokk. There were thus strong reasons against the supposition that the ore-zone was to be found at the locality of the first boulders NNW of Vuotnajaure. Definite confirmation that we were on the wrong track was obtained in the autumn of 1942, when two diamond drillholes, put down on the geophysical anomaly, ran into a dioritic rock which had never been observed

[1] A report on the geophysical work at Murjek is being prepared by S. Werner.

in the district before, either in outcrops or in boulders, and which probably occurs in the granite in a narrow band.

Considering the fact that the general direction of transport of the glacial debris in these parts of Sweden is from NW to SE, it was clear that the source of the manganese boulders should be looked for still further to the north-west. In the spring of 1943 the search for boulders was continued in the neighbourhood of Porjus, the big power-plant on Luleälven, 43 km SW of Gällivare. Here, 60 km NW of the place of the original boulder, the manganese-bearing boulders reappeared (Pl. 1). The prospecting was then extended to the barren mountain plateau NW of Porjus and, finally, at the end of July, 1943, the first manganese mineralization, a poor breccia, was located in an outcrop on Stuor Njuoskes on the southern fringe of the Ultevis plateau in the NW part of the parish of Jokkmokk. It is from this barren mountain plateau that the district derives its name.

The prospecting was now intensified and continued till the end of the summer of 1946. An extensive geophysical survey, comprising both magnetic and electrical methods, was carried out and a large area was geologically mapped and thoroughly searched for manganese boulders. The geological examination showed that the mineralization was confined to a narrow zone in a series of volcanic rocks, the zone extending from the hill Juoråive in the north to the hill Tjatitsvare in the south for a distance of 20 km (Plates 1—2). Manganese minerals were also found still further to the south in two isolated localities at Stuor Lastak and at Aitevarats. Neither outcrops nor mineralized boulders were found in the boggy country between Tjatitsvare and the two last-mentioned localities and it is not known whether the mineralized zone continues unbroken the whole distance to Aitevarats. It is not improbable, however, as the manganese-bearing volcanic series continues all the way to that hill.

Due to the poor electrical and magnetic qualities of the rocks — and the small size of the ores, as later found — the geophysical indications obtained were rather diffuse and very little elucidative. A fact of great importance was, however, that the greenstone immediately below the manganese-bearing series came out very well on the magnetic chart (Pl. 3), as it formed a good »marker bed» which was made use of when directing the drilling. In Appendix 1 S. Werner gives a more detailed account of the magnetic and electrical survey.

The geological prospecting resulted in the locating of a number of outcrops which showed good mineralization, but on trenching and drilling it was found that the »ore bodies» in all cases were discouragingly small and not mineable in view of the inaccessibility of the district, although the content of manganese in some cases was fairly high. A large number of boulders were found and some of them ran high in manganese (51 %). The source of some of the boulders has not been found, in spite of great efforts, but it seems to be beyond doubt that the ores delivering these boulders are of a small size. Of the boulders some, consisting of more or less massive piedmontite, attracted special interest as in one locality they contained an appreciable amount of molybdo-scheelite. Also in this case the source of the boulders is believed to be only a small mass, as the source could not be located despite the fact that the well-delimited locality was extensively drilled.

In view of the good ore boulders and the comparatively rich ore exposures that were found in the mineralized zone, the district looked very promising in the beginning. The extensive work, drilling and trenching, that has been carried out in a number of places, has, however, failed to locate any commercial ores and it seems to be a well-founded geological fact that although the mineralization is very wide-spread it never formed any large ore bodies.

The analysis of the first ore boulder at Vuotnajaur showed that the ore formed a type of mineralization heretofore never encountered in Sweden. In view of this and considering the unusual paragenesis with bixbyite, hollandite, piedmontite, viridine, svabite and other minerals, which may attract a more general interest, it was desirable that the district be made subject to a detailed description.

When in this paper the term »ore» is made use of in describing the mineralization, it should be borne in mind that it is used in a geological sense. The mineralization has been classified in »hematite mineralization», »manganiferous iron mineralization» and »manganese mineralization», but the classification does not follow the one generally used in commerce. The manganiferous iron mineralization consists of hematite ores, which contain a varying but generally low percentage of manganese combined in opaque oxide minerals and piedmontite. The manganese mineralization comprises both braunite ore and mixed hematite and manganese oxide ore, sometimes high in iron. The classification is a mineralogical one and has been found convenient in describing the mineralization.

Physical Nature.

The Ultevis district is situated about 60 km N of the Arctic Circle on the border between the central Scandinavian forest belt and the barren mountainous region along the Swedish-Norwegian frontier. The lower parts of the district are about 400—500 m above sea level, the highest hills rising to a height of about 900 m (Pl. 2).

The northern part is occupied by the southern fringe of the barren mountain plateau of Ultevis (Fig. 5). A series of barren-topped hills occupies the remaining parts of the district, except for the south central portion, which is boggy and flat (Fig. 3).

At the small habitation of Snavva the waters from Situojaure, Laidaure, and the wide valley W of Snavva meet and unite in the river Blackälven. The river forms the main drainage of the snow-capped Sarek Mountains.

The timber line is at about 700 m above sea level, but the pine-forests cease at a lower altitude, the upper part of the forests consisting practically exclusively of birch.

The district is comparatively inaccessible, the nearest railroad being 55 km distant and the nearest motor-road 40 km. The best ways of approach to the district are along the lakes in the valleys of the Stora and Lilla Lule Älvar. The nearest village, Tjåmotis, situated in the valley of the last-mentioned river, is 20 km distant.

Geologic Setting of the District.

The part of the Province of Norrbotten treated in this paper was not very well known geologically before the mapping undertaken in connection with the manganese prospecting. Our knowledge was mainly based on some statements by Svenonius (1880, 1900).[1] The map accompanying the latter paper does not go as far east as the manganese-bearing area. To judge by the map and the statements in the paper it would seem that Svenonius considered the porphyries to form the base of a series of gently dipping sediments, which he designates on the map as »granulitic sandstone»[2], »red sandstone» (= Sjöfall Sandstone), and »light-coloured sandstone and quartzite» (probably corresponding to the Cambrian Hyolithus Zone). Svenonius evidently regarded all these rocks from the porphyries up into the Hyolithus Zone as a conformable series.

From Svenonius's diaries (1883) in the archives of the Geological Survey it is seen that at least on one occasion he passed Stuor Njuoskes and there observed some leptitic rocks which probably represent the tuffitic sediments that crop out there. Finally, it may be mentioned that in the summer of 1931, when on a prospecting tour for the Boliden Mining Co, the author passed the hill Tjatitsvare and there noticed the streaks of hematite in the leptitic porphyries. The small showings of manganese ore in the same hill were, however, not observed.

The earlier observations now mentioned did not suffice to give more than the main features of the geology. The detailed mapping carried out in the district during the prospecting campaign has resulted in a general geological map of a wide area, part of which is reproduced in Pl. 2, and detailed maps of certain parts of special interest (Plates 3—4 and Fig. 1). The survey is as yet incomplete in some parts and more work remains to be done in the north and south extensions of the manganese area.

On the maps is shown (Plates 2—4) how the manganese-bearing volcanic series with its long and narrow greenstone and limestone horizons as »marker beds» is underlain in the west by a series of more or less metamorphosed but unmistakable sediments, here called the Snavva sediments. On Nordhårås and Stuor Lastak (Pl. 2) the sediments are comparatively fresh and quartzitic.

The manganese-bearing series is mainly volcanic and is built up of a number of different rocks. The lowermost member is a sericitized and schistose rock, probably a tuff, which is exposed only on the northern slopes of Nordhårås. In other parts of the district, except on Tjatitsvare, the greenstone forms the lowest member. On Tjatitsvare the greenstone is absent and the limestone

[1] Cf. bibliography, pp. 68—69.

[2] This sandstone may probably be compared to the Snavva sediments, which appear W of the manganese zone (Pl. 2). It also represents some of the tuffitic sediments in the manganese-bearing volcanic series.

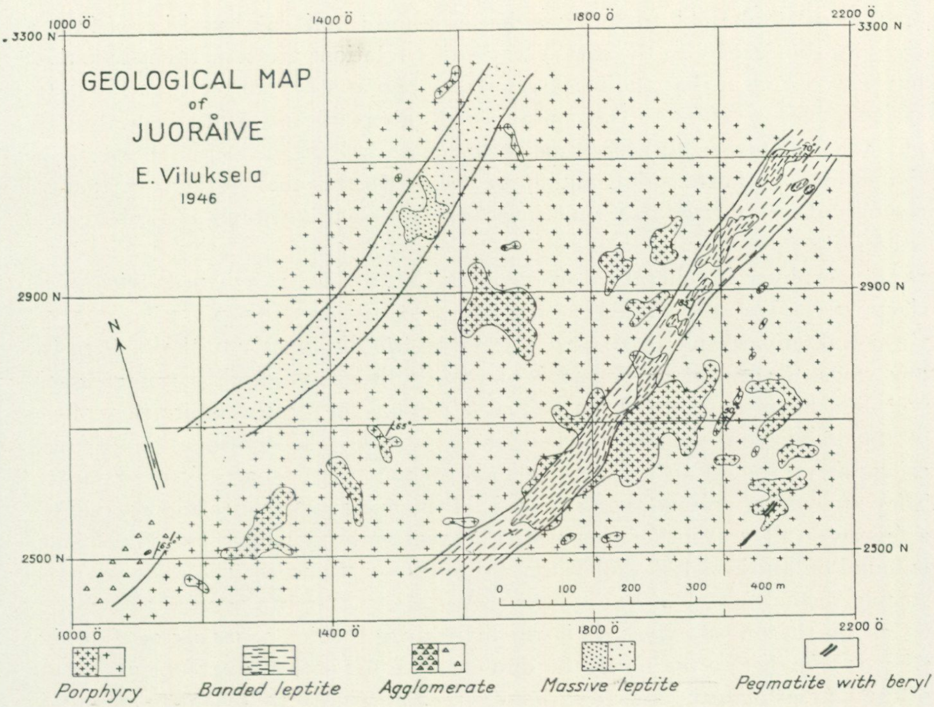

Fig. 1.

appears on the border between the Snavva sediments and the overlying volcanics. On Stuor Lastak, 4 km SW of Tjatitsvare, the greenstone reappears in several thin beds, gently dipping to the S or SE. The greenstone is considered to be effusive.

Another well developed »marker bed» is found in the limestone and has been traced in several places. On Stuor Lastak the limestone occurs in the same manner as the greenstone and forms 3—4 thin and gently dipping beds.

Above the limestone follows the thick and variegated series of acid volcanics. As distinguished from corresponding volcanics in other parts of Norrbotten these rocks are light-gray or white in colour. As is seen on the plans (Plates 3—4) the stratigraphy of the series varies from place to place. On Juoråive, Stuor Njuoskes, and Nordhårås the volcanics begin with often distinctly bedded, probably tuffitic sediments with bands and layers consisting mainly of hematite but also of braunite, piedmontite, garnet, etc., and pyroclastic fragmental rocks. Occasionally thin beds of porphyries are found. This pyroclastic series is called the »upper tuffitic sediments». In the southern parts of the area the pyroclastic rocks are poorly developed and as a rule the limestone is immediately followed by leptitic porphyries.

The next member of the volcanic series is chiefly made up of porphyries with phenocrysts of feldspar and occasionally of quartz. As will be demonstrated in fuller detail in a following chapter the porphyry in the northern part of the area, from Stankajokk to Sörhårås, has an almost horizontal position or in any case dips but gently to the east. The contact relations are sometimes indistinct but it would seem that the porphyry rests upon and is younger than the other volcanics below. Next to the contact on Raktenvare and Tjatitsvare the porphyry has a steeper dip, conformable to the underlying rocks, but towards the E the dip soon flattens out. Simultaneously with this change the rock changes colour and is converted to a sometimes fairly coarse-grained but as a rule typical red leptite.

The porphyry is generally homogeneous but in some places beds with pyroclastic rocks are intercalated.

On Raktenvare and Tjatitsvare the red leptite dips gently to the east. In the low parts of the district E and S of these hills gently dipping but gneissose volcanics have sometimes been observed, having the typical light-gray colours of the manganese volcanics. They probably form the continuation of these rocks, here brought to light in the more deeply eroded parts of the country. They are coarser grained than the rocks of the manganese series and are marked as gneiss on Pl. 2. Another area of small extent with the light-coloured volcanics is found on Juovakielas, a hill 3 km SSE of Stuor Njuoskes. The rocks here dip steeply to the east.

The northernmost exposures in the manganese-bearing series are on Juoråive (Fig. 1). Further to the north there follows the flat and barren central portion of the Ultevis plateau, and no exposures are found until we reach the mountain range 5 km further to the NE. Porphyries of various types here appear but no direct continuation of the rocks of the manganese zone has been seen although small and restricted exposures were observed which consisted of very light-coloured porphyries, identical with those in the manganese zone.

To the south the rocks of the manganese zone continue in the hill Stuor Lastak (Pl. 2). The exposures are good and in the sheer cliffs of the hill the stratigraphic succession is fully developed in gently dipping beds, beginning with the Snavva sediments and ending up with the red leptite.

Another 4 km to the SW a similar succession is met with in the E part of the Aitevarats Hills (Pl. 2). The greenstone and the limestone here seem to be absent, but the Snavva sediments and the volcanic series are represented. As before, the latter in the E changes to red leptitic porphyries. The dip is throughout the succession directed steeply to the E.

The geological relations W of the manganese zone were unravelled by E. Viluksela in the summer of 1946. In a 17 km long section from Aktse to the manganese zone in the SE he could show that the Snavva sediments, which at the Situoälven still dip fairly steeply to the E, in the Manak Hills gradually flatten out until in the western Manak Hill (4.5 km NW of S. Manak, Pl. 2) they attain an undulating, almost horizontal position. Due to the flat dip and insufficient outcrops it is difficult to state the thickness of the Snavva sediments but it probably amounts to several hundred metres.

It is not the purpose of the present paper to give an account of the geological features further to the west and we must content ourselves by stating that the

Snavva sediments are conformably underlain by another volcanic series, composed of basic and acid lavas and tuffs.

The main points of this account of the geological nature of the district are thus that there exist two supracrustal series, an upper volcanic one and an older sedimentary one. The former series with its contents of porphyries, which may be compared with the porphyries on Ultevis and in the country N of the river Stora Luleälv, may, at least provisionally, be correlated with the pre-Cambrian porphyries of Kiruna in the N and with the porphyries of Arvidsjaur in the S (Grip 1935). The correlation is founded on general geological and petrographical similarities only, as there are portions of the country between the districts mentioned that have not yet been mapped.

Within the porphyry areas mentioned no equivalence to the stratigraphic succession in the manganese volcanics is known and it is very unlikely that there should exist one, considering the quickly changing conditions of deposition and eruptions within a volcanic region. Comparisons with other porphyry areas of Upper Norrbotten disclose the abundance of pyroclastic rocks in the manganese volcanics to be a specific feature, as otherwise such rocks are comparatively rare. Large tracts with agglomerates and tuffs occur around Langassjön and Satisjaure (Svenonius and Ödman) and Geijer has described agglomerates from the Kiruna district. A similar development as in the manganese rocks is shown by the Lower Hauki series at Kiruna (Geijer 1931). Also Grip (1935) describes pyroclastic rocks intercalated in the Arvidsjaur porphyries.

It is difficult to find an equivalent to the Snavva sediments. In the southern parts of Norrbotten we meet at Skärfajaure, 50 km N of Arjeplog, a thick series of quartzitic sediments, which in many respects, even in details, resemble the Snavva sediments.[1] The Skärfajaure sediments are situated stratigraphically under porphyries of the Arvidsjaur type.

Also in other places in S Norrbotten and in the Skellefte district there appear sediments, which, even if they do not present any petrographic similarities with the Snavva sediments, nevertheless remind of them in view of their stratigraphic position. It is evident from earlier accounts dealing with the Skellefte and Arvidsjaur districts (cf summary in Grip 1946) that sediments of similar stratigraphic position are known from the Skellefte district proper and that they »occur from the Skellefte district and towards the S throughout Västerbotten» (Grip 1946, p. 8). All these sediments are, according to Grip, situated stratigraphically between the somewhat younger Arvidsjaur porphyries and the older volcanics of the Skellefte district. Although no direct connection between them and the Snavva sediments is known to exist, there are reasons to assume that the latter, with their stratigraphic position between two volcanic series, form a northern outlier from the sediments further south.

In view of the considerable thickness of the Snavva sediments and their wide extension it is understood that they imply more than an episode in the geological history of this part of Norrbotten. It is hoped that further work will solve the stratigraphic problems still connected with these sediments.

[1] Oral communication by Dr. Sven Gavelin.

Geologic and Petrographic Description.

Snavva Sediments.

These rocks are well exposed on Nordhårås, along Situoälven W of Sörhårås, in the Rakten area, and on Tjatitsvare (Plates 3 and 4). In the first two localities the sediments are not linked up with the over-lying members of the volcanic series, this due to the lack of exposures, but in the others they are in contact with greenstone and limestone respectively. The series is also well exposed in the N and E scarps of Stuor Lastak and in the hilly country W of Situoälven (Pl. 2). The thickness of the series is considerable, amounting to several hundred metres.

The rocks are as a rule strongly recrystallized and coarse-grained and in some cases the interpretation of their nature is rendered difficult. They are particularly, strongly metamorphosed at Rakten and on Tjatitsvare. On Nordhårås and Stuor Lastak, on the other hand, the sediments are considerably less altered and they are here fine-grained and quartzitic. The rocks very often show a distinct banding and stratification, brought about by a colour-banding or narrow layers with hematite. The latter have been interpreted as black sand layers. When more strongly metamorphosed the banding is lost, the rock attaining an irregularly streaky structure. Sometimes one observes rounded or often pressed fragments of porphyries and leptites. The series has a sedimentary origin and the rocks may be termed quartzites, although the high content of feldspar makes »feldspathic quartzite» a more adequate name.

The sediments are light gray in colour. In the most fine-grained and least metamorphosed members the grain size is about 0.1—0.3 mm. In the more strongly metamorphosed types it increases to about 0.3—0.6 mm and the rock takes on the appearance of a salic gneiss. In connection with the metamorphism there appear irregularly shaped pegmatite veins. They consist of quartz, white microcline, and muscovite, sometimes also of hematite and in one case scapolite. They do not seem to bear relation to any granite, as no such rock occurs in the vicinity, but they rather have the character of pegmatites formed by mobilization of the enclosing rock.

No clastic textures are seen under the microscope in the more strongly metamorphosed members and the rocks are recrystallized and have a granoblastic texture with simple grain boundaries. In the quartzite from Nordhårås there are discernible grains of quartz and feldspar which still have the character of fragments.

Among the constituents of the rocks quartz, microcline, and plagioclase dominate. The latter is often turbid. Oligoclase seems to be most common but also albite has been seen. Other constituents are hematite, muscovite, apatite, biotite, epidote, tourmaline, and zircon. More rarely present are sillimanite, viridine,[1] piedmontite, titanite, chlorite, hornblende, and pyroxene.

Viridine has been observed in the exposures on Situoälven and on Tjatitsvare. It forms 4—5 cm long and 1—2 cm thick, disk-like bodies (Fig. 8), which under

[1] This rare mineral, manganese andalusite, is described in Part 2.

the microscope are found to be composed of small, short-prismatic grains of viridine intergrown with quartz, feldspar, hematite, and other minerals. Piedmontite is otherwise the only manganese mineral that has been seen in the Snavva sediments; it is rare, however.

The table below gives the mineralogical composition, expressed in per cent of volume, of a number of types of Snavva sediments. The calculation was carried out by E. Åhman on a Leitz integration stage.

	1.	2.	3.	4.	5.	6.	7.	8.
Quartz	35.9	25.4	63.1	57.5	56.1	56.5	61.8	39.9
Microcline	36.1	38.6	11.8	18.2	12.3	26.6	9.5	29.9
Plagioclase	12.6	—	14.1	8.1	9.2	4.9	12.8	7.3
Muscovite	5.2	—	—	—	—	—	—	10.8
Biotite	—	—	—	—	12.5	—	—	—
Ore	3.6	15.5	6.4	7.5	7.4	4.2	3.4	8.6
Pyroxene	—	7.8	—	—	—	—	—	—
Hornblende	—	4.6	—	—	—	—	—	—
Viridine	—	—	—	—	—	—	—	3.5
Sillimanite	—	—	—	—	—	—	8.4	—
Accessory constituents	6.5	[1] 8.1	[1] 4.6	[1] 8.8	2.5	[2] 8.0	[2] 4.3	—
	99.9	100.0	100.0	100.1	100.0	100.2	100.2	100.0

1. Situoälven, W of Sörhårås.
2. Stuor Lastak.
3. Tjatitsvare.
4. Situoälven, W of Sörhårås.
5. Nordhårås.
6. Situoälven, W of Sörhårås.
7. Situoälven, W of Sörhårås.
8. Situoälven, SSW of Sörhårås.

The petrographic character of the rocks is on the whole fairly uniform. The abundance of feldspar is quite characteristic, a circumstance which cannot directly be interpreted as indicative of an inconsiderable chemical weathering on the continent from which the sedimentary material derived, as the feldspar is likely to have been formed during the metamorphism. The sporadic hematite bands and the occasional horizons with conglomerate pebbles indicate a deposition in a shallow basin and the proximity of a land area. This assumption is also supported by the fact that in the middle and lower parts of the series, W of Situoälven, there occur thick beds of conglomerate and greenstone lavas. On the other hand, in view of the considerable thickness of the sediments, the area was subject to a strong submergence during the sedimentation. Under the presumption that the Snavva sediments correspond to the sediments at Skärfajaure and in the Skellefte district, mentioned earlier, the submergence probably had a regional character and influenced considerable portions of Norrbotten and Västerbotten.

Lower Tuffitic Sediments.

To this series belong the imperfectly exposed leptites observed in a few outcrops below the greenstone on the northern slope of Nordhårås and intercalated

[1] Including fine-grained biotite.
[2] Including fine-grained muscovite.

in the greenstone at Stankajokk (Pl. 3). The series is not known from any other part of the manganese-bearing area. The leptites in the greenstone have been grouped together with those below it, although it is not known if they are geologically connected. As the leptites in the greenstone are badly exposed, their contours on the plan are a mere construction. In view of the conditions on Tjatitsvare and Stuor Lastak, where two or more beds of greenstone alternate with leptites, the construction seems probable. The rocks of the lower tuff series offer on the whole the same picture as the rocks of the upper tuffitic series and it seems likely that they have the same origin.

A common feature of the rocks is their strong foliation and the fairly thorough sericitization, but despite the strong alteration it is possible to differentiate between two types. The first type is a leptite with an irregular granoblastic texture, containing grains of quartz and feldspar of a fragmental appearance. A banding is occasionally visible.

The second type has been termed a tuff agglomerate and is distinguished by the presence of sheared and pressed fragments of porphyry. The interpretation of the rock is rendered difficult because of the foliation and it cannot be proved that it is pyroclastic and not a true conglomerate. No similarity exists with the conglomerates occurring in the Snavva sediments but a consanguinity with the tuff agglomerates at Stuor Njuoskes and Nordhårås is noticeable. The interpretation of the latter as pyroclastic formations is more reliable.

In some cases the leptites carry skarn minerals, such as epidote, garnet, and hematite. Grains of molybdo-scheelite, up to 10 mm in diameter, are present but are very rare. This type of alteration is particularly conspicuous among the leptites that border on or alternate with the greenstone.

Greenstone.

The greenstone forms the best »marker bed» in the area. In this capacity it is of importance as it constitutes the western limit of the manganese mineralization. Oxide manganese minerals are never found in the greenstone or beyond it. As is evident from the maps the greenstone is not well exposed and cannot be followed only by means of outcrops and boulders. The magnetic survey was here extremely helpful as it enabled us to map the contours of the greenstone (cf. Plates 3—4 and Appendix 1 by S. Werner). That the magnetic anomaly was caused by the greenstone could be checked in many places by outcrops and drillholes.

The greenstone appears as a continuous zone from Stankajokk to Raktenbäcken. On the northern slope of Sörhårås the magnetic anomalies are unusually complicated and have been interpreted by Werner as a kind of double distortion or hinge in the greenstone bed. Unfortunately there are no outcrops in this section to check the anomalies. In drillholes Nos. U 21—22 the direction of strike in the cores diverged from the normal strike and it seems clear that in this place a disturbance in the strata actually took place.

Around Raktenbäcken there is a gap in the magnetic anomaly and probably the greenstone is lacking there. It reappears a couple of hundred metres S of the creek and continues in a fairly straight course, at Rakten checked by outcrops and drillholes, to Tjatitsvare, where it peters out in the lower northern slopes of the hill.

Natural exposures in the greenstone occur at Stankajokk, on Nord- and Sörhårås and at Rakten. Several drillholes have reached the greenstone. On Tjatitsvare the greenstone is lacking, but, as mentioned before, it appears again in Stuor Lastak. At Rakten there is a small separate outlier of greenstone in the hanging wall of the main greenstone bed.

The thickness of the greenstone is considerable and amounts to 100—150 m.

The aspect of the greenstone changes somewhat according to the petrographic character, the occurrence of skarn minerals, etc. The normal type is a grayish green and fine-grained, indistinctly foliated rock, which on weathered surface or on drill cores shows small intersertal laths of plagioclase. Phenocryst-like grains of hornblende are sometimes present. Other hornblende-bearing types are distinctly foliated and more coarse-grained, thereby attaining the appearance of amphibolites.

Occasionally the greenstone carries amygdule-like formations of hornblende, microcline, biotite, epidote, and ore. Scapolite, which is not uncommon in the greenstone, sometimes occurs in patches, the surrounding rock looking quite fresh. Epidotization of the greenstone is also noticeable. Sometimes the epidote is accompanied by the formation of quartz.

The greenstone is recrystallized and only the plagioclase laths still show primary features. They may, however, be granulated. The composition of the plagioclase is approximately between 20—45 % An. Microcline is often present in the plagioclase laths or in the groundmass. Quartz is rarer. Among the mafic constituents a faintly coloured hornblende is predominant, but when the greenstone is more foliated biotite is dominant. Pyroxene is very rare. Furthermore we note epidote, ore, titanite, and apatite.

The greenstone is considered to be a lava but no definite proof of this belief can be produced. The shape of the greenstone zone, for instance, speaks against it and rather seems to indicate an intrusive origin (sill), although no intrusive contacts are known. The appearance of amygdules may be quoted as supporting the idea of an effusive origin. In drill hole No. U 7 on the south slope of Nordhårås (Pl. 3) the rock in the core from the hanging wall of the greenstone was composed of a tuff agglomerate with fragments of greenstone and leptites, which indicates that the greenstone was exposed on the land surface at the time of the formation of the agglomerate and that the greenstone presumably formed lava beds.

In wiew of the petrographical nature of the rock and if we suppose that the mineralogical composition did not suffer any radical changes during the metamorphism, the greenstone may be considered an andesite.

The result of the skarn mineralization is the formation of irregular masses, often many square metres wide, composed of scapolite, dark-brown garnet, epidote, and hornblende. The skarn is often coarse-grained and then the scapolite is developed in prismatic individuals, showing idiomorphic features. Between the intersertal scapolite crystals the garnet is accumulated, giving the rock an almost ophitic texture (Fig. 9).

A microscopic examination of the skarn discloses the presence also of apatite, biotite, titanite, and hematite. Small amounts of diopside, chlorite, calcite, microcline, and molybdo-scheelite are observed.

On a previous page mention was made of the skarn mineralization in the leptites of the lower tuffitic series. Also the leptites in the hanging wall of the greenstone, belonging to the upper tuffitic series, carry skarn minerals, which indicates that the skarn mineralization took place after the formation of the latter.

On the lower south-eastern slopes of Sörhårås there are one or two outcrops of an amphibolite (Pl. 3). The rock is fairly coarse-grained and has a well-developed linear schistosity. The nature of the rock is unknown.

Limestone.

The limestone, too, is a good »marker bed» and is found on Nordhårås, at Rakten, and on Tjatitsvare. In the latter two localities it forms fairly long and continuous beds. On Nordhårås the limestone is only exposed in two drillholes but it is known from boulders on this hill and also in the Stankajokk valley. The indications strongly support the belief that it occurs also in the latter place, although covered with up to 135 m thick glacial deposits as shown by drillhole records (Pl. 3).

On Tjatitsvare the limestone attains its maximum thickness, about 70 m. On Nordhårås the thickness is only 15—20 m. In this locality the limestone appears a short distance above the greenstone and is intercalated in the upper tuffitic series. At Rakten it rests on the greenstone and is followed by the porphyry, except in one place where a thin greenstone bed appears between the limestone and the porphyry. On Tjatitsvare, where the greenstone is lacking, the limestone occurs between the Snavva sediments and the porphyry.

The limestone is on the whole impure and intermixed partly with silicatic intercalations and partly with later skarn minerals. Among the »impurities» hollandite and braunite were noted with special interest, as they afforded hope of the presence of commercial ore bodies.

A sample of the limestone from a prospecting trench in the south part of the limestone zone on Tjatitsvare has been analyzed (by A. Bygdén):

	%
SiO_2	7.11
TiO_2	0.07
Al_2O_3	1.38
Fe_2O_3	1.40
MnO	0.22
MgO	0.26
CaO	46.93
BaO	4.12
SO_3	1.35
Na_2O, K_2O	1.05
CO_2 calc.	36.71
Sp. gr. = 2.79 (T. Swenborg)	100.60

The carbonate is thus mainly calcite. The barium content is of interest. The largest part enters barite, which also has been observed under the microscope, but a certain part of BaO, 1.20 %, was soluble in dilute hydrochloric acid, a quantity that probably entered the carbonate molecule.

The typical limestone of the district is white or light-gray in colour with shades of yellow or pink. The grain size is about 0.5 mm, sometimes less. A common feature is the appearance of light yellowish-brown garnet in patches about one cm in diameter. Small patches of quartz, feldspar, and other minerals are less conspicuous but still fairly common. Grains of piedmontite, epidote, muscovite, fluorite, and hematite are also sometimes visible. The microscopic examination increases this succession with titanite, diopside, manganese pyroxene,[1] apatite, molybdo-scheelite, scapolite, barite, and zircon.

Among the feldspars albite and microcline have been identified. There also occurs another feldspar, characterized by a low refraction and the absence of twinning structure and distinct cleavage. It is probably a microcline with a slight content of Ba (cf. the similar feldspar from Tjatitsvare described on p. 30).

The scapolite is occasionally altered and turbid, which makes the mineral difficult to identify.

The silicatic layers in the limestone are light-gray and very fine-grained rocks, often showing a fairly distinct lamination or colour-banding. They are interstratified in the limestone and form bands which as a rule are narrow but which may attain a width of several metres.

The microscopic picture of the rocks displays a fairly good leptitic texture with polygonal grains with smooth boundaries. Microcline dominates and quartz and albite are comparatively rare. Also here there is a long succession of less common minerals, such as garnet, diopside, hornblende, calcite, titanite, hollandite, braunite, bixbyite, micas, barite, piedmontite, epidote, scapolite, chlorite, and orthite.

When the metamorphism has reached a more advanced stage, almost all carbonate in the limestone is destroyed and real skarn masses develop. It is often noticed that the skarn mineralization tends to form rocks with one mineral preponderant over all the others. This is the case, *e. g.*, at Rakten, where rocks mainly composed of piedmontite, garnet or scapolite have been formed. They occur in bands or streaks, about 1—2 m thick and 10—15 m long, in less altered limestone. Also the hollandite-braunite mineralization belongs to this formation (Fig. 37).

The piedmontite rock is finely granular and dark brownish red, almost black, in colour. Besides the dominating piedmontite there occur small amounts of dark brown and in thin section faintly yellowish garnet, scapolite, and titanite. The allotriomorphic piedmontite grains are often zonary, the interior portions of the grains being more faintly coloured than the marginal parts. Occasionally

[1] E. Åhman made a preliminary optical examination of this mineral and found that probably different species are present.

the rock is more coarse-grained and the piedmontite occurs in fairly well developed crystals intergrown in calcite.

A garnet rock, examined in thin section, is fine-grained and yellowish brown with small patches of quartz. It is built up of densely packed, sometimes idiomorphic grains of garnet, which is gray or yellowish green under the microscope. The garnet is enclosed in a matrix composed of quartz and a turbid mineral, probably an alkali feldspar. Small amounts of an opaque mineral, piedmontite, and zircon are also present.

Another, fairly uncommon skarn rock is made up of fairly coarse-grained, yellowish white scapolite as the chief component with patches and streaks of light-brown mica, feldspar, manganese pyroxene, and piedmontite. Thin plates of hematite also occur.

Upper Tuffitic Sediments.

All rocks belonging to this series are interpreted as being of a volcanic origin, although some of them evidently were deposited in water. The series is composed partly of fine-grained and banded rocks (Figs. 11—14), partly of more coarse-grained and fragmental rocks (Figs. 4 and 15) and interstratified beds of porphyry. In the following the term leptite will be used of these rocks, although in view of their mineralogical composition they often deviate from the simple quartz-feldspar association which is characteristic and typical of a leptite *sensu strictu*. From a textural point of view, however, they show good agreement with the normal leptites, as their mineral components have polygonal shapes with smooth contours.

The series only occurs in the northern part of the map area from Juoråive in the north to the south slope of Nordhårås. In the latter place the series is known only in drillholes. Areas with natural exposures are known from Juoråive, Manganravinerna on Stuor Njuoskes (Figs. 6 and 7), Stankajokk, and the northern slope of Nordhårås.

The description of the rocks is divided into two sections, one dealing with the rocks from Stuor Njuoskes to Nordhårås and the other with those from Juoråive. The porphyries appearing in this series do not differ in any essential points from those of the overlying porphyry series and are only casually mentioned in this section.

Stuor Njuoskes—Nordhårås. Between the exposures in this section there are fairly wide gaps. The similar character of the rocks from the various areas exposed and the conformable strike of the rocks and the magnetic anomalies indicate that the series has the extension as shown on the map (Pl. 3).

Exposures of the contacts between this series and the adjoining ones are very rare. Only one natural contact is known — from Stankajokk, where the upper tuffitic series is superimposed by the porphyry (cf. below). In some of the drillholes contacts are seen but the comparatively small surface offered by the drill cores does not as a rule allow of reliable observations.

In drillhole No. U 7 on the southern slope of Nordhårås the greenstone is followed by a tuff agglomerate and, as mentioned above, fragments of greenstone were found here, indicating that the latter formed a lava bed exposed on the surface. It also implies that the stratigraphic succession is normal.

Immediately S of Stankajokk, about 150 m NW of the Ultevis cabin, the contact between the tuffaceous series and the porphyry is exposed. On the N side of the creek the rocks of the contact zone reappear in an accumulation of local boulders. The rocks of the tuffaceous series strike N30°E and dip vertically or steeply to the E. At the contact the porphyry, here carrying phenocrysts of both quartz and feldspar, is brecciated and cut by fissures filled with hematite and piedmontite. The brecciation is still noticeable 4—5 m up in the porphyry above the contact. Close to the contact there appears in the porphyry a dike of white pegmatite about 1.5 m thick.

Immediately W of the porphyry there follows a narrow (0.3 m) layer with a fine-grained, gray and unstratified leptite, which carries plenty of hematite (Fig. 10). A thin section showed a leptitic mass of quartz, microcline, and hematite with insignificant amounts of muscovite, faintly coloured tourmaline, and apatite.

Then follows an about 1 m thick reddish or bluish breccia with a cherty, jaspilitic groundmass (Fig. 10). The colour is caused by the presence of more or less finely dispersed hematite. Some parts of the breccia display a fine and well preserved lamination. The fragments consist of partly sharp-edged pieces of a quartz porphyry, fairly similar to the porphyry above the contact, sharp pieces or shards of fine-grained white quartz, jaspilite, and yellowish gray leptite. The fragments of jaspilite often show a fine lamination and resemble the groundmass of the breccia. The microscopic examination of a number of thin sections reveals an interesting mineral association. The texture is generally of a leptitic character with smooth grain boundaries. As a rule the rocks are fine-grained. Quartz and hematite dominate and are occasionally the sole constituents, in which case the rock may be termed a jaspilite. The hematite sometimes appears in dusty clouds within the quartz grains but it may also appear in larger individuals accumulated in certain layers. At the recrystallization a differentiation, a granular crystallization, took place in the material, and the fine hematite dust concentrated in larger grains (cf. Magnusson 1930, pp. 32 and 106, describing a similar process in the cherty quartz-hematite ore from Långban). Microcline is commonly present and also muscovite and fluorite. The latter mineral, under the microscope displaying a faint purple colour, occurs in polygonal, »leptitic» grains. Apatite, piedmontite, titanite, albite, and barite are less common. The latter mineral was seen only in one thin section, concentrated in certain layers of the rock.

The next member in the section is a zone of hematite-banded and foliated leptite, sometimes carrying a large amount of hematite. The zone is about 40 m thick. The banding is irregular and brecciated, some layers being broken up and later recemented. The content of iron decreases towards the west. Some sections of the zone are micaceous and in some layers piedmontite and yellow garnet occur.

In the west the section exposed around the contact ends up with a gray and streaky porphyry with light-coloured spots which represent granulated phenocrysts. The streaks are composed of piedmontite and hematite.

In view of the presence of porphyry fragments in the breccia, as mentioned above, one is on first thought inclined to interpret the contact relations to indicate that the fragments derived from the porphyry and that the latter was older and had formed the bottom on which a series of volcanic rocks had been deposited. In view of the east dip this implies that the beds were overturned. From Stuor Njuoskes in the north to Tjatitsvare, Stuor Lastak, and Aitevarats in the south, a distance of 30 km, the rocks always dip more or less steeply to the east (in Stuor Lastak the dip is flat), and everywhere the same stratigraphy has been observed with the Snavva sediments at the bottom and porphyry or red leptite uppermost. It is consequently hard to conceive that in this wide and stratigraphically homogeneous area the whole sequence should be inverted (on the other hand there are no direct observations to prove that the sequence is normal). The agglomerate in drillhole No. U7, containing fragments of the underlying greenstone, is the only direct indication in this respect.

The only possible answer to the question now discussed seems to be that the porphyry is younger and that the porphyry fragments in the breccia described above may either originate from one of the older porphyries, situated at a deeper horizon in the series and locally exposed by erosion at the time of the formation of the breccia, or from a neighbouring and somewhat earlier extrusion of the overlying porphyry.

The rapid change between fine-grained tuffitic sediments, tuff agglomerates, and porphyry beds is a characteristic feature of the rocks in this part of the district.

The larger part of the sequence is occupied by the fine tuffitic sediments. They are gray-coloured with layers or bands, changing in colour according to the minerals present. In this respect one can distinguish between types with bands of yellow garnet, piedmontite, hematite or bixbyite-braunite. The hematite-banded types are the most common ones. On the other hand, thick sections of the stratigraphic sequence are devoid of stratification.

In detail the banding is often irregular. The hematite-banded rock in Fig. 13 is unusually uniform but also here it is noticeable how irregular is the distribution of the bands and how they wedge out and ramify. They often have an elongate lenticular form. In the hematite-banded tuffs there are all gradations between types with only single layers of hematite to such as chiefly consist of hematite and where the »gangue minerals» only form mere streaks.

The banding with garnet, piedmontite, and the manganese oxide minerals is even less uniform than in the case of the hematite. Further, rocks banded with these minerals are much rarer than the hematite types and they are known chiefly from the exposures at Stankajokk. The bands with the manganese oxide minerals were seen only on a few occasions in the Stankajokk valley (description on p. 38). The bands with the minerals now in question, are, however, generally somewhat thicker than those with hematite. They appear to have the shape of flat lenses or plates. The colour of the individual bands varies according to the mineral present: yellow or yellowish brown for garnet, red for piedmontite, and black for bixbyite-braunite. The piedmontite may also appear in a finely divided state throughout the rock without any banding, or it may form small lenticles composed of fine grains.

The microscopic examination of the present rocks shows that besides hematite, garnet, and piedmontite, also microcline and quartz are plentiful. Albitic plagioclase, muscovite (sometimes pink-coloured), biotite, and apatite are often present. The last-named mineral occasionally has kernels with orange pleochroism. More unusual components are tourmaline, scapolite, titanite, and zircon. Fluorite, a mineral which on the whole is quite common throughout the district, is present also in these rocks. It forms simple polygonal grains which seem to have been subjected to recrystallization contemporaneously with the other constituents.

The rocks have a mosaic or leptitic texture. The recrystallization is occasionally strong but nevertheless the banding may be well preserved (Fig. 22).

Another variety of the banded leptites has the character of a mica schist. It sometimes has thin layers of hematite and shows a distinct foliated structure due to the abundant occurrence of sub-parallel foils of a pink mica, which gives the rock a pinkish colour.

Under the microscope the base of the rock is fairly typically leptitic with polygonal grains of microcline, quartz, and some plagioclase of an acid composition. In this base the mica foils are interspersed. Two kinds of mica occur. One has the character of a muscovite with a faint pinkish pleochroism and the other has pleochroism in orange yellow to grayish yellow. Among the other components we note opaque minerals, fluorite, apatite with orange-coloured kernel, viridine, colourless garnet, and yellowish tourmaline. The rock is considered to be an especially alumina-rich variety of the ordinary leptites.

The unstratified portions of the series, alternating with the banded ones now described, consist of gray and fine-grained rocks of a fairly normal leptitic character. Sometimes, and particularly well on polished surface, shadows and spots are noticed which may be interpreted as the remnants of small fragments. Now and again a small quartz grain is observed.

Microcline dominates but quartz and an albitic plagioclase are always present in varying amounts. The plagioclase is often turbid and it is likely that the kernel has had a more basic composition. Opaque minerals (hematite and manganese oxides), piedmontite, titanite, muscovite (sometimes pink), and apatite are constantly present. As before, the apatite has a kernel pleochroitic in orange. Fluorite is as usual a common component and the grains have the same polygonal shape as, *e. g.*, microcline. Barite, biotite, colourless or yellowish garnet, zircon, and rutile are less common.

From a textural point of view the unstratified leptites are less uniform than the banded ones and the grain size varies even within a small area. The grains show smooth outlines. Here and there larger grains of quartz or feldspar appear. The patchy variation in the granularity may be due to a primary difference in the grain size of the fresh rock. It is quite likely that we are here concerned with small fragments of rocks and minerals which have been enclosed in a groundmass (cf. the shadowy remnants mentioned above).

Some types of the unstratified leptites with larger grains of quartz and feldspar are similar to the porphyries described in the next chapter. On the other hand some of the thin porphyry beds in the tuffs are difficult to identify as lavas. It is thus, for instance, difficult to say whether the section of rock around the limestone bed on the north slope of Nordhårås really is composed only of tuffitic rocks as marked on the map. Some members here cannot be classified.

A third type of rock in this series consists of the tuff agglomerates.[1] They appear in beds which vary from less than 1 m to 15—20 m in thickness and which are intercalated in the fine-grained tuffitic sediments. As a rule the beds of tuff agglomerate do not in themselves show any banding but they may contain fine-grained sections which show lamination. The fragments are abundant and are composed of quartz and/or feldspar porphyries, leptites, and quartz. The freshness and red colour of the feldspar phenocrysts is a typical feature of many of the porphyry fragments. The size of the fragments varies from fine gravel to pieces about 10—15 cm in length. Many of the fragments are angular but on the other hand it is not unusual to see fragments which show distinctly rounded forms. Figs. 4 and 15 show two tuff agglomerates with small fragments.

It is a characteristic feature of the agglomerates in Manganravinerna on Stuor Njuoskes that their groundmass has been partly replaced by hematite, manganese oxide minerals, and/or piedmontite.

Most of the rocks now described are characterized by their banded nature and it is close at hand to interpret them as ordinary sediments. There are, however, certain facts that speak against this interpretation. In the first place it is striking to what extent the rocks are associated with lava beds. Furthermore, their mineralogical composition is hardly consistent with normal sediments. In this respect it is only necessary to consider the extreme content of microcline in some rocks and the jaspilitic type from Stankajokk. The latter rock indicates a chemical sedimentation in connection with volcanic processes. The fragments in the tuff agglomerates are, as mentioned, sometimes fairly well rounded, which may seem inconsistent with a volcanic origin, but only the degree of wear of the fragments cannot be used as a criteria of the origin of the rock.[2]

[1] This term is here used in order to signify fragmental volcanic rocks whose groundmass consisted of mud and ash. At least in part they were deposited in water.

[2] An illustrative example was observed by the author in 1927 on the extinct Tertiary volcano Mt. Kenya in East Africa at an altitude of 4.000—5.000 m. Thick beds of tuff, dipping with the slopes of the old volcano, were intercalated in the lava beds. One of the tuff beds contained well rounded »pebbles», varying in size from coarse gravel to boulders about 1 m in diameter. A deposition in water at this altitude on the slopes of a volcano is out of the question and the pebbles must have acquired their rounded shape from friction in the interior of the volcano and from wear during the transport

In any case it can be postulated that the rocks of the series were formed in a distinct volcanic *milieu* and that they may be considered volcanic products. The banded types were probably deposited in basins direct from showers of volcanic ash or washed down into them by torrential rains and streams. As regards the rock types with bands of hematite, garnet, piedmontite, and manganese oxides or the jaspilitic type, they were probably deposited as chemical precipitates. The unstratified leptites are considered to have been formed from finer volcanic debris, such as ash and mud, and the tuff agglomerates from fragment-bearing mud streams, ejectamenta, etc.

Juoråive. On the top and the eastern slope of the Hill Juoråive, situated on the Ultevis plateau (Pl. 2 and Fig. 1), a volcanic rock series is fairly well exposed. The rocks resemble those described above and the exposures lie in the main direction of strike of the former. As is shown on the detailed map (Fig. 1) compiled by E. Viluksela, two zones of porphyry alternate with two zones of partly banded leptitic rocks. The porphyry in the SE portion of the exposed area has a reddish colour. In the area Stuor Njuoskes—Nordhårås the boundary between the upper tuffitic series and the porphyry was fairly well defined but on Juoråive the boundary is more difficult to trace. The SE porphyry does not resemble the porphyry resting on the tuffitic sediments further south. The zone with banded leptite, immediately NW of the reddish porphyry, reminds, on the other hand, of the bedded tuffitic rocks in the Stuor Njuoskes—Nordhårås area, and in view of the conformity in the direction of strike the boundary has on Juoråive been drawn between the banded leptite and the reddish porphyry.

From a tectonical point of view Juoråive differs from the other parts of the district, since the dip sometimes has a westerly direction or stands vertical.

The leptitic rocks will be described below and as far as the porphyries are concerned the reader is referred to the following section. The porphyries on Juoråive are often inhomogeneous and brecciated, on account of which they should possibly be interpreted as lava breccias or flow breccias.

The leptites in the NW zone are unstratified but in the SE zone they are sometimes extraordinarily well banded and laminated and occasionally show a good agreement with the rocks further south. There occur for instance leptites with bands of hematite or garnet (Figs. 11, 12 and 14). As a rule the rocks are fine-grained and less metamorphosed than at Stuor Njuoskes and Nordhårås. In one of the porphyries there was thus observed a micropoikilitic groundmass, but on the whole the rocks have a fine-grained leptitic texture.

Microcline and quartz are the dominating minerals in the plain leptites but we also note the occurrence of an acid plagioclase, muscovite and a yellowish brown mica, piedmontite, rutile, tourmaline, barite, and ore minerals (mainly hematite but also bixbyite). Barite was abundant in a laminated leptite, the barite, hematite, and microcline occurring in alternating thin and irregular

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down the slope. After metamorphism and tectonic treatment this tuff agglomerate would very likely have been interpreted as a conglomerate. Similar observations were made also on Mt. Elgon (Ödman 1930, Fig. 22, p. 515).

layers (Fig. 16). The piedmontite in these rocks is unusually pale-coloured, showing only a faint pleochroism in pink and yellowish gray.

Figs. 11 and 12 illustrate one of the garnet-banded leptites. The garnet bands are yellow and alternate with lighter or darker gray bands, composed of quartz, microcline, and a yellowish brown mica. Under the microscope the garnet is yellowish gray and occurs in rounded individuals. The banding is sometimes disturbed and the garnet migrates into the quartz-microcline bands, forming patches and streaks. The garnet bands may attain a thickness of about 1 cm. The rock displays an interesting similarity to a leptite with bands of hematite and manganiferous garnet described by Geijer (1923, p. 106) from Riddarhyttan in Central Sweden.

An unusual type of rock, confined to Juoråive, has the appearance of a banded, fine-grained mica schist. The banding is most distinct, having almost a varved aspect. It is caused by the concentration of biotite and hematite (to a less extent) to certain »varves». The light-coloured bands are composed mainly of quartz, microcline, and muscovite.

Fig. 14 pictures one of the hematite-banded leptites, showing an unusually fine and regular lamination.

The appearance of beds of porphyries on Juroåive clearly indicates the volcanic *milieu* in which the rocks were deposited and it is believed that they were formed from volcanic debris of various kind in the same manner as the leptites further south. It is, however, possible that the distinctly banded rock just mentioned may have a more pronounced and direct sedimentary origin. The lack of tuff agglomerates on Juoråive should also be pointed out.

Finally, it should be mentioned that in the porphyry in the SE part of the exposed area there occur two pegmatite dykes which carry beryl and topaz (cf. p. 32).

Porphyry.

The porphyry is one of the most characteristic rocks of the district and also one of the best exposed (Plates 3 and 4).

On Tjatitsvare and at Rakten the parallel structure of the porphyry dips conformably with the underlying rocks. In the northern parts of the district, as at Stankajokk and on Sörhårås, the porphyry in general has a gentle dip to the SE or E, although locally the dip may be steep there, too.

The parallel structure is not caused by schistosity but by the sub-parallel arrangement of granulated feldspar phenocrysts, which now appear as white or yellowish white spots in the somewhat darker groundmass of the porphyry (Fig. 18). The granulated phenocrysts form thin plates or lenses, somewhat elliptic in shape and with their longer axis oriented parallel to the linear structure of the rock. The length is as a rule from 5 to 10 mm and the thickness 2—3 mm. When intercalations of tuff layers or portions showing flow structure occur in the porphyry, their parallel structure is conformable with that of the porphyry and its phenocryst spots. This circumstance indicates that the orientation of the phenocrysts is a primary feature, probably depicturing a flow structure. This feature was later accentuated by granulation and recrystallization.

When typically developed the porphyry is a light-gray and leptitic rock, in which occasional grains or streaks of opaque minerals, accumulations of fluorite, and small foils of a pink mica are discernible. Fine-grained piedmontite and yellow garnet also occur. The phenocryst spots, which are difficult to recognize on a fresh surface, are sometimes missing, and it is extremely hard to decide whether a lava or a tuff is at hand. The difficulty becomes even greater when, as for instance on Tjatitsvare or Sörhårås, the metamorphism is stronger and the rock acquires a gneissic appearance. It is very likely that in some instances the classification of the rock as a porphyry is erroneous.

The phenocrysts are chiefly made up of microcline, but quartz in rounded grains also occurs. This quartz porphyry appears in a number of places but it is mainly distributed around Stankajokk (Pl. 3). The quartz porphyry is probably only a locally developed form of the ordinary porphyry and does not seem to form separate beds.

With one exception (cf. p. 25) the porphyries throughout the district, including those occurring in the upper tuffitic series, are recrystallized and all primary groundmass textures are obliterated. The groundmass thus has a mosaic or leptitic texture (Fig. 19). Irregular and granoblastic textures occur in those places where the recrystallization is more advanced. The difference between phenocrysts and groundmass is then more or less obliterated.

Microcline and quartz are the dominating components of the groundmass, but an acid plagioclase is always present. Occasionally the amount is appreciable. Hematite is often present and so are the opaque manganese minerals. Muscovite is common and has sometimes a pink colour. Comparatively abundant are zircon, titanite, and fluorite. The grains of the latter have about the same shape as microcline or quartz and do not give the impression of being introduced later. More uncommon minerals are barite, piedmontite, apatite, rutile, and a light yellowish brown mica.

A sample of the porphyry from drillhole No. U9 at the N foot of Sörhårås (Pl. 3) has been analyzed (by F. Swenborg):

	%		%
SiO_2	73.30	BaO	0.58
TiO_2	0.26	P_2O_5	0.01
Al_2O_3	13.49	$H_2O^{+110°}$	0.29
Fe_2O_3	2.01	$H_2O^{-110°}$	0.07
FeO	0.51	K_2O	5.73
CaO	0.54	Na_2O	2.51
MgO	0.04	F	0.05
MnO	0.59		99.98

Sp. gr. = 2.66.

The analyzed rock is somewhat richer in quartz than is usually the case and petrographically it approaches the quartz porphyry. Comparatively large grains of quartz occur but it is not possible to determine whether they are phenocrysts. The sodium content is fairly high and albite with 8—10 % An occurs. The manganese content is surprisingly low seeing that manganese ore breccias occur in the vicinity. Hematite is the only opaque mineral recognized.

As mentioned above the porphyries intercalated in the upper tuffitic series do not differ in any essential ways from the porphyry now described. The spots of granulated feldspar phenocrysts are also here a characteristic feature. Occasionally, as at Stankajokk and in Manganravinerna, the spots are unusually large and attain a surface of 1—2 cm^2. Quartz-porphyritic varieties are known from drillholes on the northern slope of Nordhårås. In some cases the porphyries are inhomogeneous and give the impression of being brecciated (cf. Juoråive above).

Tuffitic Sediments in the Porphyry.

In three restricted areas, at Stankajokk, on Sörhårås, and on Tjatitsvare (Plates 3 and 4), there occur in the porphyry intercalations of bedded and banded rocks which are interpreted as being more or less directly derived from volcanic material and deposited in water. They are thus similar to the rocks of the lower and upper tuffitic series and like the latter they were formed in a volcanic *milieu*. The tuffitic rocks now under consideration are, however, homogeneous and do not contain any intercalations of lava beds.

Stankajokk. As is indicated on the map (Pl. 3) the tuff bed at this locality probably has a very restricted extension. In the west the tuff follows immediately on the massive quartz porphyry and dips 60° to the E. In the E part of the tuff bed there is a zone carrying fragments of porphyry and leptite, which is directly overlain by the feldspar porphyry dipping gently to the SE.

The rock in the tuff bed is fine-grained and displays a flamy banding in gray, white, and pink colours. Some bands are broken and are enclosed anew in the overlying bands.

A sample of the banded rock was examined in thin section. It is extremely potassic and contains chiefly microcline. Quartz is very rare. The colour of the pink layers is caused by finely divided and unusually pale-coloured piedmontite.

Sörhårås. The banded rocks on the top of Sörhårås occupy an area about 200 × 300 m in size and are superimposed on the porphyry. It is here inhomogeneous and is possibly a lava breccia. The sequence of the porphyry and the banded rocks seems to form an irregular trough but the partly imperfect exposures do not allow of any definite interpretation of the structure. In general the folding of the strata seems to have a more or less horizontal axis E—W.

The banded rocks are fine-grained, gray leptites with layers of varying thickness and composed of hematite or piedmontite. The bands with the latter mineral are unusually well developed and often attain a thickness of 5—10 cm. They are built up of a shiny, brownish black mass of fine-grained piedmontite and small grains of hematite (Fig. 20). The manganese content amounts to about 5—6%. The hematite-banded leptites are practically identical with those from the upper tuffitic series.

The microscopic texture of the rocks is equigranular and leptitic. The banding is noticeable also under the microscope. The light-coloured layers are composed of chiefly microcline, but quartz is also present although it is not plentiful. Common constituents are further muscovite (sometimes pink), yellowish brown mica, hematite, titanite, and apatite. Also garnet and fluorite occur.

In thin sections there are occasionally noticed tiny schlieren, orientated parallel to the banding and composed of quartz, microcline, hematite, muscovite, piedmontite, and fluorite. They are of interest as they are believed to form embryonal stages of the vein-like masses, mainly composed of quartz and coarsely crystallized piedmontite, which will be described in a following chapter. They appear in the piedmontite-rich leptites and are considered to be formed by the mobilization of material from the enclosing rocks.

Tjatitsvare. As is illustrated on the map (Plate 4) there are on this hill two small areas with rocks which, in view of the volcanic *milieu* in which they occur, have been placed in this group of rocks of volcanic affinity. The rocks in the E area are still in part comparatively fresh and also well exposed. The W area is not so well exposed and the relations less distinct. On the whole the rocks on Tjatitsvare are more altered than they are in any other part of the district and the rocks now in question are often difficult to classify and their boundaries to the surrounding rocks difficult to define.

The rocks in the E zone have a gentle dip and form a shallow trough, enclosed in the surrounding porphyries dipping moderately to the E. The axis of the trough strikes approximately N—S and pitches 25° to the S.

Among the rocks here present we recognize a hematite-banded leptite of the same type as occurs on Sörhårås and in the upper tuffitic series. It is still fairly well preserved.

Several other types of leptites were observed. They are less distinctly banded than the one described above, a circumstance partly due to a stronger metamorphism tending to destroy the banding. Microcline and quartz are the chief constituents and the texture is either leptitic or more irregular and granoblastic.

One of the rocks has a dark-coloured banding caused by a fine pigment of a black manganese oxide (pyrolusite?). A partial analysis by F. Swenborg gave 2.2 % Mn, 22.3 % Fe, 0.15 % Pb and 0.25 % Ba. This rock — and also others from the E zone — contains an appreciable amount of a mineral which has not been conclusively identified.[1] The optical qualities of the mineral seem

[1] E. Åhman has kindly undertaken a preliminary study of the optical qualities of the mineral and has communicated the following. The mineral is colourless in thin section and occurs in small orunded or short-prismatic grains, displaying an indistinct cleavage parallel to the elongation (c-axis). The extinction is parallel to this cleavage and to the mineral is biaxial and consequently rhombic. The refringence is fairly high (> 1.6) and the birefringence about 0.02. The optic angle was measured and appears to be $2V_\alpha = 80—90°$, in some cases $> 90°$. The mineral is not pleochroitic.

to indicate that it belongs to the entstatite-hypersthene group. The only opaque mineral observed in the rock is hematite: no opaque manganese mineral, except the secondary oxide pigment, was seen. As there are no other manganese minerals present, one may suspect that the manganese primarily enters the mineral in question and that it is a manganiferous rhombic pyroxene.

As regardsthe contents of iron, manganese, lead, and barium, there is nothing to indicate that the elements were introduced after the formation of the rock and it is believed that this is a case where these elements were deposited contemporaneously with the other constituents of the rock.

Another type of the leptites is unusually rich in viridine. The rock is indistinctly banded and the viridine is concentrated in nodular masses, arranged in irregular layers about 5—10 cm wide (Fig. 21). In thin section these masses consist of a »base» of quartz-microcline with large poikiloblastic, optically homogeneous individuals of viridine, grayish garnet with poikilitic quartz, barite, and muscovite.

Another banded leptite, rich in viridine, is shown in Fig. 39. Other leptites from the same zone are distinguished by sillimanite, accumulated in fibrous aggregates, and yellowish green, globular aggregates of garnet.

The leptites of the W zone on Tjatitsvare are more metamorphosed than the ones now described and the boundaries to the adjoining rocks are difficult to discern. The mineralogical composition is sometimes exceptional. Barite, fluorite, and hematite are thus fairly common. E. Åhman has carried out a volumetric analysis of two specimens of the barite leptite, the results being shown in the table below. Quartz is rare in some cases. A K-feldspar is abundant but its qualities are somewhat exceptional and probably two types are present. The grating structure of normal microcline is absent or at least very indistinct and the cleavage is poorly developed. In a number of cases the optic angle of the feldspar was found to be $2V_\alpha = 80—84°$, in which cases the mineral evidently is a microcline. In other cases $2V_\alpha$ was smaller, about 73—75°, and one may suspect an orthoclase with a small percentage of hyalophane. The extinction angles showed only slight deviations from those normal of orthoclase.

	Vol. %	Vol. %
Barite	15.0	22.0
Feldspar	19.4	31.4
Quartz	35.8	20.9
Hematite, etc.	23.7	23.1
Flourite	4.9	—
Accessories	1.2	2.7
	100.0	100.1

Other minerals present in these leptites are muscovite, titanite, piedmontite, and zircon.

In this zone there also occurs a brownish garnet rock, chiefly composed of garnet, which under the microscope has a yellowish gray colour. Microcline, quartz, and titanite are also present. The rock does not seem to be connected with the limestone a little to the W, but shows transitions to a garnet-bearing leptite, chiefly composed of microcline and the same barium-bearing feldspar as mentioned above. No calcite is present in these rocks.

It should finally be mentioned that within the tuffitic leptites on Tjatitsvare there occur small concentrations of iron and manganese ore minerals, forming either beds of a sedimentary origin or replacement bodies. A further description follows in an ensuing chapter.

Red Leptite.

East of and on top of the porphyry in Raktenvare and Tjatitsvare there follows a red-coloured, sometimes fairly coarse-grained leptite with a gentle dip to the SE. Occasionally it shows an indistinct parallel structure, resembling flow-structure in fresh lavas. In some cases the rock contains feldspar phenocrysts. The same red leptite outcrops also in Stuor Lastak in a thick bed that rests with a gentle south-easterly dip on the underlying volcanic series.

The coarse-grained leptite has the appearance of a fine-grained granite. The size of grain in this type is about 0.5—0.6 mm and in the more typical leptite about 0.3 mm.

The granularity changes aspect from irregular granoblastic to leptitic, even within the small space of a thin section, and the impression gained is that the recrystallization advanced in an irregular manner.

As in the porphyry, microcline and quartz are the dominating constituents of the leptite. Albite is comparatively rare. Ore grains are common and muscovite, chlorite, titanite, zircon, apatite, calcite, garnet, and orthite occur in insignificant quantities.

The following analysis by F. Swenborg was carried out on a sample of leptite from Tjatitsvare.

	%		%
SiO_2	71.75	BaO	nil
TiO_2	0.40	P_2O_5	< 0.01
Al_2O_3	15.36	$H_2O^{+110°}$	1.84
Fe_2O_3	0.48	$H_2O^{-110°}$	0.13
FeO	1.51	K_2O	6.29
MnO	0.52	Na_2O	1.19
CaO	0.36	F	0.04
MgO	nil		99.88

Sp. gr. = 2.64.

The main difference between the leptite and the porphyry — and the other acid volcanics — underlying the former is the difference in colour. The leptite is always more or less distinctly red but the other rocks are almost always light-gray. It is suspected that this difference is in some way or other connected with the manganese mineralization. It is quite conspicuous that almost everywhere the light-coloured volcanics carry manganese minerals, oxides or silicates, in disseminations or in breccias. The red leptite, on the other hand, has never been seen to contain any manganese minerals. From a mineralogical point of view the difference is due to the microcline in the volcanics under the leptite being colourless or white, whereas the microcline of the leptite is red.

Pegmatitic Veins.

Pegmatitic veins have been observed in many places in the district. As a rule they are not very well defined and streaky and of a small extension.

In their simplest form they consist of quartz, white or faintly pink microcline, muscovite, and sometimes hematite. There are many variations of this simple type with a more complicated mineralogical composition. A common type, occurring *e. g.* on Sörhårås, contains, apart from quartz and white microcline, coppery red mica in sheets about 15—20 cm^2 in size. A test for manganese gave only 0.5 % MnO (G. Assarsson). No Li was present. The optic angle $2V_\alpha$ is about 38—39° and β varies from 1.595 to 1.607, according to E. Åhman. Pending a complete analysis, to be given in Part 2 of the present paper, the mineral is provisionally called simply »red mica».

Another pegmatite on Sörhårås carried hematite in nodular pieces of the size of a fist. The hematite contained 2.5 % Mn (F. Swenborg) without any specific manganese mineral having been seen in polished section.

In other cases a number of manganese minerals of various kinds appear and the pegmatitic character is lost, the veins rather assuming the character of manganese ore veins. A closer description of the paragenesis follows on pp. 46—49.

On Juoråive two pegmatite dykes appear[1] in the porphyry on the E slope of the hill. They are worth mentioning because of their content of beryl and topaz. The dykes, which are close together, are 1—2 m wide and have been traced about 90 m along the strike.

The pegmatite is mainly composed of quartz, pink microcline, a grayish green muscovite, and fine-grained white feldspar, probably an albite. Thin plates of hematite occur.

The beryl is accumulated in certain portions of the pegmatite and intervening sections may be quite devoid of the mineral. It occurs in the usual six-sided crystals with a maximum diameter of 10 cm and approximately the same length. As a rule the crystals are smaller. The basis is occasionally developed. The colour of the mineral is yellowish white or pale green and under the microscope it is clear and fresh. A chemical analysis (by Mrs. A. M. Byström) of a composite sample taken from several crystals gave 12.5 % BeO.

Topaz is less common than the beryl and occurs in scattered individuals in the shape of long prismatic crystals of a maximum length of 10 cm and without any distinct faces. The whitish gray mineral resembles quartz and is translucent. A thin section cut at right angles to the prismatic zone gave a biaxial positive interference figure. The optic axis is $2V_{\gamma Na} = 60°.5$ and the specific gravity 3.58.

[1] In this case they are well-defined, ordinary dykes.

Mention should here be made of a small boss of a peculiar whitish gray granitic rock, which occurs at Stankajokk in the greenstone and in one of the inliers of leptite in the former (Pl. 3). The light-coloured rock is medium-grained and composed of white feldspar and smoky quartz in well individualized grains. It contains cavities with small crystals of epidote. Microscopically the rock is found to consist of chiefly quartz, oligoclase (15—20 % An), and microcline. The latter generally grows around the plagioclase. Some rutile and muscovite are also present. It is not clear whether the rock should be interpreted as a truly igneous rock, or if it marks a far-advanced stage in the mobilization caused by the younger red granite (cf. p. 58).

Structural Geology.

The tectonic relations in the district are as a rule quite simple. The direction of strike is practically the same from Juoråive in the N to Tjatitsvare in the S and the dip is mainly directed to the E or SE throughout the whole district. Exceptions from this rule are met with on Juoråive where in part the rocks dip to the W, within the Snavva sediments, which in the W lie horizontal or even dip to the W, and, finally, on Sörhårås, where the rocks in the higher portions of the hill show deviations from the general structure. In the following table are recorded the strike and dip in the different sections of the district.

	Strike	Dip
Juoråive	N35—60°E	65°E—60°W
Stuor Njuoskes	N30°E	60°E
Nordhårås-Stankajokk	N25—40°E	60—90°E
Sörhårås, SE part	N10—20°E	10—45°E
Bend in Situoälven	N10°W—N20°E	20—80°E
Rakten	N40—60°E	40—50°E
Tjatitsvare	N20—40°E	25—70°E

Observations on linear schistosity and on the pitch of the feldspar phenocrysts in the porphyry, etc., indicate that in the section from Stankajokk to Tjatitsvare the pitch of the fold axis dips at a low or moderate angle (15—35°) to the S or SSW.[1] From Stankajokk to Juoråive observations are lacking, but on the latter hill a pitch was observed dipping 20° in N30°E. Somewhere between Nordhårås and Juoråive a culmination evidently took place in the fold axis and it changed its dip from a southerly to a northerly direction.

A geological section across Nordhårås in an east-south-easterly direction to Stankajokk below the Ultevis cabin gives the following features (Pl. 3).[2] In the west the Snavva sediments occupy a very flat or somewhat undulating position. After a break in the exposures of about 350 m the rocks of the lower tuffitic series appear, dipping about 50° to the E. The dip of the Snavva sediments, adjoining the lower tuffitic beds, is a mere assumption (cf. the conditions at

[1] The amphibolitic greenstone intercalated in the porphyry on the lower SE slopes of Sörhårås pitches 45° to the SSW.

[2] The section is constructed so that the observation points, scattered on both sides of the section plane, are projected on this plane. The section must thus be considered idealized.

Rakten and on Tjatitsvare). Then follows the thick series of acid volcanics up to the contact to the porphyry. The dip of the porphyry in the portion between the contact and the tuff bed immediately N of the Ultevis cabin is not known; despite a careful search no structure could be seen.[1] The tuff dips steeply to the E and then the porphyry follows with a gentle dip directed to the SE.

The same conditions are met with in the section in Pl. 4, which is drawn through Tjatitsvare. In the west the Snavva sediments are gently folded but in the east their dip steepens and they are followed by the conformable series with limestone and acid volcanics. The latter dip in under the red leptite, which finally acquires a gentle dip to the SE.

The same structural features are met with around Rakten but the conditions are here less distinct, as the exposures are not so complete as in the other sections.

To summarize, it is clear that the structure in the district is developed as a large monoclinal fold or flexure. The development of the flexure in the volcanics instead of the gentle folds of the Snavva sediments may be attributable to the fact that the comparatively weak compressional force — that it was comparatively weak is evident from the type of the folds in the sediments — was insufficient to force the rather rigid and thick porphyry-leptite series into folds, the underlying banded rocks only being turned up.

Finally, it should be mentioned that the flat position of the rocks, noticed in the Snavva sediments and on Stuor Lastak and at other localities, also prevails in the regions to the west and south of the manganese zone. Flat-lying sediments of the Snavva type thus still occur 20—40 km S of our district.

The tectonic lines of the district run chiefly in the direction N or NNE. The main tectonical lines in the district around Kiruna (Geijer 1931, Pl. 1) and in the Arvidsjaur district (Grip 1946), situated N and S, respectively, of Ultevis, have the same general direction. According to Geijer's views (1931, p. 28) the oldest pre-Cambrian, the so-called porphyry-leptite formation, of Northern Norrbotten seems to have been but slightly folded before the intrusion of the late pre-Cambrian Lina granite and its present geological structure was developed in connection with the intrusion of this granite, *i. e.*, during the Carelidic orogenesis. This is in good agreement with the conditions ruling in the Ultevis district and its environs. The volcanics and the underlying Snavva sediments are all pre-Cambrian and, broadly speaking, comparable in age with the rocks from Kiruna and Arvidsjaur. In the vicinity of Tjåmotis and Niauve, S of Ultevis, the Snavva sediments are folded and to a large extent migmatized in connection with the intrusion of a red granite, which we have reason to believe is contemporaneous with the Lina granite. The metamorphism in the manganese district is due to the same granite, no other possible eruptive rock occurring here. The folding of the Ultevis rocks belongs to the same cycle as the metamorphism and migmatization. There are thus strong reasons indicating that the folding and metamorphism of the rocks of the Ultevis district belong to the Carelidic cycle.

[1] The banking is, however, well marked, as seen in Fig. 17.

Description of the Mineralization.

Hematite Mineralization.

Sedimentary Types.

A hematite mineralization of this type is met with on Juoråive, Stuor Njuoskes, at Stankajokk, and on Tjatitsvare.

The hematite-banded ores, merely small and economically valueless concentrations of hematite in the tuffitic leptites, are of interest mainly from a genetic point of view and for comparisons with the manganiferous ores of a similar origin.

The hematite-banded types from Juoråive and Stuor Njuoskes are very low in iron. A partial analysis of a type from the former locality gave 13.2 % Fe and 0.1 % Mn. They are, however, mineralogically interesting, as sometimes an appreciable amount of barite occurs. Quartz and microcline are the dominating components, and structurally and texturally they do not differ from the hematite-banded leptites.

At Stankajokk, a short distance below the contact to the porphyry (pp. 21—22), there occurs a narrow zone in the hematite-banded leptite which carries an abundance of hematite. The banding is well developed and the layers of gangue minerals are thin and insignificant. Under the microscope the alternating bands of hematite and gangue are well discernible (Fig. 22). The texture is leptitic, both in the hematite bands and in the layers of gangue minerals. Microcline, quartz, and a sericitic mica are dominating in the latter. A partial analysis (by F. Swenborg) gave the following result:

Fe	24.03 %	K_2O	3.95 %
Mn	0.23 %	Na_2O	0.51 %

In the sedimentary tuffs on Tjatitsvare there occur hematite-banded rocks of the same type as on Juoråive, at Stankajokk, and at other localities. In two or three places they also contain compact but only 3—4 m thick and discontinuous beds of hematite ore. As mentioned above, the metamorphism on Tjatitsvare is comparatively strong and it has also struck the hematite ores, which often are coarse-grained and crumbly. Consequently, practically all primary structures such as banding have been obliterated. A migration of material within the ores has probably also taken place and brought about changes.

One sample of a hematite ore contained 73.9 % FeO and 2.3 % MnO (analyst F. Swenborg). It should be pointed out that in some parts of the iron mineralizations, manganese minerals, such as bixbyite and piedmontite, have also been observed and that consequently, depending on the position of the sample or specimen, the mineralization may be classified as manganiferous iron ore.

The texture of the ores is leptitic. Quartz and K-feldspar are common gangue components but there also occur garnet, light brown mica, fluorite, calcite, barite, and the questionable rhombic pyroxene (cf. p. 29). The paragenesis thus resembles that of some of the leptites from the same locality.

Epigenetic Types.

Hematite mineralization of another character is met with in the foot wall of the manganese ore in Övre Manganravinen on Stuor Njuoskes (p. 41). The two ores are in contact and in the hematite ore schlieren of manganese ore are seen and vice versa. As the manganese ore, the hematite ore, too, occurs in tuff agglomerate and replaces it. The ore contains remnants of fragments of the agglomerate and in thin section one can see how both groundmass and fragments are filled with grains of hematite. The analysis below (by Statens Provningsanstalt, Stockholm) gives an idea of the composition of the ore.

	%		%
Fe	37.0	CaO	1.6
Mn	1.24	SiO_2	31.6
PbO	0.02	S	0.006
BaO	0.22	P	0.040

The ore is fine-grained and of a bluish gray colour. Hematite is the only ore mineral present. Piedmontite occurs in small grains and it is quite likely that the manganese content is due to this mineral. Besides these two minerals, quartz, microcline, light-brown mica, fluorite, titanite, apatite, and zircon are present in small amounts.

In this connection it should be mentioned that a hematite mineralization is met with also in other tuff agglomerates (cf. small streaky mass in Fig. 4).

Manganiferous Iron Mineralization.

Under this heading are grouped poor mineralizations with iron and manganese from Nordhårås and Tjatitsvare. Apart from hematite, also fair amounts of bixbyite, braunite or piedmontite are present. It would seem evident that during the metamorphism, particularly pronounced on Tjatitsvare, a migration of material took place in the ores, considerably hampering the interpretation of their origin. The mineralization occurs in banded leptites and there are reasons to believe that they are of a sedimentary origin.

Nordhårås.

On the north slope of Nordhårås, about 800 m SW of the Ultevis cabin, there occurs a quartzose iron ore which in places is rich in manganese. The ore is intercalated in tuffitic rocks of the upper series. The mineralized zone is about 6 m wide and the length hardly more than 20—30 m. A sample across the full width of the zone gave the following average values:

Fe	25.0 %	Mn	4.7 %

Two ore boulders from the same locality — the find of manganese ore boulders on the slope of Nordhårås gave rise to the localization of the mineralized zone in question — have been analyzed and their content of manganese was considerably higher:

% Fe	% Mn
20.2	27.6
23.3	28.0

The ore is fine-grained and rich in quartz which occasionally may form streaky masses. The iron-rich parts are bluish gray and the manganese-bearing portions are black. The latter occur in the form of schlieren in the hematite ore. The quartzose parts of the ore are reddish (piedmontite in one case caused the red colour). The ore has traces of banding preserved and the wall rocks show a distinct lamination and occasional fragments.

In thin section the gangue minerals appear in irregular areas or on fissures clearly cutting the ore. Besides quartz, small amounts of calcite, muscovite and fluorite are present.

In the manganese-rich parts of the ore, bixbyite is the prevailing opaque mineral. Against the areas with gangue minerals it shows an idiomorphic development. Hematite is present in bixbyite in the form of a net-work distinctly cutting the host mineral (Fig. 23). Where veinlets of hematite cross each other, the surrounding bixbyite is replaced by the hematite. Sometimes the hematite veinlets pass over into veinlets of gangue minerals. The hematite is occasionally lamellar and intergrown with the bixbyite along crystallographic planes.

Braunite is often associated with hematite and gangue in the veinlets (Fig. 24). Some braunite also occurs in the bixbyite in the shape of lamellar grains intergrown // (100). Bixbyite is sometimes replaced by braunite, hematite, and gangue. This breaking-down of the bixbyite may proceed so far that nothing is left of the original mineral, only a lattice-work of braunite filled with the other two minerals remaining.

Tjatitsvare.

The manganese mineralization is wide-spread on this hill and black manganese oxide staining is seen in several places in the banded tuffitic rocks. The mineralization occurring here is considered to be sedimentary and will be briefly mentioned below.

The mineralizations, which on the whole are comparatively poor in manganese, are composed of a granoblastic or occasionally more regularly leptitic base of mainly quartz and the same exceptional K-feldspar described above (p. 30). Other minerals occurring in the ores are muscovite, light-brown mica, fluorite, and barite.

Hematite, bixbyite, braunite, and pyrolusite are encountered in polished sections. Hematite generally forms leptitic aggregates, and the braunite may have the same appearance. Particularly braunite but also hematite are found as decomposition products in bixbyite. The latter as a rule forms quadratic or rectangular grains which with high magnification under the microscope are seen to be more or less decomposed. Large portions of the bixbyite grains are occupied by a skeleton intergrowth of an unknown gangue mineral,[1] hematite, and braunite (Figs. 25 and 26). The latter mineral may carry inclusions and remnants of bixbyite. Some of the isometric bixbyite grains are intact but others are almost completely decomposed. Braunite is sometimes missing and hematite is occasionally developed in needle-like grains which cluster together to an isometric pattern.

[1] It was not observed in thin section and could not be identified in polished section.

Pyrolusite occurs on thin veinlets, cutting the other manganese ore minerals. It is a late oxidation mineral.

The two analyses below illustrate the proportions of iron and manganese in this type of mineralization (analyst F. Swenborg).

	%	%
FeO	32.4	44.3
MnO	15.0	12.8
BaO	—	1.43

Manganese Mineralization.

Sedimentary Types.

In the upper tuffitic series at Stankajokk and in Manganravinerna there were found in some places jet black layers of a fine-grained mass containing appreciable quantities of bixbyite, hollandite, and braunite. The layers are only 1—2 cm thick and 1—2 m long. A fine banding is noticed in the manganese-bearing layers.

The layers occur in a fine-grained gray leptite, mainly composed of quartz, microcline, and ore minerals, with small additional amounts of turbid plagioclase, mica, piedmontite, and zircon. In one thin section viridine and the questionable rhombic pyroxene described from Tjatitsvare (p. 29) were seen associated with the manganese oxide minerals. The occurrence of viridine and rhombic pyroxene is of interest, as it shows the relationship between the comparatively little metamorphosed manganese layers now under consideration and the more strongly metamorphosed rocks on Tjatitsvare with their occasional content of manganese ore minerals.

In one of the polished sections examined braunite is predominant. It forms fine-grained, mosaic aggregates, intimately intergrown with the gangue (Fig. 27). Some aggregates enclose gangue minerals in their middle and others carry in the centre a grain of hollandite. Hematite is rare. Towards the leptite surrounding the manganese layer the braunite aggregates gradually grow smaller and sparser and the mineral begins to appear in separate, fairly well crystallized individuals. They contain kernels of isometric bixbyite or else the two minerals appear in a lamellar intergrowth. Further away from the manganese ore bands the size of the braunite grains diminishes simultaneously with an increase in the size of the bixbyite kernels. Finally the braunite disappears entirely and only bixbyite in idiomorphic grains occurs associated with hollandite in the typical short-prismatic grains.

In another polished section the ore minerals are intimately associated with viridine and the presumed rhombic pyroxene. The surrounding leptite carries abundant bixbyite, here exceptionally poorly developed. Occasionally braunite and hematite are intergrown with bixbyite. In the ore-bearing band bixbyite dominates but in local areas braunite prevails. The small grains of bixbyite are well crystallized but the aggregates are composed of allotriomorphic grains. Braunite often occurs in lamellar intergrowth with bixbyite.

The observations made under the microscope apparently indicate that braunite is later than hollandite and bixbyite and that it belongs to the so-called metamorphic type (p. 51).

Although the manganese mineralization now described is quantitatively negligible, it plays — in connection with the bands of piedmontite and garnet occurring in the tuffitic sediments — an important rôle in the discussion of the origin of the manganese mineralization in the district.

A chemical analysis was made of one of the manganese ore layers and of a leptitic layer adjoining it (1 and 2 respectively in the table below). The amount of FeO is approximately the same in both cases but MnO varies considerably owing to the different amounts of manganese ore minerals present in the two samples. The presence of barium and lead is of particular interest (cf. discussion on p. 55). The lack of SO_3 shows that the two elements are combined in hollandite, which as a rule contains both barium and lead.

	1.	2.
FeO	4.63 %	4.88 %
MnO	43.2	12.8
BaO	0.64	0.59
PbO	1.73	1.25
SO_3	nil	nil

Analyst F. Swenborg.

Epigenetic Types.

The majority of the manganese mineralizations of the district are entirely different from the ones mentioned above and are characterized by epigenetic features, such as replacement, breccias, and veins.

Breccia Ores. In many places in the district and particularly in the section between Stuor Njuoskes and Sörhårås the porphyry and occasionally also the tuffitic types contain breccias with manganese ore minerals. On Tjatitsvare the breccias seem to be missing. The breccias are identical to the boulders with manganese ore breccias which were found in the Murjek area and it cannot be doubted that the boulders eminated from the Ultevis district.

In the following description of the ore breccias we distinguish between two different mineralogical types, namely 1) breccias with mainly hollandite and some hematite and braunite, and 2) breccias with practically exclusively braunite.

Some of the breccia localities were extensively drilled in the hope that large even though low-grade ore bodies might occur. This does not seem to be the case, however. In general the breccias do not contain more than about 5—10 % Mn.

The brecciating manganese ore veins are megascopically well defined and consist of a fine-grained, bluish gray ore, when hollandite is the prevailing mineral (Figs. 28 and 29). The braunite breccias are black in colour and of a granular and often crumbly consistency. The breccias are sometimes associated with small compact ore bodies, probably seldom exceeding a few tons in weight. They are due to a more advanced replacement of the enclosing rocks in the vicinity of the ordinary breccias and show resemblance to the type of manganese mineralization described in the following section. They consist of high-grade manganese ore and contain only small amounts of gangue or wall-rock remnants.

Some manganese breccias carry more or less replaced remnants of the wall rocks and in some cases one observes how the breccia passes over into a disseminated ore type. The breccia network of veins and fissures is as a rule unorientated, but occasionally, for instance on the N slope of Sörhårås, the breccia is elongated in the general direction of the fold axis.

As mentioned above, the hollandite breccias are fine-grained, and besides hollandite only piedmontite, fluorite, and quartz are occasionally visible to the naked eye. In some cases the hollandite is more coarse-grained and forms needle-like and fibrous aggregates in which the individuals attain a maximum length of 5—10 mm. The bluish manganese breccia veins are difficult to distinguish from the similar veins of hematite which appear in association with the hollandite breccias. The hematite has a finely granular structure, which is lacking in the hollandite, and the latter has a streak which is distinctly brown in comparison with the red streak of hematite. However, occasionally hematite is present in an appreciable quantity in the hollandite ore, and in those cases the distinction mentioned does not exist.

In thin sections of the breccia remnants of the replaced wall rock are seen in the ore veins. Laterally the veins sometimes pass over into a dissemination of manganese ore minerals. The mineralizing solutions presumably entered the host rock along narrow fissures, which acted as starting points for the replacement.

Quartz seems to be formed in connection with the mineralization, as it occurs within the ore veins, some of which may be seen to pass gradually over into quartz veinlets. Muscovite is also sometimes seen. The occurrence of fluorite has been mentioned. Under the microscope it is seen how the interior parts of the grains are colourless or faintly purple, but towards the surrounding ore grains the mineral is almost opaque or obtains an extremely strong purple colour.

The microscopic texture of the ores is generally granoblastic or leptitic in the same degree as the wall rocks, indicating that also the former are recrystallized. The hollandite of the fibrous aggregates has not acquired the granoblastic texture and under the microscope it resembles uralite.

Besides the predominant hollandite, braunite and small amounts of hematite and bixbyite are also met with. Pyrolusite is rare and occurs on microscopic veinlets in the other manganese oxides as a late oxidation product.

Braunite breccia is only encountered in a local accumulation of glacial boulders, named, from the locality, the Tjålme boulders and situated 2.5 km NE of the Rakten cabin. The boulders are partly typical breccias and partly massive ore, probably emanating from small accumulations of ore associated with the breccia. The breccia boulders sometimes measure 2—3 tons in weight. They are localized to an area about 150 × 200 m in size and they are certainly of a quite local character. Despite these circumstances and the four drillholes drilled in the limited area, no mineralization was found. It is quite likely that the whole »ore body» was contained in the boulders. The compact ore ran fairly high in manganese, as is shown in the two analyses below (by the Boliden Laboratories, Boliden):

Mn%	Fe%	P%	S%	Ba%	Pb%
37.4	16.3	0.004	< 0.1	0.10	0.04
45.8	12.4	0.009	0.1	nil	0.03

The texture of the ore is distinctly leptitic as is the texture of the porphyry wall rock in the boulders. Generally the ore is fine-grained but locally the braunite grains may attain a diameter of 2 mm. Braunite is dominating and the mineral has a characteristic appearance in polygonal grains (Fig. 38). Some boulders carry fine-grained aggregates of hematite. In some polished sections hematite occurs on thin veinlets, cutting the braunite, or as thin coatings on braunite grains. Hematite is here later. The mineral may also appear in separate grains within the braunite individuals, in which case the age relations are more uncertain. Some braunite grains contain small inclusions of bixbyite; they are probably replacement remnants. The Fe_2O_3 liberated in the replacement may have formed some of the hematite present in the braunite ore.

The chemical composition of the Tjålme boulders is so far interesting as the contents of Ba and Pb are exceptionally low in comparison with the hollandite ore. This question will be discussed further below.

Compact Ores. The ores of this type form small bodies of replacement character. They are known from Övre Manganravinen on Stuor Njuoskes, Tjatitsvare, and Rakten.

In Övre Manganravinen there occurs, in the pyroclastic series, an ore body measuring 25 m in length and about 2 m in maximum width. The pyroclastic rock is a fine-grained tuffitic type alternating with beds of tuff agglomerate. A bed of the latter rock has been replaced by the ore minerals, fragments of the rock still being visible. The ore body strikes conformably with the wall rocks and dips 70—80° to the E.

The manganese ore borders in the west on a small body of hematite ore, as mentioned on p. 36. The contacts are indistinct and the hematite ore contains irregular streaks of manganese minerals.

The ore is fine-grained and has a bluish black colour, thus resembling the manganese breccias. The main mass of the ore is hollandite. Other minerals megascopically visible are bixbyite in small cubic porphyroblasts and measuring 3—4 mm, quartz in fine-grained, sometimes pinkish aggregates, piedmontite, and fluorite. The ore contains sporadic pores, which are clad with small needles of hollandite. The quartz is occasionally drawn out into schlieren which give the ore a parallel structure.

The examination of thin sections of the ore also disclosed the presence of minute quantities of alkali feldspar (microcline?) and a light-brown mica.

In polished section under the microscope the ore has a granoblastic texture built up of hollandite in typical short-columnar grains, resembling hornblende in shape, and irregular aggregates of hematite in polygonal grains (Figs. 30 and 31). In the same manner as the surrounding rocks, the ore is recrystallized and no primary features are observed. As in the breccia ores the hollandite may sometimes be developed in needle-like grains.

The bixbyite is developed in cubic or step-like grains, distinctly showing the isometric symmetry (Figs. 35 and 36). The mineral contains inclusions of gangue, hematite, and hollandite. Those of hollandite are as a rule smaller and scarcer than the hollandite grains outside the bixbyite individuals and it thus seems quite likely that bixbyite is later than hollandite.

Braunite, amply scattered in the ore but only in small quantities, belongs to a later phase (the metasomatic type, p. 50), as it is seen to cut and replace hollandite and bixbyite. The mineral is inhomogeneous and built up of two components. One of them is probably braunite *sensu strictu*, but in polished sections the other is somewhat lighter gray than the former. It has the same pleochroism and anisotropism as the ordinary braunite. The intergrowth between them is irregular and it is believed that they are contemporaneous. In this connection we may quote Schneiderhöhn-Ramdohr (1931, p. 570), who mention that they have noticed inhomogeneities in braunite. The braunite grains are always too small to allow a separation of the two components.

Manganite was seen in one polished section only and nothing definite can be said about its position in the paragenesis; it is, however, a late-crystallizing mineral. All the manganese minerals, including the manganite, are under the microscope seen to be cut by narrow veinlets of a soft, yellowish white and strongly anisotropic mineral, which has been identified as pyrolusite. It is considered to be a recent oxidation mineral.

Two samples of the ore, the one an average sample from a dump and the other a specimen of rich ore, have been analyzed with the following result:

	I.	II.
Fe	27.2 %	7.50 %
Mn	18.8	39.91
Ba	4.2	10.85
Pb	1.9	4.20
S	0.04	0.02
P	0.010	nil
SiO_2	17.5	4.29

I. Average sample. Analyst Statens Provningsanstalt, Stockholm.
II. High-grade specimen. Analyst A. Bygdén.

On the northern slope of Tjatitsvare (Fig. 2) there occurs a similar ore in a small body measuring 2—3 m in thickness and approximately 10 m in length. The axis of the ore body pitches gently to the S, conformably with the general pitch of the rocks on Tjatitsvare. The wall rocks are light-gray, fairly coarse-grained and strongly metamorphosed leptites which are difficult to classify. It

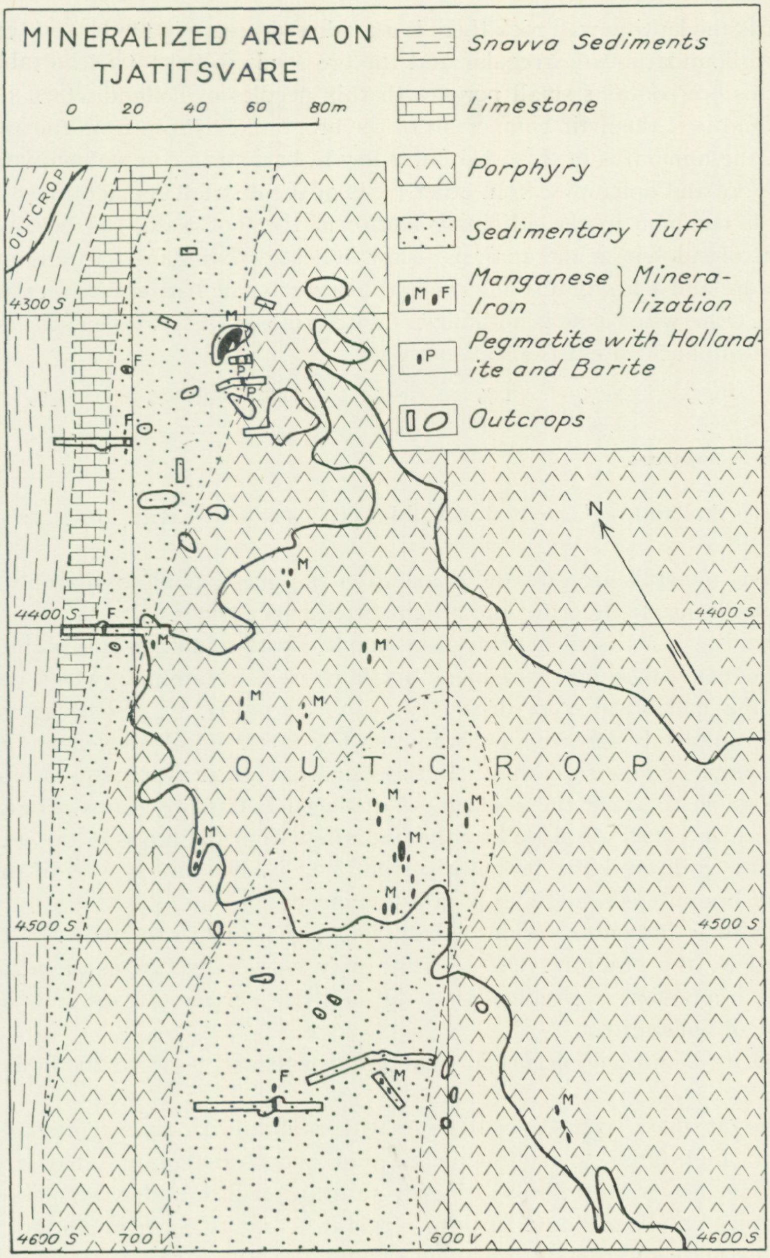

Fig. 2.

seems as if the ore was situated on the contact between porphyry in the E and the western one of the small zones of sedimentary tuffs. The high content of barite (p. 30) is characteristic of the foot-wall leptite.

The ore is bluish gray in colour and fine-grained. Wall-rock remnants are rare.

Towards the leptitic wall rock there is a gradual decrease in the tenor of the ore. The ore boundaries are irregular and the ore sends »off-shoots» into the walls. Also this ore contains small pores with thin needles of hollandite(?).

Hollandite is the main component of the ore, but as is seen from the analysis below, the mineral is in this case fairly low in barium in comparison with hollandite ore and hollandite from other parts of the district. As mentioned above barite is common in the adjoining leptite in the foot wall. The insignificant amount of sulphur in the analysis below indicates that some barite is present in the ore and a few grains of a mineral believed to be barite were seen in thin section. Otherwise barite is not known to occur in ores of this type in the district and the sulphur content is always very low.

Mn%	Fe%	P%	S%	Ba%	Pb%	SiO_2%
37.8	9.76	0.04	0.19	0.39	2.02	5.44

Analyst: F. Swenborg.

Besides hollandite, also braunite, bixbyite, some hematite, and pyrolusite occur.

Gangue minerals are rare and apart from the questionable barite only small amounts of quartz, fluorite, and a light-brown mica occur.

Hollandite is as usual developed in simple, short-columnar grains (Fig. 32). They float in a base poor in gangue but fairly rich in braunite, which here replaces the hollandite more distinctly than usual (Fig. 33). Some grains are almost completely replaced by braunite. The latter is inhomogeneous in the same manner as described above. In the somewhat larger aggregates of braunite it is possible to trace the contours of replaced hollandite grains through the difference in colour displayed by the braunite within the limits of the previous hollandite grain and the braunite surrounding it. The intergrowth of the two kinds of braunite is sometimes zonally arranged.

Bixbyite is present in grains, often showing a cubic symmetry. They are replaced by the braunite. The bixbyite may contain inclusions of hollandite and the impression is obtained that the bixbyite porphyroblasts grew at the expense of hollandite.

Hematite is rare and occurs in small grains enclosed between the hollandite grains.

In the ore there occurs a small pegmatitic nodule with an exceptional composition. Light-gray, platy microcline and quartz dominate. They are cut and replaced by a flinty, brownish gray substance which under the microscope is recognized as chalcedony. In thin section it is seen to occur in distinct veins which brecciate and replace chiefly quartz but also feldspar (Fig. 34). In narrow veinlets of chalcedony there are formed small cavities, clad with »warts» of chalcedony spherulites. The chalcedony contains small grains of a mineral resembling barite(?).

Under the microscope, in ordinary light, the chalcedony is practically colourless and has irregular cracks which are considered to be due to shrinkage. The refraction of the chalcedony lies between that of quartz and microcline. In polarized light it appears to be built up of spherulites with a maximum diameter of 0.2 mm.

At the Rakten cabin at the western end of Raktenvare the limestone contains in a number of places streaky lenses with partly fairly high-grade braunite-hollandite mineralization (Fig. 37). It may appear directly in the limestone but more often the ore minerals occur in the silicate-bearing bands in the latter. The ore-bearing zones are only about one m wide and 4—5 m long.

During the search for ore boulders in the area a great number of boulders were found, sometimes carrying a high percentage of manganese (Pl. 3). As against the former type the boulders consisted of braunite ore without any hollandite. The ore is associated with garnet and piedmontite and it is very probable that also this type of mineralization is associated with the limestone zone. Only very little calcite was seen in the boulders, however, and it is quite likely that mainly silicate-bearing portions of the limestone were mineralized. Despite a thorough drilling in the area no mineralization was struck representing the type in the boulders. It is believed that they came from very restricted and insignificant concentrations.

From a mineralogical point of view we may thus differentiate between two types of mineralization at Rakten: 1) braunite ore and 2) mixed braunite-hollandite ore.

In the table below are listed a number of analyses of the ores. The analyses were made by the Boliden Laboratories in Stockholm.

	Mn%	Fe %	P%	S%	Pb%	Ba%	SiO_2%
1. Braunite ore; boulder	50.7	5.6	0.005	0.3	0.04	nil	—
2. »	42.1	4.8	0.012	0.5	0.02	0.20	—
3. »	45.1	4.17	0.01	0.03	< 0.1	0.31	16.2
4. Braunite-hollandite ore; boulder	23.4	2.72	0.02	0.02	0.58	6.88	32.7
5. »	22.9	1.97	0.02	0.08	0.37	7.79	28.5
6. Braunite-hollandite ore in limestone	31.4	2.6	0.024	0.2	0.05	5.10	—

The braunite ore is black and fine-grained; in appearance it resembles the Tjålme ore boulders. Megascopically there is hardly anything but braunite to be seen. Piedmontite and small spots with calcite or quartz-feldspar aggregates were occasionally observed. To these may be added titanite, which was observed in thin sections.

The leptitic texture is distinct in the braunite ore and the braunite occurs in equi-dimensional grains. It belongs to the metamorphic type (p. 51). Besides braunite, also hematite, manganite, and pyrolusite occur, but always in small amounts. Braunite is normally developed in most cases and only once was it found to be inhomogeneous in the same manner as mentioned above. Hematite occurs as inclusions in braunite or on veinlets of gangue cutting the braunite. The manganite has not been definitely identified. The mineral may be hausmannite but the multiple twinning typical of this mineral is absent. Pyrolusite is as usual a late oxidation mineral.

The braunite-hollandite ore is bluish gray and in the fine-grained material shiny needle-like crystals of hollandite are visible. Gangue minerals and remnants of the wall rocks, such as limestone and leptite, are often seen. Piedmontite seems to be particularly common and is seen to form massive, streaky bands alternating with the manganese ore minerals. Otherwise the ore contains about the same gangue minerals as are characteristic of the limestone and the silicate bands in it. It may be pointed out that the calcite spots in the ore are remarkably free from ore minerals, despite a rich dissemination in the adjoining portions.

Braunite and hollandite in different proportions are the dominating opaque components of the ore. Hollandite is corroded and veined by braunite. The latter carries small inclusions of hematite, hollandite, and gangue. In one case small inclusions of bixbyite were also seen.

The difference in chemical composition between the braunite and the hollandite mineralizations has already been pointed out (p. 41). The difference is noted also here at Rakten. As is seen in the table above, the braunite-hollandite ore at Rakten contains about 5—8 % Ba, whereas the sulphur content is low. With Tjatitsvare as the only exception, the hollandite ore of the district carries appreciable quantities of Ba and probably it is so at Rakten as well. The braunite ore, on the other hand, is poor in Ba. Two of the analyzed braunite boulders contained more S than the braunite-hollandite ore, and this sulphur may be combined with the small amount of Ba present and form barite, although the mineral was never seen.

The same conditions as here outlined are ruling also in the Tjålme braunite boulders as regards chemical composition, and the contents of Ba and Pb are very low.[1]

In the hollandite-bearing braunite ore from Rakten the content of lead is low in comparison with that of the hollandite ores from, *e. g.*, Stuor Njuoskes and Tjatitsvare and the sedimentary manganese layers at Stankajokk. The lead content varies from 1.73 % at the latter place to 4.20 % in the high-grade ore at Stuor Njuoskes. The pure braunite ores, on the other hand, as at Tjålme and Rakten, are very poor in lead.

Manganese Ore Veins.

In connection with the description of the pegmatitic veins in an earlier chapter (pp. 32—33) it was mentioned that in some places they pass over into veins carrying a variety of manganese oxide and silicate minerals. These manganese veins are known from a number of places within the district and some of them

[1] It may here be pointed out as a peculiar feature that the braunite ores at Tjålme and, to some extent, also at Rakten contain a surprisingly high percentage of iron. Data are as yet insufficient and it is not known whether the iron is due to hematite intermixed in the braunite, or if this mineral has in itself a high content of iron. This question will be dealt with in Part 2.

will be described below. To some degree the paragenesis of the veins is dependent on the *milieu*, in which they occur. This is evident from the fact that the pegmatitic veins preferably carry manganese minerals in those cases where the surrounding rocks are enriched in manganese.

Övre Manganravinen. In immediate connection with the manganese ore body in this locality there occurs a younger vein about 30—40 cm wide. Quartz is plentiful but white microcline is sparse. Among the more unusual minerals we note bixbyite in masses several kg in weight, well crystallized hollandite in 10—15 cm long columnar crystals in quartz, braunite, piedmontite, yellowish brown garnet, hematite, and small books of the red mica (p. 32). Occasionally the minerals are well crystallized but usually they occur in crystalline masses. Small cavities are common, filled with crystals of bixbyite, hematite, piedmontite, garnet and/or quartz.

In addition to the minerals enumerated the microscopic examination of thin sections and polished sections disclosed the presence of small amounts of colourless hornblende, barite, and pyrolusite.

Bixbyite from this locality has been analyzed (cf. Part 2). The material chosen contained some piedmontite, braunite, and hematite. In one case rectangular grains of bixbyite were full of extremely thin, sometimes hardly observable lamellae of a grayish mineral resembling braunite. In a cubic bixbyite grain the braunite lamellae were orientated at 45° to the cube face. A similar occurrence has been described by Dunn (1936, p. 115) from the Indian manganese ores.

The crystals of hollandite in the quartz are also homogeneous and picked material has been analyzed (cf. Part 2). In polished sections small grains of hematite and narrow veinlets of braunite were observed.

Sörhårås. At the N foot of this hill there appear, in the porphyry close to some manganese breccias, pegmatitic veins with quartz and white microcline. One of the veins carries concentrations of bixbyite of the size of a fist. Occasionally the mineral is developed in perfect cubes modified by a trapezohedron and with an edge length of 2.5 cm (Fig. 41). Books of the red mica occur in the crystalline bixbyite.

In another of the veins, here of the character of a gash vein, there was a shallow cavity, whose walls were crowded with bixbyite cubes up to a size of about 2 cm. They were embedded in quartz and yellowish gray fluorite. The latter mineral is quite common in the veins but it generally has a purple colour. Delicate bixbyite crystals could be seen all by themselves in drusy cavities in quartz.

A polished section of bixbyite showed that also here the mineral is partly decomposed to braunite and hematite, appearing on narrow veinlets. In one case hematite was associated with a mineral which probably is hausmannite. It is similar to braunite but in oil immersion the pleochroism is too strong and the mineral has a moreen shimmer (Schneiderhöhn-Ramdohr 1931, p. 575). Strong anisotropism, red internal reflexions, and twinning are other features.

On the E slope of Sörhårås pegmatites with quartz and white microcline are also common. The abundant occurrence of well crystallized hollandite is here noteworthy. In one case the thick-tabular microcline was pierced by up to 0.5 m long bundles as thick as an arm and composed of long-columnar crystals of hollandite. The individual crystals measured in section about 1 cm^2. In another case the mineral was intergrown with quartz and had the shape of some mm thick and 5—10 cm long acicular crystals accumulated to fan-shaped bundles. In a third case acicular hollandite crystals were intergrown with practically black fluorite.

On the top of the hill there occurs another type of veins. In some of the piedmontite-banded leptites in this locality the rocks contained microscopic schlieren, composed of various minerals, *e. g.* piedmontite, fluorite, and hematite (cf. p. 29). In the same rocks there occur irregular concentrations and vein-like masses which are built up of a similar paragenesis, namely quartz, microcline, light-brown mica, sometimes well crystallized and coarse-grained piedmontite, fluorite, and hematite. Also molybdo-scheelite has been observed. The piedmontite has been analyzed and will be dealt with in greater detail in Part 2.

Tjålme. To this group of veins may also be counted a pegmatite which contains the rare mineral svabite, $FCa_5(AsO_4)_3$.[1] One of the braunite breccia boulders from Tjålme (p. 40) consists in part of a pegmatite with quartz, gray or faintly pinkish microcline, and occasional grains of bixbyite. The svabite occurs in irregularly prismatic grains attaining a maximum size of 4 × 2 cm. The mineral is partly weathered out and has a light gray-coloured surface with a silky luster. On a fresh surface it is whitish gray and resembles quartz.

Rakten. In this section of the district veins of the present type seem to be less common, although bixbyite-bearing pegmatites are known. Worth mentioning is a drusy vein formation in the limestone, immediately S of the Rakten cabin. The walls in the shallow cavities were clad with perfect crystals of microcline, measuring about 2—3 cm in length, and yellowish brown garnet. Small crystals of a manganese pyroxene (pink-couloured) and piedmontite also occur.

Just before the manuscript was ready to go to press, the core of drillhole No. R 23 at Rakten was received in Stockholm. The limestone in this hole contained a considerable amount of pegmatite in which unusual quantities of svabite were detected by the aid of the ultra-violet lamp (cf. Part 2).

Tjatitsvare. During trenching work on the small manganese ore body on the northern slope of Tjatitsvare two irregular pegmatitic veins were encountered (Fig. 2). Quartz is rare in this case, a pale red microcline being the only typical pegmatite mineral. In the microcline mass there occur big and coarsely crystalline lumps of greenish barite. It brings to mind the high content of barite in the surrounding leptites. Hollandite is present in coarsely crystalline masses, built up of 4—5 cm long and about 1 cm wide, fibrous crystals. They are densely

[1] The mineral will be described in greater detail in Part 2.

packed and consequently no distinct faces are developed. The hollandite contains bixbyite, hematite, and braunite, the two last-mentioned minerals appearing on veinlets cutting the host mineral. In small cavities between the hollandite crystals there occur small tabular crystals of a pale brown, translucent mineral. Owing to the small quantity as yet found no proper examination of the mineral could be undertaken and its identity remains to be settled.[1] It may finally be mentioned that also fluorite occurs.

Molybdenum-Tungsten Mineralization.

During the search for manganese boulders in the country S of Sörhårås a couple of boulders of a rather unusual rock were found in a locality about 3 km NE of Rakten (Pl. 3). The chief constituent of the rock was piedmontite, and in thin sections small grains of a mineral resembling scheelite were found. A preliminary chemical test established the presence of tungsten and appreciable amounts of molybdenum, indicating the mineral to be molybdo-scheelite, a name proposed by Strunz (1941) for members of the isomorphous powellite-scheelite group. The mineral has a distinct yellowish luminiscence in ultra-violet light, the colour, according to Greenwood (1943), being due to the presence of molybdenum. The entire collection of specimens and drill cores from the district were then tested in ultra-violet light, resulting in the find of molybdo-scheelite in sporadic grains in a number of places and in the most varied rocks. It was seen in the porphyry at Rakten, in the limestone, in the piedmontite-bearing veins from Sörhårås, in the skarn-bearing greenstone, and in the lower tuffitic series. The mineral everywhere has the distinct yellowish luminiscence colour and, although only the molybdo-scheelite from the original find has been chemically tested, it is very likely that throughout the district the mineral is molybdenum-bearing.

The analysis of the piedmontite rock in the boulders first found showed high values in W and Mo and efforts were made to establish their source. Trenching in the place where the first boulders were found disclosed an accumulation of about 15 large boulders of the same rock, but in the vicinity there was not a trace of piedmontite rock in the moraine. These circumstances indicated that the boulders were of local origin and that their source ought to be close by. Trenching was abandoned, as the overburden proved to be too thick, and a number of drill holes (Nos. R 16—21, cf. Pl. 3) were put down around the boulders. Only a few narrow streaks of piedmontite were encountered. Molybdo-scheelite was present in a few places. It was concluded that the mineralization had but an insignificant extension and the prospect was abandoned.

The piedmontite rock is fine-grained and brownish red in colour. In addition to piedmontite, quartz, calcite, and molybdo-scheelite were seen megascopically. The quartz appears in streaks and irregular veinlets. The molybdo-scheelite occurs in small grains directly in the piedmontite rock or on the quartz veinlets.

[1] A partial qualitative spectrographic analysis disclosed the presence of chiefly Ba, Al, and Si and also Na, Ca, Fe, Pb, Mn, and Sb.

It is also found on fissures or on thin, sub-parallel and disk-like bodies about 1—2 mm thick and 4—5 cm in diameter.

A couple of the piedmontite boulders consisted partly of a light-gray, striped leptite of a type associated with the porphyry. The contact between the leptite and the piedmontite rock, as seen in these boulders, clearly showed that the latter replaces the leptite.

The microscopic texture of the piedmontite rock is granoblastic with the main components, quartz and piedmontite, in an indistinctly parallel arrangement (Fig. 40). The piedmontite often shows crystal faces against the quartz. Molybdo-scheelite occurs in small grains in the quartz-piedmontite aggregates and seems to be contemporaneously crystallized with these minerals. In part the mineral is somewhat later crystallized, as it also occurs on fissures in the piedmontite rock.

In addition to the minerals enumerated we also note a colourless hornblende, abundant titanite, apatite, fluorite, and calcite. Part of the last-mentioned mineral appears on fissures cutting the piedmontite rock.

In the table below the partial analyses of average samples of three different boulders are given.

	Mo%	W%	Fe%	Mn%
1.	0.85	0.16	6.2	3.6
2.	0.16	0.02	9.0	8.7
3.	0.99	0.19	—	—

1 and 2. Analyst Boliden Laboratories, Stockholm.
3. Analyst G. Assarsson.

Some Paragenetic Relations.

The preceding account of the mineralization shows that the manganese ores of the district, with the exception of the manganese ore veins, are recrystallized and have a granoblastic or leptitic texture. The crystallization order of the ore minerals is therefore attributable to the metamorphic processes.[1]

Hollandite and hematite are most perfectly recrystallized, even if hollandite, due to its distinctly columnar form, does not acquire the same equigranular texture as the hematite. Bixbyite behaves in a somewhat different manner, in so far as it generally forms porphyroblastic grains of a more or less distinct idiomorphism. The behaviour of braunite varies and it is possible to differentiate between two types according to its relation to the other ore minerals and to its texture. The first braunite type, the metasomatic one, appears as a later formation, veining and replacing the recrystallized hollandite, hematite, and bixbyite. In this process some hematite is formed, belonging to a later generation than the hematite associated with hollandite. This braunite is thus later than the recrystallization and differs considerably from the next braunite type, which is found in the boulders from Tjålme and Rakten and in

[1] Manganite and pyrolusite are excluded from the discussion as they presumably are later oxidation products.

the manganese ore layers at Stankajokk. In these ores the braunite is recrystallized and has a leptitic texture. This is the metamorphic braunite type.

It is possible to follow the general trend in the metamorphic crystallization order in the ores.

As regards the sedimentary mineralization, in the first place, it unfortunately has a rather small extent and is comparatively little known. Hollandite, braunite, and bixbyite are common constituents. Among these, braunite of the metamorphic type is the younger mineral and has replaced the others. Whatever the primary manganese minerals in this mineralization type may have been, it seems as if bixbyite and hollandite, in addition to some hematite, constituted the earliest minerals in the metamorphic crystallization order.

Regarding, then, the epigenetic mineralization, we find that hollandite and hematite to some extent are the oldest members in the metamorphic evolution and very likely form primary crystallization products.

Bixbyite is developed in porphyroblasts, more or less completely replacing the earlier hematite and hollandite, and the mineral thus belongs to a later phase in the evolution. Of the minerals present, bixbyite possesses the strongest tendency to the development of porphyroblasts (cf. Dunn 1936, p. 120).

As regards the relation of braunite to the minerals now mentioned it is evident, as pointed out above, that the metasomatic type is later, and veins and replaces hollandite, hematite, and bixbyite. As a rule there are only small quantities of this type of braunite, but the braunite-hollandite ore from Rakten contains a large amount of it. Contemporaneously with the braunite small amounts of hematite, belonging to a later generation, are formed.

In summing up we obtain for the hollandite ores, where the conditions seem to be clearest, the following metamorphic order of crystallization:

hollandite, hematite — bixbyite — braunite.

In his ore-microscopic study of the Indian manganese ores Dunn (1936, p. 120) writes that »the crystalloblastic order is: bixbyite[1] — hollandite — braunite. Whether this is also the general time sequence of formation it is difficult to judge.» Dunn seems to be uncertain of the age of the bixbyite, as in conjunction with the foregoing quotation he says that »it is almost impossible to decide on the relation between hollandite and bixbyite». Not having seen the case in question the present author has no right to offer an opinion but the similarity in behaviour and appearance between the Ultevis bixbyite and the Indian one mentioned by Dunn, suggests that also the last-named is later than hollandite.

There is good agreement in the age relation of braunite to hollandite and bixbyite in the Indian and Ultevis manganese ores. Dunn states (op. cit. p. 120) that »it is certain that some braunite is later than bixbyite and hollandite — such braunite as definitely veins and replaces these minerals — but it is not assumed that all the braunite is of late age». This is also the case in the Ultevis

[1] Dunn writes 'sitaparite', but according to B. Mason's recent investigation (1942) this mineral is identical with bixbyite. The last-named has priority. In later quotations the present author has changed sitaparite to bixbyite.

ores, where braunite of the metasomatic type replaces hollandite and bixbyite. Dunn considers this type of braunite to be formed by retrogressive metamorphism and regards »braunite in part to be the consequence of a grade of metamorphism lower than hollandite and bixbyite» (op. cit. p. 121).

Braunite is also a constituent of the hydrothermal manganese veins, carrying, inter alia, hollandite and bixbyite, which minerals are replaced by the braunite. It is therefore close at hand to connect the formation of the metasomatic braunite type with those solutions that gave rise to the veins (cf. p. 59).

The metamorphic braunite type is most plentiful in the boulders at Tjålme and Rakten. Hollandite is here absent and bixbyite is only rarely found in small grains in braunite. It is not known whether in this case, as before in the hollandite ores, the evolution leads over hollandite—bixbyite and these have partly been completely replaced by braunite. If this be the case, one would expect the presence of remnants of hollandite. The possibility must be considered that braunite is a »primary» mineral, directly deposited by the ore-bearing solutions. Subsequently it has suffered a recrystallization, in which process the leptitic texture developed.

Also the South African manganese ores from Postmasburg present some points of interest in this connection. In 1941 Schneiderhöhn (1931) published a paper on the ore-microscopic features of the ores (the author is not aware of any more recent study on the microscopy of these ores). Hollandite is not mentioned by Schneiderhöhn, but braunite and bixbyite are common. Schneiderhöhn believes that bixbyite belongs to a higher grade of metamorphism and that it was formed by braunite and hematite. The bixbyite porphyroblasts penetrate and replace the braunite aggregates (op. cit. p. 709). The order of metamorphic crystallization is thus contrary to the one in the ores from Ultevis and in the Indian ores described by Dunn.

The age relation of the recrystallization to the process of mineralization will be briefly discussed. It has repeatedly been pointed out that the ores and their wall rocks are strongly recrystallized and more or less leptitic. The metasomatic braunite and the manganese ore veins are the only exceptions from this rule. The recrystallization seems to have been over, or about to die out, when the latter were formed. A strong recrystallization would in all probability have left its marks on the delicate hollandite crystals in some of the veins. The observations tend to show that the epigenetic mineralization was contemporaneous with and was partly followed by a recrystallization and metamorphism, which, however, ended up before the epigenetic mineralization was completed. During the calmer conditions that followed, the mineralization continued in the formation of the manganese veins and the metasomatic braunite.

The nature of bixbyite has recently been discussed by Brian Mason in two papers (1943, pp. 168—174 and 1944, pp. 66—69). He arrives at the conclusion that from a paragenetic point of view the bixbyites fall into two groups: 1) those of pneumatolytic origin with a Fe_2O_3 content of 45—60 %, and 2) those occurring in metamorphosed manganese ores and with a Fe_2O_3 content of 0—30%. In the former group belong the bixbyites, *e. g.*, from Rio Chubut, Patagonia, and Thomas Range, Utah, and in the second group bixbyites from Långban, Sweden, Sitapar, India, and Postmasburg, S. Africa.

In one of the papers quoted (1943, p. 173) Mason mentions the bixbyite in the glacial boulders from Murjek[1] and asks what its composition will be in relation to that of the bixbyites previously described.

As regards the hydrothermal bixbyite from Ultevis, occurring in the veins, it was easy to obtain a sample for analysis from the vein on Stuor Njuoskes (p. 47). It contains about 44.5 mol.% Mn_2O_3 and 55.5 mol.% Fe_2O_3 (for the complete analysis see Part 2) and is thus placed in Mason's group of bixbyites of a pneumatolytic origin, where, from a geological point of view, it actually belongs.

It was impossible to obtain pure samples for analyses from the bixbyite porphyroblasts in the massive hollandite-hematite ore, as generally they are quite small and often abound in inclusions, chiefly hollandite and hematite. Four porphyroblasts from the ore on Stuor Njuoskes were polished and with a dentist's borer small quantities of bixbyite were extracted from portions which under the microscope were seen to be more or less devoid of inclusions. The four samples were micro-chemically analyzed (table below) by Mrs. A. M.

	1.	2.	3.	4.
Fe_2O_3 mol. %	50	39	46	37
Mn_2O_3 mol. %	50[1]	61	54[1]	63

[1] Calculated.

Byström, who submitted the following communication: »Determinations of Fe and Mn were carried out on four samples. The material available for analysis was very small: Nos. 1, 2, and 4 were each of 3 mg and No. 3 of 1.6 mg only. The accuracy of the determinations cannot be considered greater than ± 10 %. All the samples were dissolved without residue in HCl 1 : 1. The figures for Nos. 2 and 4 are more reliable than the others. Fe and Mn are considered to be present as sesquioxides.» It is evident from the figures obtained that also in this case the bixbyite — although the content of Fe_2O_3 generally is lower than in the bixbyite from the vein, quoted above — falls within the bounds of or close to the lower limit of Mason's high-temperature type. The bixbyite porphyroblasts were formed by recrystallization in the massive ore during a hydrothermal process, which also brought about the formation of the manganese veins (cf pp. 58—59), and one may consequently expect the temperature of formation to have been approximately the same in both cases, as is indicated by the analytical data. The evidence of the porphyroblasts is not conclusive, however, in view of the risk of the samples having been polluted by hollandite and hematite and the small quantity of each sample.

[1] When his paper was written, the mineralized zone on Ultevis was as yet unknown.

Origin of the Mineralization.

Sedimentary Mineralizations.

The iron and manganese ores occurring in the tuffitic sediments indicate by their often preserved banding and their interbedding with banded rocks that they are syngenetic and originated in connection with the sedimentation. The same reasoning may be applied to the bands and layers of piedmontite and manganese garnet which here and there are found interbedded with the tuffitic sediments. The idea that we are here dealing with sediments of mechanical origin can be dismissed at once. All features indicating a mechanical sedimentation and one typical for iron sand formations are lacking. Moreover, no analogous formations with manganese are known (Hanson 1932, p. 11). An endeavour will be made in this chapter to show that we are dealing with chemically sedimentary deposits.

As far as quantity is concerned, the mineralization in question is negligible and by no means comparable with similar and often enormous deposits of sedimentary iron and manganese ores found in many places in the world. Despite this the sedimentary mineralization has a certain theoretical interest and the manganese-bearing sediments play an important rôle, as they have delivered the material for the epigenetic ores.

It has been established that in places a chemical differentiation of iron and manganese occurred to the extent that the hematite-banded ores contain only insignificant amounts of manganese. But on the other hand, the two metals do not seem to have been subject to any separation in the manganese ore layers in the tuff, described on p. 38, or in the manganiferous iron ores from Nordhårås or Tjatitsvare. The content of iron in proportion to manganese is here fairly high.

Chemically sedimentary ores with iron and manganese are widely distributed and are present in practically all geological formations. In many places, for instance in our lakes, iron and manganese are being deposited at the present time. The literature dealing with sedimentary iron and manganese ores is voluminous and it is not within the scope of this paper to go into a detailed review of it. It will suffice to refer to the comparatively recent and theoretically fundamental works of Savage (1936) on manganese, and of Moore and Maynard (1929) on iron and silica. The ore-forming processes here referred to take place on the surface of the earth under normal pressure and normal temperature, and they are thus more suitable for laboratory study than ore-forming processes in general.

From the papers quoted we learn that carbonated water is an active solvent for iron and manganese in minerals and rocks. The authors further discuss the manner in which the metals may be transported in solution, and, finally, how they are precipitated.

As regards the source of the iron and manganese present in the deposits under review, it seems probable that it should be sought for in the surrounding bedrock and the metals have been brought in solution by the action of carbonated waters. We must, however, not forget that the mineralization at Ultevis took place in a distinctly volcanic *milieu* and it is highly probable that even stronger solvents than carbon dioxide, for instance HCl and H_2SO_4, originating from volcanic springs, contributed to the solution of Fe and Mn. In this connection the possibility should be pointed out that in part the metals in a soluble state may have directly emanated from volcanic sources.

As a likely source of iron and manganese we may in the first place consider the underlying Snavva sediments and the rocks between the latter and the manganese-bearing tuffitic leptites. The Snavva sediments contain occasional grains of viridine and piedmontite, indicating that manganese is present. An analysis (by F. Swennborg) of a large sample of chips of greenstone drill cores showed a content of 0.24 % MnO. Also the limestone contains some manganese (p. 18). Very little is known about the manganese content of the volcanic rocks beyond the mineralized area. The iron may have derived from hematite, which is present in all the rocks mentioned.

The analysis of a manganese ore layer and the bordering leptite from Stankajokk shows the presence of barium and lead in addition to iron and manganese (p. 39). The analysis did not disclose any SO_3 and no barite was observed under the microscope. Thus, it can be inferred that the two metals enter into the manganese oxide minerals, preferably the hollandite. Barium and lead are typical constituents of the hollandite in the Ultevis district. Barite was, however, seen on many occasions in the adjoining pyroclastics. The question then arises how the barium and lead came to enter this association.

It is probable that partially at least these elements were leached from the surrounding bedrock in the same manner as iron and manganese. But in view of the distinct volcanic *milieu* in which they occur, it is likely that barium and lead to a large extent had a direct volcanic origin, having been brought down into the sedimentation basins by way of volcanic springs. Both elements, but especially barium, are known to occur in spring waters and spring deposits and may be transported together with iron and manganese. Barium is probably transported as chloride but also sulphate may be considered, primarily in acid or neutral chloride-bearing water (v. Engelhardt 1936, p. 235). According to Lindgren (1933, p. 71), alkali carbonate with excess CO_2 may keep Ba in solution despite the presence of sulphate ions. The transport of lead may occur in practically the same manner. Berg (1929, p. 256), for instance, mentions the transport of lead in the form of bicarbonate in carbonated water.

Periodically, iron was practically the only metal precipitated and only insignificant amounts of manganese enter into the hematite sediments. It is difficult to say whether this is due to selective precipitation, manganese being deposited in one place and iron in another, or if less manganese was available during certain periods. Selective precipitation of iron and manganese is a comparatively common occurrence which may cause a fairly complete separation of the two metals (cf. for instance Berg-Friedensburg 1942, pp. 6—10).

On oxidation of solutions of bicarbonate, chloride or sulphate under the influence of the atmosphere, hydroxide sols of iron ($Fe(OH)_3$) and manganese ($Mn(OH)_4$) are formed. Behrend (1924), who thoroughly discusses the part played by these compounds in mineralization, emphasizes the importance of their different electric charges: ferri hydroxide has a positive charge and manganese hydroxide a negative one. When the colloidal solution of manganese hydroxide meets positively charged bariun, lead or potassium ions, these are absorbed by the precipitated manganese hydroxide. The substances formed had the nature of gels of varying composition but may approximately be classified as wad, *i. e.* hydrous manganese oxides. During the diagenesis part of the water content is expelled (according to 14 analyses in Dana (1944) wad contains 3.76—24.5% H_2O) and molecular rearrangements take place. Also the iron hydroxide loses its water and limonitic minerals are formed. The formation of hematite then easily follows. As regards manganese one would expect these processes to result in the formation of abundant hollandite (or psilomelane), but hollandite occurs in comparatively small quantities in those deposits which are considered to be truly sedimentary. Bixbyite is the oldest and most common mineral in the paragenesis in its present state. It is not known whether it developed from the primary hydrous manganese oxides without any intermediate stages.

When barium ions were not absorbed by manganese hydroxide they were instead precipitated as barium sulphate, now appearing as barite in some of the banded leptites.

Behrend pointed out in his work quoted above (1924, pp. 105—106) that in consequence of the opposite electric charges of the hydroxide sols of iron and manganese, they discharge and precipitate each other mutually. The precipitate formed in Behrend's experiment when the precipitation was complete was composed of schlieren alternately rich in Fe or Mn. This may possibly be applied to some of the sedimentary ores at Ultevis, for instance the quartzose iron-manganese mineralization on the N slope of Nordhårås, where streaks of iron and manganese minerals alternate. Also some of the mineralizations on Tjatitsvare, showing rapid changes in iron and manganese contents, may belong to this type. Some of these features may be primary, although during the recrystallization chemical and mineralogical changes took place.

As mentioned before (p. 24), some of the tuff agglomerates carry disseminations of opaque manganese minerals and piedmontite. The mineralization may be epigenetic, but on the other hand it is possible that it is due to chemical precipitation in connection with or immediately after the formation of the agglomerates, which are considered to be deposited in water to a large extent. E. M. Kindle has described how in certain Canadian lakes pebbles in the gravel are covered with a thin coating of manganese oxide (1936, p. 757) cementing them to a solid rock.[1] A similar process may be supposed in regard to the agglomerates on whose fragments the manganese-bearing lake and river water deposited its manganese content. As soon as the process has started, it will proceed

[1] In this connection G. De Geer (1882) may be quoted. From an esker at Upsala he described how the pebbles in the gravel were cemented by a manganese oxide mineral, carrying about 1% Cu.

rapidly in view of the catalytic action exercized by MnO_2 on the precipitation of manganese from aqueous solutions (Zapffe 1931). The occurrence of piedmontite postulates that in addition some calcium carbonate was precipitated, which during the subsequent metamorphism reacted with the oxidic manganese minerals and silica.

During the formation of the leptites with bands and layers of piedmontite and manganese garnet there was probably also originally a precipitation of carbonate. A primary deposition of manganese silicate, corresponding to the formation of greenalite in the Lake Superior district, is out of the question. The complex manganese silicates were formed by reactions between carbonate, silica, and oxidic iron and manganese minerals. There is hardly any carbonate present in the manganese-bearing rocks but it is not at all unlikely that some carbonate was precipitated in connection with the iron and manganese.[1] The latter were mainly in the form of oxides or hydroxides, but in favourable cases, for instance under reducing conditions, iron- and manganese-bearing carbonates may also have been deposited. Excess of SiO_2 is always at hand in the sediments and the premises are given for the formation of manganese silicates during the metamorphism.

The limestone in many places contains manganese minerals of various kinds, either in the form of scattered grains or in sometimes high-grade schlieren or lenses. In most cases this mineralization must be interpreted as epigenetic and connected with the mobilized ore type. The epigenetic nature is evident from the general appearance of the ore minerals and from the presence of scapolite in the paragenesis.

On the other hand there are features that indicate that the limestone primarily contained manganese. The unaltered limestone probably contained only small amounts (cf. analysis on p. 18) but the leptitic bands in the limestone are often banded with manganese minerals which appear to be of primary sedimentary origin. The metal was deposited in connection with the formation of the limestone and the leptitic layers. It was dissolved from the surrounding bedrock and possibly also contributed from volcanic springs. When the manganese-bearing water, presumably carrying the metal in bicarbonate solution, came in contact with carbonate, a reaction took place and manganese carbonate was formed. When carbonate was deficient, mainly in the leptitic bands, oxides and hydroxides were deposited. Manganese carbonate deposits formed in this manner have been described by Dale (1915) from Cambrian sediments on Newfoundland and have been discussed by Savage (1936).

Finally there remains to discuss the origin of the jaspilitic hematite ore from Stankajokk. The occurrence has a very restricted extension and is only a local feature. The jaspilite is typically developed only in part and is composed of quartz and hematite. A number of other minerals (p. 21) are often present. The volcanic *milieu* in which the jaspilite occurs, is quite obvious and it is believed to have been formed in connection with volcanic springs.

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[1] The lower part of the upper tuffitic series contains the limestone bed.

Epigenetic Mineralizations.

The greater part of the mineralization in the district has been formed under quite different conditions to those prevailing during the formation of the sedimentary deposits. The other forms of mineralization, as the breccia ores, the small ore bodies on Stuor Njuoskes and Tjatitsvare and the manganese ore veins, all have epigenetic features. The epigenetic origin of the last-named veins and the breccia ores, which vein and replace the wall rocks, is self-evident. The two ore bodies on Stuor Njuoskes and Tjatitsvare occasionally contain replacement remnants and display epigenetic contact relations.

An epigenetic origin is also indicated by some features of the paragenesis, and some of the minerals present are typical hydrothermal products. The universal occurrence of fluorite, the flakes of the red mica and muscovite in many of the rocks and the mineralizations, and the pegmatitic manganese ore veins are indications of the action of hydrothermal solutions throughout the whole district. The solutions in fact soaked the bedrock to quite a considerable extent.

In a preceding chapter it was stated that the metamorphism and probably also the folding of the manganese-bearing series are connected with the intrusion of the younger red pre-Cambrian granite — an equivalent to the Lina granite — which occurs in large areas S and SE of the Ultevis district. As no other intrusive rocks are known here, the red granite constitutes the only possible magmatic source of the hydrothermal solutions responsible for the mineralization. This does, however, not imply that the granitic magma is looked upon as the source of the metallic constituents of the mineralizations.

It is considered that during the migration from their magmatic source the hydrothermal solutions — chiefly carrying water but also considerable quantities of fluorine — on encountering the manganese-bearing tuffitic sediments dissolved their content of manganese and other metallic constituents. The solutions thus enriched in these new constituents continued their migration along favourable ducts until conditions suitable for deposition were encountered. As a rule they consisted of brecciated sections in the brittle porphyry but occasionally, as on Stuor Njuoskes and Tjatitsvare, other loci were selected.

The mineralization as here outlined is the result of a mobilization process in which primary sedimentary material was brought into solution by means of deep-seated hydrothermal emanations. In other words, the process may be described as a lateral secretion at an elevated temperature.

This hypothetical explanation prompts many questions: What is the nature of the solutions and how is the solution, transportation, and precipitation of manganese, iron, barium, and lead, etc., accomplished? It is not feasible to present any definite proofs of this explanation and, as so often happens in geology, one is restricted to general reasoning and to balancing pros and cons.

Considering first the appearance of manganese and iron on the epigenetic mineralizations, it is an interesting coincidence that they occur in the comparatively limited area in which there are found sedimentary manganese and iron precipitations of a rather specialized type. This circumstance is the strongest support of the explanation proposed by the author. If the two metals derived from the granitic magma and had been brought in with the hydrothermal solutions, one would expect to find mineralized zones also in those other places, beyond the present district, where an action of the hydrothermal solutions has been noted.

Turning now to barium and lead it may be asked if they possibly had a magmatic source. Also these two elements are present in the sedimentary manganese ore layers in the tuffitic sediments at Stankajokk and this circumstance indicates that they were mobilized together with manganese and iron.

In this connection we call to mind the irregular distribution of barium and lead in the epigenetic mineralizations, discussed on p. 46, and that the two elements are almost exclusively restricted to the hollandite types, whereas the braunite ores contain only insignificant quantities. It is difficult to give an adequate explanation of this relation. The cause may be the absence of barium and lead in the sediments from which the braunite ores were mobilized or, more likely, it is due to the braunite itself and an inability of this mineral to carry with it any extraneous substances.

Another problem involved is the hydrothermal formation of the complex mineral hollandite. This mode of origin is indeed unusual, as otherwise it is generally considered to be a metamorphic mineral formed by recrystallization of wad and similar substances. That hollandite actually may appear in a pegmatitic-hydrothermal association is, however, proved by the fact that it occurs in the manganese ore veins in the district. Another case with hollandite as a likely hydrothermal mineral is described by Fermor from the Kájlidongri Mine in Jhabna State, India, where »it occurs in the quartz veins that traverse the ore-body — — —» (1909, p. 685).

In close connection with the epigenetic manganese mineralization also iron mineralization occurs. The former occasionally contains appreciable amounts of hematite and there are probably all transitions between the two kinds of mineralization. The iron ores that are of the same appearance as the manganese ores are also believed to have been caused by a mobilization process as described above. The cause of the chemical differentiation of iron and manganese that actually took place here, for instance at Stuor Njuoskes, where manganese and iron ore occurs side by side, cannot be accounted for.

The paragenesis of the manganese ore veins is distinctly hydrothermal or occasionally even pegmatitic. Nor is it in this case possible to trace a direct connection with any magmatic source and the veins are believed to have been formed by the same mobilization process as outlined above. It is difficult to indicate the circumstances that caused the mobilized solutions to form veins of this type. In part it may depend on specific structural conditions, suitable to the formation of veins, present in the rock, *i. e.* fissures and other ducts along which accumulations of solution occurred.

In the voluminous literature dealing with manganese ores and their origin, the majority of the deposits are considered epigenetic inasmuch as decomposition and oxidation of manganese-bearing rocks, as for instance gondite and kodurite as described by Fermor (1909) from India, lead to an enrichment of manganese under the formation of oxides and hydroxides. The process takes place at or close to the surface and is promoted by a moist and tropical climate. The manganese deposits in Minas Geraes, on the Gold Coast,[1] and in India (»Residual Manganese Ores», Lindgren 1933, pp. 362—369) belong here. Similar deposits are known also from French Morocco. The Taousdremt deposit is here of special interest, as the manganese ores in this locality appear on replacing veins and breccias in a Lower Cambrian porphyry (Neltner 1934, pp. 99—102), and thus show similarities to the breccia ores from Ultevis.

This similarity may induce us to test another explanation of the origin of the breccia ores and the ore bodies from Stuor Njuoskes and Tjatitsvare. The possibility exists that the breccias originated as superficial fissures in the volcanic rocks soon after their formation. Surface water with manganese, etc., in solution then percolated through the fissures and there deposited its metallic content. In favourable places the process resulted in concentrated deposits. During the metamorphism the soft oxides and hydroxides recrystallize in connection with chemical rearrangements and hollandite is formed. If this explanation be applied, the difficulties encountered are even greater than those enumerated above in connection with the mobilization theory. The presence of fluorite and mica, for instance, will be very difficult to explain. Another circumstance, contributing to make this explanation less probable than the one proposed above, is that the breccia ores rest on and are later than the manganese-bearing rocks from which the manganese content of the percolating surface water presumably emanated.

Molybdenum-Tungsten Mineralization.

Molybdo-scheelite is, as mentioned previously, spread all over the district and occurs in occasional grains throughout the stratigraphic succession from the greenstone up into the porphyry. The richest and largest concentration was found in a local accumulation of glacial boulders between Rakten and Sörhårås (p. 49).

The contact relations in some of the boulders indisputably showed that the piedmontite is later than the leptite and has replaced it. In view of this and the circumstance that the molybdo-scheelite is strictly tied to the piedmontite it must be assumed that tungsten and molybdenum were brought in when the piedmontite was formed. The absence of intrusive rocks also in this case implies that the mineralization cannot be ascribed to a direct magmatic source or to contact-metasomatic action. The only possibility seems to be that the pied-

[1] In a paper by Service (1943), recently received, the origin of the Nsuta manganese deposits on the Gold Coast is discussed. It is surmised »that the bulk of the ores were not formed by the Tertiary to Recent weathering of gondites, but were in the form of oxides before the weathering took place» (p. 25) and that they were in existence in pre-Devonian time. A hydrothermal origin is discussed but Service seems to favour an alternative explanation, implying a sedimentary origin (a comparison with the Nikopol deposits is drawn) and an ensuing enrichment by the action of meteoric waters during the interval between the pre-Cambrian Birrimian and Tarkwaian Systems.

montite has been mobilized and leached by »high-temperature lateral secretion» from adjoining rocks in the same manner as the mobilized iron and manganese ores. The agent that brought about the mobilization is believed to be the hydrothermal solutions emanating from the younger red granite. The question is why in this case a complex manganese silicate was formed and not oxidic minerals as in other cases. No definite answer can be given but it is probable that primarily piedmontite-rich rocks delivered the material. In this connection the observation on an earlier occasion should be kept in mind, that the paragenesis of the manganese ore veins is to a certain degree attributable to the mineral composition of the surrounding rocks. Thus, for instance, the veins on Tjatitsvare contain abundant barite, a mineral which is common in the leptites in this locality, and the veins on the top of Sörhårås, cutting piedmontite-banded leptites, are rich in this mineral.

The next question is: Where did the tungsten and molybdenum come from? Two possibilities may be mentioned: 1) the two elements were either leached and mobilized from adjoining rocks contemporaneously with the manganese, or 2) they were transported with the hydrothermal solutions and are primary constituents of the granitic magma.

In order to find out whether the iron- and manganese-bearing sediments in the district contained any noticeable concentrations of Mo and W, spectrographic analyses of a number of samples of these rocks were carried out in the Geochemical Laboratory of the Survey. The result is shown in the table below.

	Mo %	W %
1.	< 0.001	< 0.003
2.	0.006	0.001—0.003
3.	0.008	0.003
4.	< 0.001	0.003
5.	< 0.001	< 0.003
6.	< 0.001	0.005
7.	< 0.001	0.003

Analyst B. Gustafsson.

1. Banded manganese-bearing leptite, Tjatitsvare.
2. Layer of manganese ore, Stankajokk.
3. Wall-rock leptite to above.
4. Garnet-banded leptite, Juoråive.
5. Piedmontite layer in leptite, Sörhårås.
6. Piedmontite-banded leptite, Juoråive.
7. Hematite-banded ore, Stankajokk.

In view of our imperfect knowledge of the average content of tungsten and molybdenum in the upper lithosphere, no definite conclusions can be drawn from the figures above. In a recent paper Sandell (1946) estimates the content of tungsten to be 1 g/ton and that of molybdenum to about 2 g/ton. Goldschmidt (1938), on the other hand, estimated the content to be 69 g/ton W and 15 g/ton Mo.

In comparison with Sandell's estimates the figures obtained for the leptites and ores from Ultevis imply a concentration of the two elements, but if they are compared with Goldschmidt's higher values only molybdenum shows a noticeable concentration in Nos. 2 and 3.

Enrichment of tungsten in manganese ores is, however, known from a number of foreign localities. Lindgren (1922) thus describes from the Uncia tin mine in Central Bolivia a psilomelane- and barite-bearing thermal deposit (tufa) containing 0.5% WO_3. Tungsten was evidently colloidally combined with psilomelane. Another deposit, from Golconda, Nevada (Pardee and Jones Jr. 1920, pp. 235—238; Kerr 1940, pp. 1359—1390), consists of soft oxides of manganese and psilomelane, which underlie a calcareous tufa. The ore contains from 1 to 7 % WO_3. In addition may be mentioned that in the new edition of Dana's System (1944, p. 669) four analyses of psilomelane are quoted, which contain varying amounts of WO_3. No examples of molybdenum being in a similar way absorbed by manganese minerals are known to the author. In view of the chemical resemblance between the two elements the possibility exists that so may be the case.[1]

From the above discussion and the examples mentioned one can only infer that it is probably within the bounds of possibility that molybdenum and tungsten at Ultevis were primary constituents of the sedimentary manganese mineralization.

The second alternative seems to present some advantages as compared with the first. The hydrothermal solutions emanating from the granite have thoroughly soaked the entire district, as is proved by the regional distribution of the hydrothermal minerals and the veins. Also the molybdo-scheelite is regionally spread over the area. This conformity in occurrence strongly speaks in favour of the assumption that molybdenum and tungsten emanated from the granite with the hydrothermal solutions. Finally, attention should be called to the well-known fact that both elements are typical constituents of pegmatitic and hydrothermal emanations from granitic magmas.

In view of the different points that have been brought out in the discussion above, the author is most inclined to favour the last explanation.

Manganese Mineralization at Porjus.

On Porjusvare, a small wooded hill immediately above the power station at Porjus, there occur narrow zones with manganese garnet and rhodonite in a microcline gneiss. The deposit was mentioned as early as 1862. In 1919 it was described by Geijer (1919) and the following account is chiefly an excerpt from his paper.

The rock around the deposit is mainly a fine-grained red gneiss with microcline as the predominant component. Small amounts of quartz, plagioclase, biotite, and apatite are present. The »ore» may be described as a microcline rock with schlieren of manganese garnet and rhodonite. Among other constituents we note quartz, magnetite, orthite, and fluorite. In a narrow veinlet of magne-

[1] In a description of manganese deposits of the Lyndhurst-Vesuvius district of Virginia, M. M. Knechtel (1943, p. 174) quotes an analysis of a manganese ore containing 0.01 % MoO_3. One may suspect that the molybdenum is contained in the psilomelane of the ore although the matter is not discussed in the paper.

tite the present author observed small grains of a mineral which was suspected to be hausmannite. This was confirmed by B. Mason, who made an X-ray study of it. The manganese minerals are superficially oxidized and black oxides of manganese are precipitated in the surrounding rocks.

Although the mineralization hardly possesses any economic interest, its extent being small and the average manganese content only 15.7 %, it is still interesting from a geological point of view because of the comparison that can be made with the mineralization in the Ultevis district.

During the geological survey of the district around Porjus it was established that the volcanics, mainly syenite porphyries and quartz porphyries, occurring in the Stubba Hills N of Porjus, towards the south become increasingly more metamorphosed and in the vicinity of Porjus have the appearance of gneisses. They are intruded and migmatized by granite and pegmatite, possibly of different age. In all probability the microcline gneiss on Porjusvare is a strongly metamorphosed member of these volcanics.

It is now close at hand to assume, in view of the fact that in Ultevis similar volcanics carry syngenetic deposits, that the manganese silicates on Porjusvare had a similar origin. Among the mineralization types in Ultevis which are comparable to those from Porjus, we may consider in particular the microcline-rich leptites with bands of manganese oxides, garnet, and piedmontite, occurring at Stankajokk and on Juoråive. The metamorphism of these may lead to gneisses of the type present on Porjusvare.

Summary and Conclusions.

In 1935 a manganese ore boulder of glacial origin was found in the small village of Vuotnajaure, 8 km N of Murjek, a station on the railroad from Luleå in North Sweden to Narvik in Norway. In 1940 the boulder was handed over to the Geological Survey of Sweden and the Survey began a prospecting campaign in the district in order to locate the source of the boulder. The prospecting seemed to indicate the occurrence of an ore-bearing zone a short distance NNW of the original boulder. Diamond drillholes disclosed, however, nothing but a dioritic rock enclosed in granite. During the drilling other manganese-bearing boulders were discovered further to the NW. As the Quaternary continental ice transported the glacial debris in these parts of Northern Sweden from NW to SE, it became evident that the source of the boulders was to be looked for still further to the NW. In July 1943 a poor manganese mineralization was finally located on Stuor Njuoskes, a hill on the S fringe of the barren Ultevis mountain plateau in Jokkmokk Parish, about 125 km from the original find at Vuotnajaure.

A thorough geological and geophysical survey of this area indicated the presence of a mineralized zone about 30 km long and stretching from the hill Juoråive in the N to the Aitevarats Hills in the S (Pl. 1). In spite of a large

number of high-grade manganese- and molybdo-scheelite-bearing glacial boulders of local origin found within the mineralized zone and a number of outcrops showing high values in manganese, the prospecting, including trenching and drilling, did not disclose any commercial ore bodies.

The rocks of the district all belong to the oldest pre-Cambrian of North Sweden, approximately contemporaneous with *e. g.*, the volcanic rocks in the Kiruna district. The geologic column begins with the Snavva sediments, a thick series consisting of feldspathic quartzites interbedded with conglomerates and greenstone lavas. The sediments are overlain by a volcanic formation, which has reached its full development in the north and in order from bottom to top consists of a lower tuffitic series, greenstone lava, limestone, an upper tuffitic series, acid porphyry, and red leptite. The tuffitic series contain occasional beds of porphyry and are thus formed in a distinct volcanic *milieu*, although banded and stratified forms, particularly common in the upper series, are indicative of a deposition in water. Interbeds of coarse pyroclastics are common. The tuffitic rocks are chiefly composed of microcline and quartz but some of the banded types carry abundant manganiferous garnet, piedmontite, barite, micas, fluorite, and hematite. At Stankajokk there is a narrow section in the upper tuffitic series which is composed of a jaspilitic rock, consisting of quartz and hematite when typically developed. The porphyry carries phenocrysts of microcline and occasionally also of quartz. The red leptite is the youngest rock in the volcanic succession. Only rarely does it show phenocrysts of microcline. The rock is sometimes fairly coarse-grained. The rocks of the tuffitic series and the porphyry are light or whitish gray, in that respect differing quite considerably from the distinctly red, brown or dark gray volcanics in the neighbourhood. The light colours are due to the presence of white microcline and they seem to be restricted to rocks in the manganese-bearing areas.

The geologic structure of the district is simple, as shown on the geologic maps (Plates 2—4). It is developed as a large monoclinal fold striking mainly NNE—SSW, the central portion of which is occupied by the upper part of the Snavva sediments, the greenstone, the limestone, and the rocks of the tuffitic series. These members of the stratigraphic order have a moderately steep easterly dip. In the southern part of the district, from Stankajokk to Stuor Lastak, the pitch of the fold axis dips at a low or moderate angle (15—35°) to the south or south-south-west. In the northern part, on the other hand, the fold axis pitches to the north at a low angle.

The following mineralization types have been encountered: 1) sedimentary deposits with iron and manganese minerals, 2) epigenetic deposits with iron and manganese minerals, 3) veins with manganese minerals, pegmatitic in character, and 4) disseminations of molybdo-scheelite.

The sedimentary deposits are typically developed *e. g.* at Juoråive, Stuor Njuoskes, and in the Stankajokk valley. In the latter place the tuffitic sediments occasionally contain short and narrow layers consisting of hollandite, bixbyite, braunite, and viridine (»manganese andalusite»). In other places the tuffitic rocks contain bands of manganiferous garnet and piedmontite. In the localities enumerated the tuffitic rocks also contain bands and layers of hematite. They are practically free from manganese minerals. On Nordhårås there occurs in the stratified sediments a mixed iron and manganese mineralization showing banding and composed of hematite, bixbyite, and braunite. A sedimentary mineralization more or less similar to those now mentioned occurs on Tjatitsvare. The metamorphism is here generally strong and the ores more strongly recrystallized than in the former localities. There are chiefly hematite ores, but occasionally manganese minerals, such as braunite, bixbyite, and viridine are present.

Among the epigenetic ores we may differentiate between such with mainly hematite and such with predominantly manganese minerals. The hematite type is not well represented. At Stuor Njuoskes there occurs in the pyroclastic rocks a small body of hematite, replacing the wall rocks, and on the northern slopes of Sörhårås hematite occasionally appears in brecciating veinlets in the porphyry. In both cases the mineralization is closely connected with the epigenetic manganese ores. These may appear either in the shape of breccias or as small replacement bodies. The former are well represented in the part of the district between Stuor Njuoskes and Sörhårås, the latter are found on Stuor Njuoskes and Tjatitsvare and are represented at either locality by one small ore body. At Rakten the limestone and interbedded leptitic bands are replaced by manganese minerals forming narrow and streaky mineralization zones of the replacement type.

The manganese breccias distinctly cut and replace the wall rock, which is chiefly composed of the porphyry. From a mineralogical point of view it is possible to distinguish between two types, one of which mainly consists of hollandite with varying amounts of hematite, bixbyite, braunite, and fluorite. The other type, only represented by glacial boulders at Tjålme (NW of Rakten, Pl. 3), mainly consists of braunite with local accumulations of hematite. The braunite contains a few small grains of bixbyite. The ore has a distinctly leptitic texture.

The manganese replacement ores are composed of hollandite and occasionally abundant hematite as chief constituents. Bixbyite occurs in the shape of porphyroblasts, apparently replacing hollandite and hematite. Braunite is present but only in small quantities. It replaces the other minerals. Among the gangue minerals we note piedmontite and fluorite, both minerals being typomorphic constituents of the manganese paragenesis in the district. The ore on Tjatitsvare contains a pegmatitic nodule with microcline, quartz, and chalcedony. — The mineralization at Rakten is characterized by braunite and braunite-hollandite appearing in separate zones. The braunite type is practically identical with the braunite ore at Tjålme. Insignificant quantities of hematite and bixbyite are the only minerals present, except braunite. The braunite-hollandite ore differs from the other hollandite ores only in that respect that braunite is plentiful.

As regards the chemical composition of the manganese ores the analyses disclose that the braunite ores are poor in barium and lead, whereas the hollandite types generally carry appreciable percentages of these elements. The sedimentary manganese bands in the tuffitic sediments at Stankajokk contain a fair amount of barium and lead.

The manganese ore veins are met with in several localities from Stuor Njuoskes to Tjatitsvare. They have the character of pegmatitic veins, inasmuch as quartz and microcline are typical minerals in most cases. When manganese minerals appear in any quantity the veins lose their character of pegmatites. Among the more uncommon components of the veins we note bixbyite, hollandite, piedmontite, manganiferous garnet, svabite, molybdo-scheelite, barite, and »red mica» (containing a low percentage of manganese). Many of the minerals enumerated are well crystallized, particularly so bixbyite, hollandite, and piedmontite.

The microscopic study of the manganese ores has disclosed that, with the exception of part of the braunite and the manganese ore veins, the ore minerals are recrystallized and that the ores, as well as the wall rocks, have a more or less distinct leptitic texture. The metamorphic order of crystallization is considered to be: hollandite, hematite — bixbyite — braunite.

The banded and stratified character of the iron and manganese mineralizations in the tuffitic rocks indicates that they were formed by sedimentation. It is suggested that the metallic content of the ores, mainly comprising iron, manganese, barium, and lead, in part derived from the surrounding bedrock and in part, in view of the volcanic *milieu*, had a more direct volcanic origin and derived from volcanic emanations. The metals were leached from the bedrock by carbonated water. On oxidation of the iron- and manganese-bearing solutions hydroxide sols of iron and manganese were formed. From the precipitates, mainly consisting of wad-like and limonitic substances, the present ore minerals crystallized in consequence of diagenesis and metamorphism. The colloidal manganese hydroxide absorbs barium and lead ions and these elements are precipitated along with the manganese minerals. Some of the precipitates were probably carbonatic and during the metamorphism garnet and piedmontite were formed from them.

The greater part of the mineralization has an epigenetic character and some of the minerals are distinctly hydrothermal. The metamorphism of the manganese-bearing series was apparently caused by the late pre-Cambrian granite occurring to the south, and this granite constitutes the only possible source of the hydrothermal solutions responsible for the mineralization. This, however, does not imply that the granite is considered to be the source of the metallic constituents. The theory is proposed that the content of iron, manganese, etc., was dissolved from the tuffitic sediments by the hydrothermal solutions and later deposited in favourable loci, mainly fissures in the bedrock. The epigenetic mineralization is thus the result of a mobilization process during which the sedimentary material was brought into solution.

The fourth mineralization type consists of weak and not mineable disseminations of molybdo-scheelite. By the aid of an ultra-violet lamp this mineral was found to be widely spread throughout the district, from the greenstone up into the porphyry. A rich concentration occurred in some locally accumulated glacial boulders consisting chiefly of piedmontite and some quartz. The piedmontite rock has replaced the porphyry and is considered to have been formed during the mobilization, piedmontite-rich tuffitic rocks being looked upon as the source of the manganese. In view of the wide-spread action of the hydrothermal solutions and the regional distribution of molybdo-scheelite throughout the district, it is assumed that molybdenum and tungsten were brought in together by the hydrothermal solutions and that they emanated from the granite.

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APPENDIX I.

Geophysical Investigations in Connection with Prospecting for Manganese Ores in the Parish of Jokkmokk.

By Sture Werner.

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Introduction.

The investigations were carried out partly in the vicinity of Murjek and partly within an area between Stuor Njuoskes and Tjatitsvare in the Ultevis district (Plates 1, 3, and 4).

The geophysical field work in the vicinity of Murjek was mainly performed during the years 1941 and 1942. An account of these investigations will be given in a future paper. The prospecting in the area around Murjek did not disclose any manganese-bearing formation and the geophysical results obtained are mainly of interest in so far as they elucidate the general conditions within a pre-Cambrian area typical of the province of Norrbotten.

Within the area Stuor Njuoskes-Tjatitsvare some preliminary magnetic measurements were carried out during the autumn of 1943, after which detailed magnetic and electrical measurements were performed during different periods of the years 1944 and 1945. The areas surveyed by electrical methods totalled about 33 km^2 and those by magnetic methods about 26 km^2.

General Conditions for the Use of Geophysical Measurements.

When the geophysical investigations began in the Ultevis district, the manganese-bearing formation was only known in some outcrops in the northern part of the district. The principal manganese ore minerals were found to be hollandite and braunite. A small deposit of hollandite had been encountered on the southern slope of Stuor Njuoskes and lean hollandite breccias had been noticed at the northern base of the hill Sörhårås. No braunite mineralization was observed in the manganese rock series during 1943, but in many of the boulders found earlier in the neighbourhood of Murjek and to the north-west of that place, braunite was a characteristic ore mineral. Everything seemed to indicate that these boulders emanated from the Ultevis district which was now to be investigated more closely. At the deposit on Stuor Njuoskes also a body of compact hematite ore had been found, appearing in contact with the hollandite ore. About 100 m to the south of this place and at Stankajokk some outcrops occurred containing fairly rich disseminations of hematite. There was no reason to expect the presence of any other ore mineral in the district that might be of importance to the electrical or magnetic properties of the rocks, except magnetite. Magnetite is probably a rare mineral in the rocks present, but the amount of magnetite required in a rock in order to exert a dominating influence on its magnetic properties is so small that, in the case of crystalline rocks, the possibility of a magnetite concentration of this magnitude must always be reckoned with.

In planning the geophysical investigations, there were carried out determinations of the electrical conductivity and the magnetic susceptibility of samples from the hollandite and hematite deposits on Ultevis and of braunite boulders from the vicinity of Murjek. These tests showed that by the use of electrical survey methods only the presence of hollandite could be indicated. This assumption has also been verified by the results hitherto obtained. The susceptibility values of the various samples are between 10^{-4} and 10^{-3}, the values of the braunite boulders being on an average somewhat higher than those of the other samples. However, a magnetite content of only 0.05 to 0.5 volume per cent increases the susceptibility of a rock with an amount corresponding to the susceptibility values mentioned above. It therefore seemed uncertain whether the rocks of the manganese formation in general would be so weakly magnetic that the anomalies caused by any ore deposits present would appear with the necessary distinctness on a magnetic map. In order to obtain a tolerably reliable orientation on this matter and an idea of the applicability of the magnetic method on the whole, a test survey was performed on an area of a few km², measurements being made along a number of sparsely spaced E—W profile lines across the known part of the manganese-bearing series. The results of these measurements showed that presumably no deposits of magnanese ore could be located only with the aid of magnetic measurements, but that, on the other hand, such measurements might be expected to yield valuable information as regards the geological mapping of the district.

The Performance and Extent of the Magnetic and Electrical Measurements.

The magnetic measurements included only determinations of the vertical intensity and were carried out with the aid of two Schmidt balances, with scale values between 40 and 50 γ.[1] The measurements were made according to a principle used by the Geological Survey of Sweden for several years,[2] allowing

[1] 100 000γ = 1 Oersted, C.G.S. unit of the magnetic field strength.

[2] This method of magnetic survey will be described in the forthcoming account of the geophysical work at Murjek.

a fairly accurate correction of the time-dependent variations of the earth's field and the instrumental drift without the establishment of a recording station.

In the electrical survey an inductive electromagnetic method was used, as elaborated by the Geological Survey of Sweden and called the Sling-ram (verbal translation: loop-frame) method. The principle of this method is as follows. An electromagnetic a.c. field of audio-frequency is produced by a transmitter and measured by the aid of a receiver placed at a certain fixed distance (*measuring distance*) from the transmitter, this distance in each case being adjusted according to the object of the investigation. The transmitter consists of a tube generator connected with a transmitting coil and the receiver consists of a receiving coil, a compensator, and an amplifier with a headphone. This device has a very light weight and small dimensions and can thus easily be carried around in the field. When the observations are made, the transmitting coil and the receiving coil are held with their winding planes in a horizontal position. As a rule the *measuring distance* between these coils is 20 to 80 m. The transmitter and the receiver are connected by an electric cable, transferring to the compensator circuit a known alternating voltage from the transmitting circuit. The voltage induced in the receiving coil is compared with this known alternating voltage. This is done in the following way. Two potentiometers provided with reading scales, and included in the compensator, are adjusted so as to make the sound in the headphone disappear. When readings are taken on electrically neutral ground, the magnetic alternating field passing through the receiving coil is always identically the same (normal field) and thus the same adjustment of the potentiometers is always obtained. The scales of the potentiometers are graduated so that their alignment in this case is zero. If an electrical conductor is situated in the vicinity of the transmitter, currents generated in this body produce a field of disturbance in the receiving coil. The scale readings then indicate the size of the disturbing field expressed in per cent of the strength of the normal field. The component of the disturbing field, which is 0° or 180° out-of-phase in relation to the normal field (the real component), is read on one scale, and the component of the disturbing field which is 90° or 270° out-of-phase in relation to the normal field (the imaginary component), is read on the other scale. In the field the transmitter is carried by one man and the receiving coil by another. A third man carries the compensator and the amplifier on his back and also annotates the readings. An operator walks behind and makes the readings of the compensator. This team make observations along a system of parallel lines in the same way as is done in the case of magnetic measurements. The intervals between the observation points along the lines are usually half the *measuring distance*. In places where electrical indications are encountered, closer observations are taken. The speed at which the field measurements can be made, counted in length of lines measured by one team, is about twice as much as can be performed when measuring with the Schmidt vertical balance. A more detailed description of the Sling-ram method will be given in a future publication.

In the Sling-ram measurements a *measuring distance* of 40 m was used and the frequency of the transmitting field was 3 600 p/s.

In the geophysical survey two different systems of base lines were laid out, the direction and coordinates of which are evident from the systems of cross-rules in Plates 3 and 4. The magnetic as well as the electrical measurements were carried out along a system of parallel compass lines perpendicular to the N—S baselines. The area of the northern system of baselines is called the Njuoskes area and the southern one is called the Rakten area.

The area over which magnetic measurements have been performed is marked out in Plates 3 and 4. The northern limit of the area surveyed is situated at 1 200 N within the Njuoskes area and its southern limit at 6 000 S within the Rakten area. The maps do not embrace those parts of the Rakten area which are situated between 1 500 S and 2 800 S nor the part south of 5 000 S. The intervals between the magnetically measured lines within the Njuoskes area are 80 m and within the Rakten area 40 m. Observations have been made at every 20 m along the lines. In certain small areas where mineralizations were known to occur, more detailed observations were made.

Sling-ram measurements have been carried out over the greater part of the area magnetically investigated but also over parts of neighbouring areas. Within the Njuoskes area an electrically surveyed portion is situated between 2000 N and 7400 S and another between 7600 S and 10,000 S. The eastern and western limits of the first mentioned area are between 2000 N and 1000 N situated at 2000 E and 400 W resp. and between 1000 N and 0 at 1600 E and 800 W resp. Between 0 and 7400 S the eastern limit is situated at 1200 E, while the western limit is situated at 2000 W between 0 and 2400 S, after that at 1600 W to 5000 S, at 1200 W to 6000 S and along the zero-line to 7400 S. The southern area has the same limitations in E and W as the magnetically surveyed area except that the eastern limit between 7600 S and 8400 S is along the line 400 W instead of the zero-line. Within the Rakten area Sling-ram measurements have been carried out north of the river Blackälven between the river Rakten and 1900 S and south of Blackälven between 2900 S and 6000 S. The eastern limit of the northern area follows the line 800 E, except between 200 N and 1600 S, where it includes an area of about 1 km² situated to the east of that line. The western limit follows the zero-line between the Raktenbäcken and 400 N and otherwise 400 W. The southern area has almost the same E—W limitation as the magnetically surveyed area.

In the Sling-ram measurements the intervals between the lines were 40 m and the intervals between the observation points along these lines 20 m. Where electrical indications were encountered, more detailed observations were made.

Results of the Measurements.

The results of the magnetic survey have been exhibited on an anomaly map on which iso-anomaly lines are drawn at intervals of 100 γ (in the following this map, which has not been published, is called the Complete Anomaly Map).

For the computation of the anomaly values a common normal value for the entire area surveyed has been used. Corrections of latitude have not been considered necessary as in this case they do not amount to more than 3 γ per km, which implies that the normal value only increases with about 50 γ from the southernmost to the northernmost part of the area surveyed. On Plates 3 and 4 only the iso-anomalies for — 500 γ, 0, 500 γ, and 1000 γ are drawn. Positive anomaly values of 1500 γ and up to 3500 γ occur within certain of the closed 1000 γ-curves. All negative anomaly values, however, are less than 1000 γ. In order to make the magnetic map clearer the signs + and — have been added in certain places, indicating that the anomaly values here are higher or lower resp. than those valid for adjoining iso-anomalies.

The situation of the electric conductors as indicated by the Sling-ram measurements is denoted on the maps by dotted lines.

In the following (and on Plates 3 and 4) the most important magnetic and electrical indication areas are marked M and E resp., accompanied by a number according to the list below:

The *Njuoskes* area

M 1 An about 200 m wide anomaly-area between 400 N and 1700 S. The central part of the area is indicated by the long curve of 1000 γ, crossing Stankajokk at 400 W and from there extending about 1 km in a northerly direction.

M 2 The distinct anomaly situated on the eastern slope of Nordhårås between 1900 S and 2600 S and between 400 W and 600 W.

M 3 The magnetic indication zone extending from 2100 S and 800 W to 9000 S and 1400 W.

E 1	Indications	at	400 N	and	1100 E	
E 2	Indication	»	4600 S	»	650 W	
E 3	»	»	4900 S	»	450 W	
E 4	»	»	4900 S	»	370 W	
E 5	Indications	»	6000 S	»	200 E to 600 E.	

The *Rakten* area.

M 4 The magnetic indication zone extending from 1000 N and 100 E to 3600 S and 400 W.

E 6 Indication at 500 N and 300 E.

E 7 The long indication passing across Raktenvare from 380 N and 530 E to 800 S and 1250 E.

E 8 Indication at 4250 S and 675 W.

E 9 » » 5050 S » 750 W.

Interpretation and Analysis of the Geophysical Results.

Magnetic Anomalies.

The most important results of the magnetic measurements are the indications M1, M3, and M4. On the Complete Anomaly Map the magnetic horizon, marked M1, can be followed to the south as far as to 2900 S. At 2000 S this horizon runs through the gap between M2 and the magnetic depression east of M3 and joins the eastern limit of this depression in the south. At Stankajokk and in Nedre Manganravinen (at 200 S) some outcrops occur, which run across M1 and which contain zones of hematite disseminations. It thus appears as if the magnetic horizon in question is referable to these hematitic zones.

The closed 500 γ anomalies, indicating the position of M3 on Pl. 3, appear on the Complete Anomaly Map as peaks on one continuous and distinct magnetic ridge. At 5500 S this magnetic indication makes a double bend, so that in its continuation to the south it lies 200 m farther east than it does north of the double bend. The indication M 4 has the same continuous character as M3 and can be considered a continuation of it. M3 as well as M4 is caused by a greenstone, most likely effusive (p. 17). The presence of greenstone in M3 was first proved in drillholes U6 och U7 (at 4000 S). In this indication outcrops were later encountered on the south-western slope of Sörhörås at 6000 S. Finally, the holes U 15 and U 17 (at 8000 S) showed that greenstone really occurred in those places where it was expected. Within M4 the connection between the anomaly and the greenstone is fully proved by outcrops around point zero and by a considerable number of drillholes between 100 N and 1000 S. These holes were drilled in order to investigate a limestone horizon, which was assumed to follow the eastern boundary of the greenstone. In those places where there were no outcrops, the holes were placed only with the aid of the results of the magnetic survey. The agreement between the computed greenstone boundary and the data from the drillholes has been good throughout.

On Plates 3 and 4 boundaries of the greenstone within the areas covered by M3 and M4 are drawn according to the magnetic indications. It is very remarkable, however, that the greenstone in the Njuoskes area does not terminate at 2100 S, as might be expected from the appearance of the magnetic map, but continues towards the north with strongly increasing width. Within the Rakten area the connection between the geological and magnetic conditions is somewhat confused in the southern part of M 4. In an outcrop crossing the indication at 3550 S, there occurs a limestone, 90 m wide and in the west bordered by quartzite and in the east by porphyry (Pl. 4). In spite of the magnetic indication, which speaks in favour of the recurrence of the greenstone, there is no trace of it here. For that reason the greenstone has only been drawn south to 3000 S on Pl. 4, as the indication south of this point has a fairly heterogeneous character.

The magnetization relations of the rocks in the area surveyed have been found to be very unusual for Swedish conditions. Investigations carried out on core samples (95 samples in all) from a number of drillholes (U 1—U 3, U 5—U 8, R 1) disclose that broadly speaking it is only within the greenstone and the limestone areas that the induced magnetism of the bedrock (I_i) exceeds or is of the same magnitude as that of the remanent magnetism (I_r). In other areas the remanent magnetism is quite predominant. In most of the greenstone samples studied the relation $I_i : I_r$ lies between 2.7 and 0.8 and in the limestone samples between 2.7 and 0.7. For the majority of about 50 core samples of porphyries, agglomerates, and tuffitic leptites, on the other hand, the value of the relation $I_i : I_r$ lies between 0.02 and 0.001. Determinations of this value on porphyry samples from the Rakten area, however, disclose values about ten times as high (mean value 0.08). The direction of the permanent magnetization seems to correspond fairly well to the direction of the earth's field. The susceptibility[1] ($\varkappa$) of the greenstone varies within broad limits. The measured values of $\varkappa \times 10^6$ lie between 34 and 21,000, and it was found that in the drillholes investigated (U 6, U 7, R 1) thick layers with high $\varkappa$-values alternate with thick layers (20 m in U 6 and U 7) with low $\varkappa$-values. In the limestone samples the values of $\varkappa \times 10^6$ range between 14 and 44. In the porphyries, agglomerates and tuffitic leptites hematite, hollandite, braunite, and piedmontite occur abundantly as accessory minerals. Hematite is especially plentiful within the northern part of the Njuoskes area. The susceptibility of these rocks has been found to be proportional to the amount of the accessory minerals mentioned and can briefly be expressed so that $\varkappa \times 10^6 = 120\ (S - 2.60)$, where S = the specific gravity of the rock sample.[2] In most of the core samples examined the values of the above-mentioned quantity lie between 3 and 30. The formula above can also be considered to express the lower limit of the susceptibility values measured on ore samples of hollandite, braunite, bixbyite, and piedmontite. Especially the braunite often shows considerably higher values than those corresponding to this formula. The highest value ($\varkappa \times 10^6 =$ 1300) was obtained on a braunite boulder from the Rakten area.

The results of the tests on the core samples examined are found in the table below. The lowest and the highest values of the total magnetization intensity ($I = I_i + I_r$) of the different samples are here stated for each separate drillhole. The highest anomaly value of the vertical intensity, expressed in γ, that can be caused by a rock may be written $0.2\,\pi\, I \times 10^6$.

Table 1.

Total magnetization intensity ($I \times 10^6$) of the core samples examined.

Drill-hole	Hollandite Braunite Piedmontite Bixbyite	Greenstone	Lime	Porphyry	Tuffitic leptite	Agglomerate
U 1				510—1290		
U 2	429—1680				120—2320	585—4950
U 3	1160—2050			1920	196—1680	1300
U 5	60 (viridine)			320—525	135—19200	
U 6		173—20800				
U 7		85—9150			190—1160	
U 8	510			405—1630		
R 1	32—63	30—8300	15—40	65—170		

1 $I_i = 0.5\,\varkappa$.

2 Cf. p. 75: Werner, S. Determinations of the magnetic susceptibility of ores and rocks from Swedish iron ore deposits, Sveriges geologiska undersökning, Ser. C. Nr 472, 1945.

From this we may conclude that the boundaries of the greenstone zone cannot be mapped magnetically with great exactitude, not even in those cases where strong indications appear, since even here practically non-magnetic parts of considerable width appear within and along the boundaries of the zone. On that account the greenstone boundaries in Plates 3 and 4 are only roughly correct, having been drawn without the aid of any detailed computations on magnetic profiles. The shape of the anomalies M 3 and M 4 shows that the greenstone zone to the north of the double bend at 5500 S (Njuoskes area) stands approximately vertical, while the greenstone to the south of it displays a fairly uniform dip of 50—70° to the east. When the dip is approaching 50°, it causes a noticeable displacement of the positive apices of the anomalies towards the hanging wall of the greenstone.

It appears from Table 1 that the magnetization intensity of the magnanese ore samples is of the same magnitude and shows about the same variations as the samples of the surrounding rocks. Thus, one cannot expect the manganese mineralizations to appear on the magnetic anomaly map. Nor is this true of any of the ore deposits encountered either within the Njuoskes area (at 400 N and 1080 E, 0 and 180 E, 2200 S and 550 W, 4600 S and 640 W, 4880 S and 440 W, 4880 S and 370 W, 6480 S and 380 W) or within the Rakten area (at 50 N and 20 W, 4310 S and 670 W). The prospects are indeed small, but with two exceptions in the Njuoskes area the overburden is very insignificant and in several cases measurements have been made on exposed ore. The three first-mentioned small ore prospects in the Njuoskes area as well as the mineralization on Raktenvare (4310 S and 670 W) are situated alongside rocks that cause strong magnetic anomalies.

M 2 has been investigated by drillholes U 4 and U 5. This anomaly was found to be caused by a fairly rich hematite-bearing tuffitic leptite, where the hematite in some cases is stratified and in other cases occurs as uniform dissemination. The magnetization of the rock does not, however, stand in any direct relation to the hematite content. This appears in the diagram in Fig. 1, which shows the relation between specific gravity and the total magnetization intensity of core samples from U 5. The greater part of the magnetization intensity of these samples is probably due to an insignificant amount of magnetite, which is magnetized to the limit of its saturation value or very close to it. As regards the tuffitic leptite, the diagram thus prompts the conclusion that where the highest amounts of magnetite (or magnetization values) occur, there the hematite content is likewise fairly high, but, on the other hand, a high content of hematite does not always correspond to a relatively high amount of magnetite.

What has been said above about the magnetization conditions of the tuffitic leptite in U 5 seems to hold true as regards this rock as well as the porphyries and agglomerates within the whole district as demonstrated by the results of the investigations of other drillholes. From the shape of the anomalies on the areas occupied by the rocks mentioned above it seems possible to conclude that hematite occurs much more frequently within the north-eastern parts of the Njuoskes area than within the rest of the district. It may also be expected

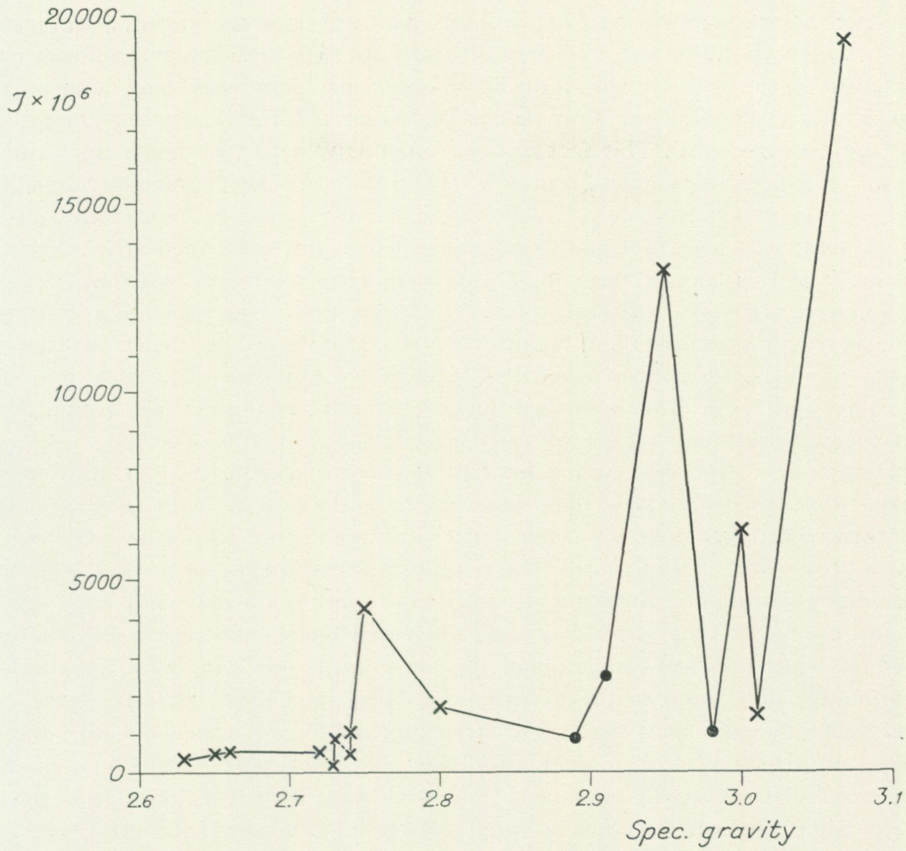

Fig. 1. The relation between spec. gravity and total magnetization intensity (I) of core samples from U5.

× core samples with stratified hematite.
• » » » hematite in uniform dissemination.

that at least within the closed curves for 1000 γ, situated to the east and north-east of M1 and M2, disseminations will occur with a hematite content corresponding to that in M1 and M2. Besides the small manganese prospects situated in the last-mentioned anomalies, the manganese ore breccia at U 1 is thus probably also situated close to a richly hematite-bearing zone. It is thus not unlikely that in these cases a genetic relation may exist between the hematite and the manganese mineralization (cf. pp. 52—58).

Between Sörhårås and Blackälven negative anomaly values occur over large parts of the porphyry areas, although the magnetization intensity of the porphyry generally must give rise to positive anomaly values. This may be due to the fact that the fixed normal value of the vertical intensity (p. 71) is higher than that in reality valid within the area in question. In the same manner, however, as the greenstone zone where it dips to the east gives rise to a magnetic depression channel on its western side, the negative anomaly area lying to the east of the greenstone zone may also represent a depression channel, belonging to a highly positive anomaly area situated to the east. The magnetization intensity of the bedrocks within the above-mentioned depression must, however, in any case be considered lower than what is generally the case within the rest of the area surveyed. This fact also corresponds well to the results from the tests on porphyry samples from R 1 (see Table 1). The depression channel extending over Tjatitsvare (Pl. 4) no doubt mainly belongs to the positive anomaly area to the east of it and its irregular shape is probably due to the rugged country in this part of the area. The appearance of the irregular anomalies at the eastern boundary of the area surveyed, between 4000 S and 5000 S, is closely connected, as shown in Pl. 4, with the occurrence of the red leptite. On Raktenvare around zero the same red leptite has been found in contact with the porphyry at 700 E. The anomaly values are negative at this contact as well as at the corresponding contact on Tjatitsvare but they probably become positive immediately to the east of the limit of the area surveyed. Further, it seems likely that the boundary of the porphyry runs to the west of the positive anomaly area cutting across the eastern limit of the area surveyed south of Raktenvare between 500 S and 1000 S. This boundary seems, too, in the main to follow the depression cross Tjatitsvare also north and south of the exposed part of the contact zone. In these cases, however, it is possible that some other rock than the red leptite borders the porphyry. In addition the negative anomaly values within the depression to the north of the river Blackälven decrease towards the east in such a way that the eastern limit of the negative anomaly area generally speaking can be expected to follow the known parts of this boundary line. It is close at hand to assume that the boundary of the porphyry has a corresponding uniform direction, at least between Tjatitsvare and Raktenvare.

The appearance of the distinct, north—south magnetic »indication» on the southern bank of the river Blackälven is noteworthy. It is possible to trace it from the eastern limit of the area surveyed almost as far as the greenstone zone.

It appears from Pl. 3 that the porphyry in the Njuoskes area as far south as 8000 S extends towards the east to at least 800 E and that a minor enclosure of greenstone, elongated in N—S, has been found in the porphyry at 7800 S and 700 E. Within the anomaly complex that overlaps the eastern limit of the area surveyed between 8500 S and 10000 S uniform and distinct N—S strike directions appear. This fact and for the rest the appearance of the anomalies on the Complete Anomaly Map, make it seem likely that there occur large enclosures of greenstone of the same kind as mentioned above.

Electrical Indications.

Besides the electrical indications earlier mentioned (see p. 75), such indications have been obtained in the Njuoskes area partly on the most strongly magnetic parts of the greenstone zone between 2100 S and 5000 S and partly on an area up to 400 m wide and describing a curve with slight convexity to the west. Towards the north it tapers out at 1000 N and 300 W and towards the south at 1300 S and 800 W. On the greenstone there only occur disturbances of the real component and they amount to maximum 7%. The disturbances were caused by magnetic induction in the greenstone area and not by electrical currents induced in it. This is evident, inter alia, from the circumstance that the markings of the anomaly values are opposite to those appearing in Sling-ram measurements above electrical conductors. Within the last of the indication areas mentioned above only imaginary disturbances occur and they are probably caused by water-bearing layers in the drift. These layers seem to fill up a deep depression in the bedrock. This is definitely the case in the southern part of the indication area, where the thickness of the overburden in a number of drill-holes (U 16—U 18, U 23) exceeds 60 m, and in the only drillhole that reached bedrock the thickness was found to be 136 m. Further, it may be mentioned that only weak gradients occur on the magnetic anomaly map within the electrical indication area here treated.

Within the indication areas E 1—E 9 the disturbances are wholly imaginary and the measured values of the disturbances are in every case small (< 2 %). E 1—E 4 have been investigated by means of drillholes and they were all caused by weak hollandite mineralizations. The strongest indications within E 1 are shown in Fig. 2. The negative anomaly areas here indicate the position of the outcroppings of the electrical conductors. The mode of occurrence of the positive anomaly areas indicates that these bodies dip towards the east, the western body probably more steeply than the eastern one. Drillhole U 1 is inclined 45° and its depth is 47 m. The rock is here a prophyry brecciated by veins of hollandite and to a minor degree of piedmontite. From the surface of the bedrock to 37 m, measured along the drillhole, the manganese brecciation is fairly uniform though notably richer between 20 and 25 m. Below 37 m the brecciation is very insignificant. Analyses of the manganese content of the section 20.8—26.7 m showed an average amount of 5.1 % Mn. In Fig. 2 are shown the positions of the boundaries mentioned above, projected on the rock surface on the assumption that the breccia dips 60° and that the depth of the overburden is 5.5 m.

E 2 was shown to be caused by a steeply inclined manganese breccia, about 2.5 to 3 m thick. Hollandite is the predominant ore mineral and it appears mainly on brecciating veins but sometimes also in small, compact masses. An analysis of the mineralized section in drillhole U 8 showed a manganese content of 7.9 %. The thickness of the overburden is here about 12 m.

E 3 and E 4 refer to flat-lying ore breccias with manganese contents, undoubtedly somewhat lower than in E 2. In the vertical drillholes U 9 and U 10, breccias occur at a depth of 0.4 to 8 m and of 29 to 33 m resp.

E 8 and E 9 were examined by means of trenching. In both cases the indications were caused partly by thin lenses of kaolin in the overburden and partly by other thin lenses, containing a very fine-grained, manganiferous substance and probably consisting of hydrous manganese oxides (wad).

E 5, E 6, and E 7 have as yet not been examined. The highest disturbance values obtained within E 6 and E 7 do not amount to more than 0.55 % and 0.75 % resp., but, nevertheless, the indications obtained are very clear and

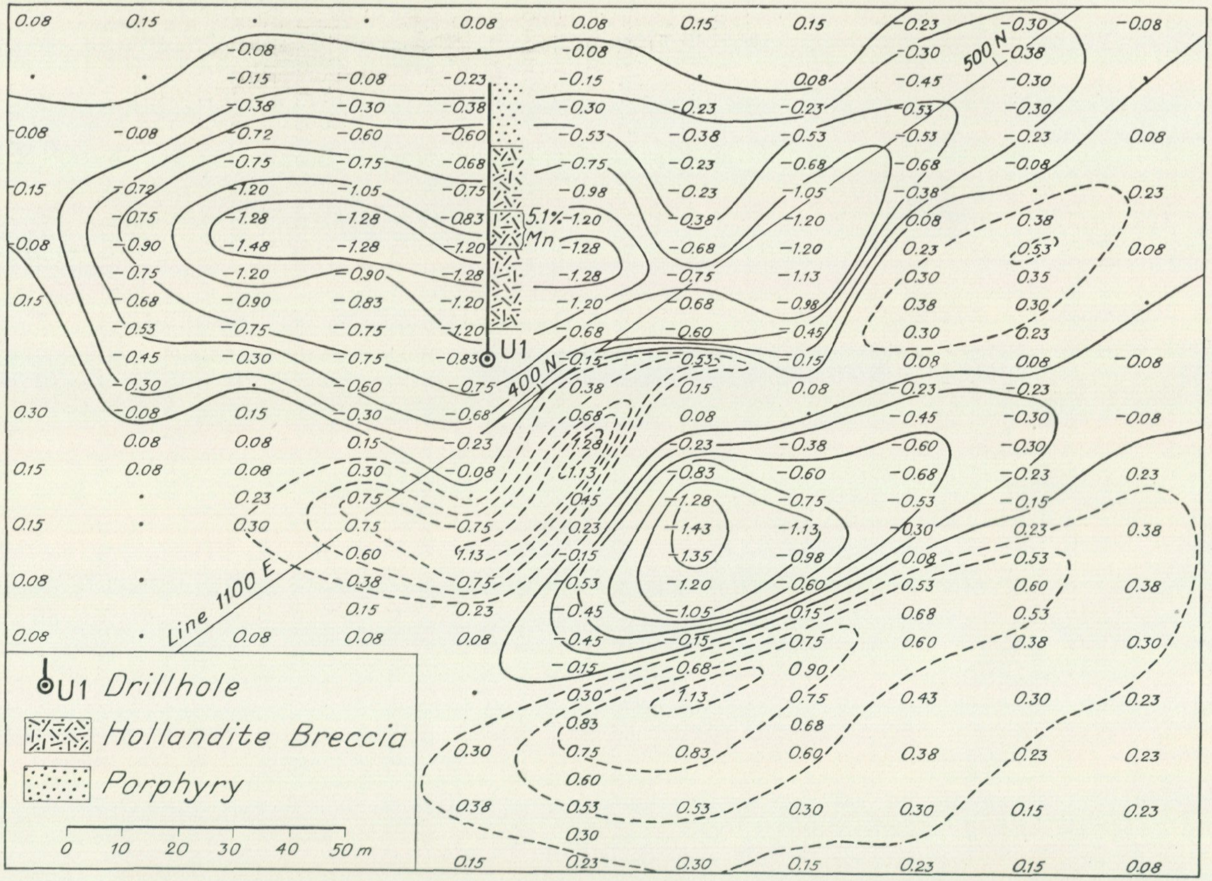

Fig. 2. Imaginary disturbance component at the two strongest indications in E 1. Curves (solid lines indicate 0 and negative disturbance values, broken lines positive values) drawn with an interval of 0.25 %.

distinct. Both these indications seem to be caused by fairly thin, flat conductors dipping 50—60° to the east.

It is noteworthy that no electrical indications were obtained on the hollandite mineralizations in drillholes U 2 and U 3 on the southern slope of Stuor Njuoskes. This shows, however, that the dimensions of this mineralized zone are too small in relation to the *measuring distance* (40 m) used in the Sling-ram measurements. This has also been verified by means of trenching and drilling.

It appears from the statements above that we cannot expect to find any compact hollandite ores of workable dimensions close to the surface of the bedrock within the electrically surveyed areas. Such ore deposits ought to have given rise to considerably stronger indications than those brought about by the weak hollandite breccias discovered within the Njuoskes area. No braunite mineralizations have been indicated in any of the cases, nor were such indications to be expected (cf. p. 68).

APPENDIX 2.

Ice-Movements and Boulder Trains in the Murjek-Ultevis Districts.

By G. Lundqvist.

As the discovery of the manganese mineralization described in this paper may be of interest in regard to the geological methods used, some data will be given on this matter.

The country where the first manganese boulder was found, the vicinity of Vuotnajaure, is extremely hillocky. Ridges in all directions alternate with bogs and lakes. Generally speaking, the country is very flat, however, the average height being 300—350 m above sea level. From this rugged plain there rise slightly rounded ridges, about 100 m high and elongated in a NW—SE direction.

A knowledge of the development of this rugged country seemed to be of importance to the prospecting. Therefore it may be justified to examine the area more closely. Even a brief survey of the area disclosed that the soil partly consists of a typical moraine, and partly, although it is more subordinate, of equally typical glaci-fluvial gravel. As to grain size the character of the moraine varies from gravelly to more or less sandy or finer. The quantity of erratic boulders within morainic areas of this type, ablation moraine, is often high and the occurrence of large boulders is almost normal. In this area, however, the large-boulder moraine occurs together with another type of moraine, boulder-rich moraine, but the latter type is relatively subordinate. Moraine types with a normal content of boulders or types poor in boulders predominate.

As already mentioned, the surface forms are very irregular. It is quite difficult to obtain a concrete conception of the landscape, but a study of the direction of the ridges, made completely at random during a day's march, gives a general idea of the situation. The result is as follows.

N—S	7 %	W—E	11 %
NNW—SSE	14 %	WSW—ENE	5 %
NW—SE	18 %	SW—NE	27 %
WNW—ESE	2 %	SSW—NNE	16 %

The directions NW—SE and SW—NE predominate, even if all other directions are represented. It is possible that a larger material would show other values but the general tendency would hardly be different.

The surface forms and the profiles of the ridges are of importance for our knowledge of the nature and genesis of the deposits. Tanner (1915) believes

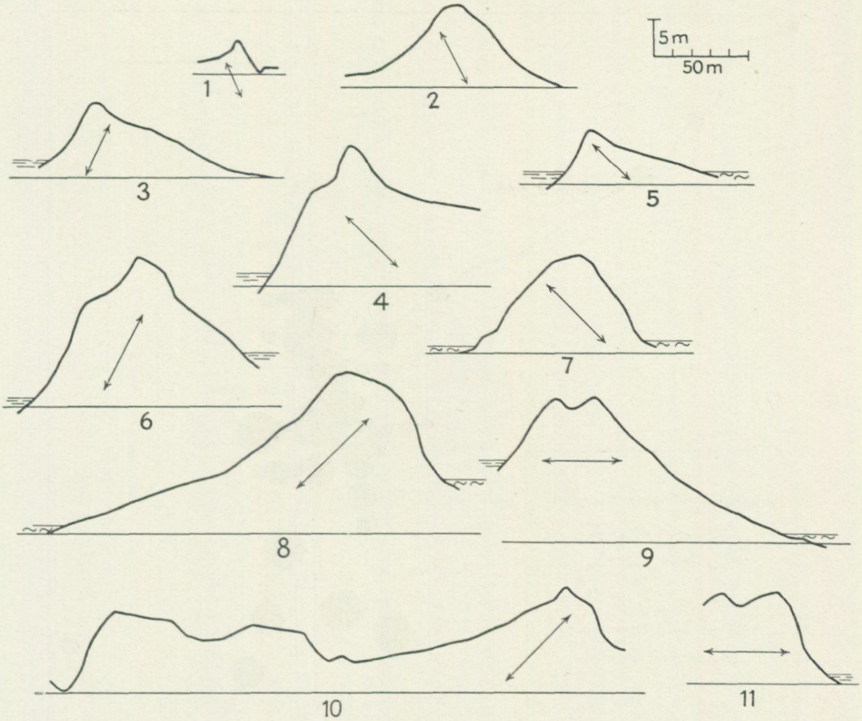

Fig. 1. Profiles across the ridges in the ablation area NW of Murjek. The arrows indicate the elongation of the ridges, North is assumed to be due upwards.

that the country has been influenced, perhaps pushed together, by an ice-cap advancing from the west. If this be true, the land-forms would most likely mirror these events. The profiles (fig. 1) measured on a number of ridges in different parts of the area do not show any signs of such a compression. The sides of the ridges slope steeply one way or the other. A consistent feature, however, seems to be that the steepest slopes occur at such places where a pond or a small bog is alongside the ridge. These depressions in the ground thus seem to have been formed by ice-blocks. Genetically they resemble kettle-holes, etc.

Consequently the surface forms of the moraine do not give much guidance as to the direction of the ice-movement. This should be obtained from the striae but they only occur very rarely in this country. Judging from the drillings, the thickness of the moraine is about 40 m, and the bedrock is seldom exposed. Where the bedrock outcrops it consists of strongly weathered Lina granite of late pre-Cambrian age and does not allow any detailed observations of the youngest striae. On the hill Ranesvare, however, a small outcrop occurs. A fresh part of the outcrop was exposed by digging and striae with the direction from N 36°—38° W were observed. Not a single hint of any other direction appeared. This small outcrop is cut sharply in NE, and thus dips vertically in that direction. The edge is quite fresh and sharp, and consequently no ice-movement from

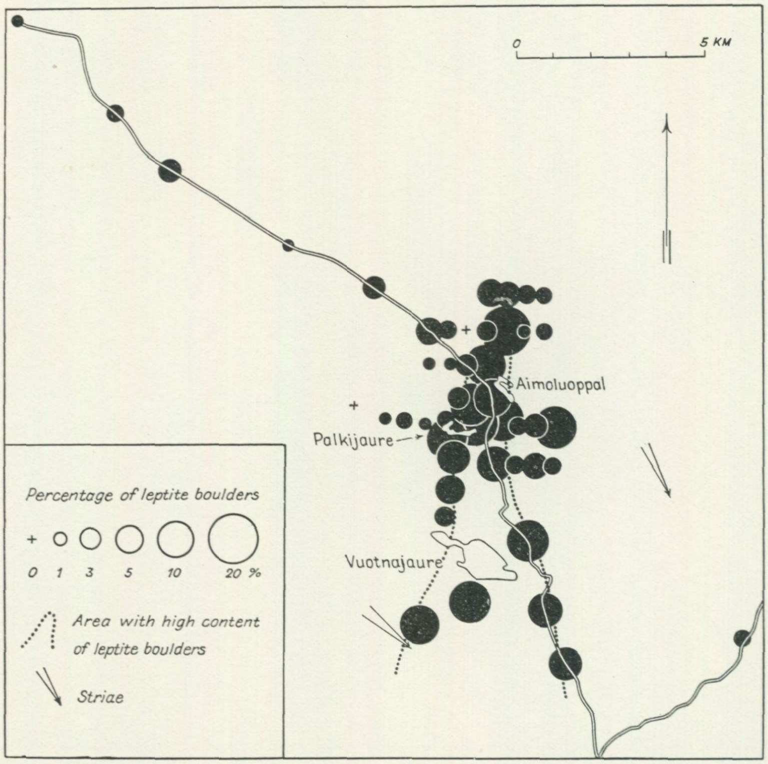

Fig. 2. The distribution percentage of leptite boulders at the localities investigated in the Högträsk—Murjek area. The limited accumulation is assumed to indicate that the mother rock of the leptite boulders is to be found immediately NW of the line Vuotnajaure—Palkijaure.

NE can have occurred. The striae show that the last observable compression must have emanated from N 36°—38° W.

In order to elucidate the Pleistocene history of the country the following data were collected. Ridges occur in all directions, but two are predominant: NW—SE and SE—NW. The ridges display steeper slopes towards depressions of the same character as kettle holes. The direction of the ice-movement is from N 36°—38° W. Generally speaking the surface forms of the area coincide with or are perpendicular to the direction of the ice-flow. These features are thus identical to those found by Russell (1897, p. 114) on the Malaspina Glacier: »The heaps of debris left as the ice front retreated have a general parallellism with the present margin of the glacier and are pitted with lake basins, but only their higher portions are exposed above the general sheet of sand and gravel spread out by streams draining the glacier.»

This brief analysis of the landscape thus indicates that this irregular moraine must be interpreted as an ablation moraine, mainly transported from NW.

It was then necessary to examine the composition of this moraine more closely and that not only as regards the presence of the very sparse ore boulders.

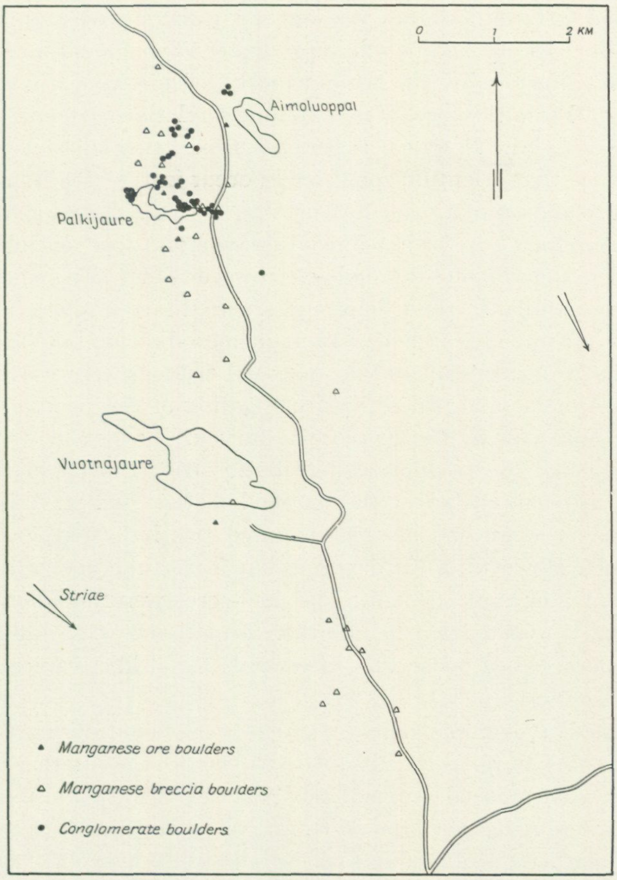

Fig. 3. Within the area of the manganese breccia boulders a limited occurrence of conglomerate boulders is to be found. According to our experience gained at that time, this was considered an additional indication of the proximity of the mother rock.

In collaboration with O. Ödman a statistical study of the boulder content of the drift was carried out in an area between Murjek and Högträsk (Pl. 1). It appeared from this examination that Lina granite is the predominant rock. Its relative frequency is generally 40—50 %. It is followed by a gneiss with about 30 %. The rest consists of leptites, porphyries, amphobilites and other greenstones, conglomerates, mica schists, etc. At the same time special attention was paid to the occurrence of ore boulders and a search for such boulders was successively performed within the entire area from the vicinity of Murjek to Porjus (Pl. 1). A large number of boulders carrying disseminations of manganese minerals were encountered. These boulders demonstrated that the manganese mineralization was connected with the leptite. A conception of the distribution of the leptite would thus make possible a localization of the manganese mineralizations. Already in June 1942 a hint was obtained as to where the leptite might occur. Fig. 2 shows that leptite boulders occurred along the highway as far as

Högträsk, but in addition they showed a striking increase in number in a belt from the vicinity of Vuotnajaure up to Aimoluoppal in NNE. The increase in the direction of the ice-movement occurs very rapidly from 1% to about 20 %. From this zone of maximum the relative frequency continuously decreases towards SE. Practical experience from other districts thus made it appear probable that a leptitic zone should occur in the area immediately NW of Vuotnajaure and up to a point NW of Aimoluoppal. The manganese boulders of various types found up to that time also favoured these conclusions. The few leptite boulders found along the highway towards Högträsk might derive from a leptitic zone parallel to the former and situated farther away to the west.

During the continued search several manganese-bearing boulders were found also NW of Högträsk. In spite of this, diamond drillings were started in the area Vuotnajaure-Aimoluoppal, since the investigation of the boulders in this part was strongly supported by the geophysical survey. The decision to start drilling was also supported by the limited distribution of the conglomerate boulders, within the distribution fan of the leptite boulders (fig. 3). According to the practical experience we had already acquired this indicated a comparatively short transport. However, a discouraging but from a methodical point of view interesting fact now came to light: The drill-cores were found to consist of a rock type (quartz diorite) that had nowhere been found as boulders. This riddle has not yet been solved, as shortly afterwards the drillings were discontinued in this area.

As mentioned above, manganese boulders were found during the continued search even farther towards the NW. Also the mode of occurrence of these boulders was somewhat unusual. Immediately NW of Högträsk a number of manganese boulders were lying in a depression. According to experience gained in other districts such gatherings of boulders consist almost exclusively of local material. Normally it is thus possible to assume that the rock found in this material occurs in the immediate vicinity. This, however, appears not to be the case here. It should also be observed that farther towards NW, in the neighbourhood of Sarkasvare (Pl. 1), a number of manganese boulders were encountered within a limited area. Also in this case the source of the boulders would have been expected to be in the vicinity.

Also in the neighbourhood of Porjus, along the highway between Harsprånget and Ligga and on the northern slope of Ananasse (Pl. 1), several manganese boulders of local occurrence were found. In the country between this area and the Ultevis mountains in NW the search for ore boulders was not so systematic as in the Murjek area. The geological mapping showed that the rocks NW of Porjus mostly consist of gneiss and granite. On the search being extended towards Ultevis, manganese boulders were encountered here and finally also disseminations of manganese minerals in outcropping rocks. The distance between these manganese mineralizations and the boulder first encountered at Vuotnajaure is 125 km. With this discovery a new phase in the search for the manganese ore was started, viz. the exact localization of the mineralized zone itself.

However, new complications arose. Prospecting for ores in glaciated areas is usually aided by a study of the striae and the distribution of boulders. In this case, however, it was found that the mother rock, a small outcrop in a lateral drainage channel on the hill Stuor Njuoskes (Nedre Manganravinen, Pl. 3), was situated all the way up in the zone of the ice-shed. It was thus necessary to establish what was the direction of the ice-movement in this part. So few striae have been found, however, that at least some of the localities had to be studied more closely. This could not be done in this small area alone but information had to be collected also from the area to the north, more exactly from the vicinity of the Saltoluokta Tourist Station and N of the lake chain there. The notes below refer to names on the topographical map and to the plates in Ödman's report.

1. On some recently uncovered rock surfaces close to the summit of Tjatitsvare (Pl. 2 and 4), thin striae in N 75° W were observed, crossing coarser striae in N 35° W. The former only occur on the small peaks of the outcrops and show a distinct stoss-side towards the west. Sometimes also the older striae are fairly thin but then they occur lower down and not on exposed portions of the outcrop. Towards SE no stoss-side was observed.

2. Close to the Rakten cabin (Pl. 3) cross striae in N 20° W occur on more or less weathered surfaces.

3. On the SE slope of Sörhårås (Pl. 3) the bedrock is exposed in a number of outcrops. They are rounded and on the tops thin striae in W—E and N 100° W are seen. They appear to have been eroded by a rigid ice. About 100 m further E and on a steep eastern slope coarse and partly destroyed striae in N 10°—20° W occur. They are crossed by narrow striae from N 70° W, obviously belonging to the same late system as those mentioned before. Close to this outcrop were seen some small rocks with preserved stoss-side towards SE.

4. Besides the striae now mentioned a fairly great number exist, almost all of which indicate an ice-flow from about N 70°—80° W.

5. Close to the south-eastern end of Sitojaure and immediately N of the hut belonging to the Touring Club badly developed striae have been observed.

SE of the Saltoluokta Tourist Station striae occur sparsely. The following observations have been made there.

6. On the northern side of the hill Keinotnjuoske coarse, weathered striae from S 60° W are seen on a greenstone rock.

7. On an outcrop in the depression between the locality just mentioned, and the peak on the map to the S of it thin striae from S 60° W are seen.

8. About 30 m S of the foregoing and higher up striae in N 45° W occur. They are sharp and the stoss-side is distinct. Just above this rock the direction S 60° W reoccurs.

On a small outcrop close to the summit the connection between them is indicated as is shown in fig. 4. From this it appears that S 60° W is younger.

9. Where the trail crosses the highest promontory of Kirkastjåkko quartzite is exposed. On these rocks sharp and distinct striae in S 60° W are seen. This is thus the younger system. Not a single trace of the older system of N 45° W was

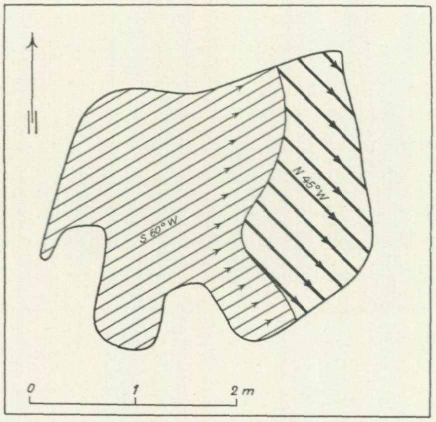

Fig. 4. Outcrop on Petsnavarats (locality description No 10); fine ruling denotes younger, coarse ruling older directions on the lee side.

seen here, although the situation would seem to indicate that this system still ought to be preserved.

10. At the first »t» of Petsnavarats on the map, outcrops of porphyrite were seen with striae in N 45° W and S 60° W. As far as could be judged, the last-mentioned system is younger, but the relation could not be settled with absolute certainty.

Some details that may be of special interest were observed. The direction N 45° W crosses some small fissures almost perpendicularly. Small flakes were broken loose SE of the fissure, so that the greatest depth is very close to the fissure (fig. 5). The direction S 60° W crosses the fissures obliquely and here the deepest loosening occurred towards NE. The greatest depth of the loosening is thus in both cases in the same relation to the flow of the ice.

11. At the northern end of Tarvasvarats, on the northern side of Lake Langas, a small pond is marked on the map. The hill south of it is built up of greenstone, showing distinct striae in N 60° W or S 60° E. As far as could be judged the stoss-side is, however, towards SE; the form of the rock thus indicates an ice-movement towards NW. This also agrees with the surface form of the hill: an even SE-slope with an ordinary boulder frequency in the moraine, and a steep, boulder-rich NW-slope.

12. To the north of the small pond there is a sparse growth of mountain birch with scattered outcrops of sandstone. On one of them, striae in S 65° E were seen, though the stoss-side is uncertain. A small outcrop close by has, however, a distinct stoss-side towards SE. Here, too, striae and scars convex towards SE occur. Outcrop No. 3 lies on a NW slope and the stoss-side is undoubtedly towards SE. Another small outcrop close by is in a similar position. It shows striae in S 65° E and small scars convex towards SE. A similar condition is shown by a neighbouring rock, No. 5; in this case no uncertainty of the observations exists. On another neighbouring rock the same conditions were

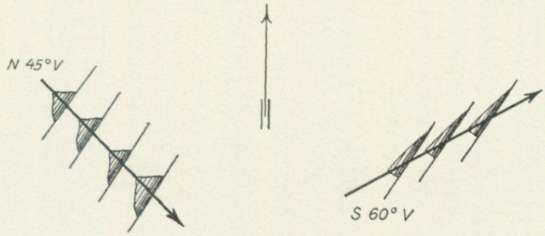

Fig. 5. The loosening close to the striae, when they cross a fissure, is deepest on the distal side.

observed but in addition narrow striae from S 65° E descend into the larger scars.

A summary of the ice marks in this area thus shows that the ice must have advanced from SE (S 60°—65° E). It is further noticed that the quartzite sandstone dips towards NW. The notches in the joints towards SE are thus filled with thin morainic deposits and therefore the outcrops are seldom seen from this direction.

13. On the north-western slope of Kebnats three outcrops have been studied, all tree consisting of quartzitic sandstone. One of them is penetrated by a hematite vein, a few dm in width. Narrow striae are here seen in N 50° W or S 50° E. The last-mentioned direction is the most likely one.

14. About 50 m NW of the foregoing there is a fairly flat outcrop, somewhat broken in its shape along a NE—SW line. The SE surface is striated but the striae terminate at the break.

The stoss-side is probably towards SE and the direction of the striae thus from S 60° E.

15. About 30 m to the NW there is an outcrop, partly consisting of a flint-like rock, showing a well developed striation. In view of the scars, the stoss-side of this outcrop seems to be towards NW. Striae in N 50° W were seen and thin, younger striae from S 60° W.

It was possible to break off a small slab of the outcrop and this was brought home (fig. 6). At my request Dr. E. Ljungner made a close examination and has submitted the following notes:

»1. the oldest from N 20°—45° W, represented by some crossgoing notches.

2. next from S 35° E, good sculpture.

3. next from N 55° W, striation.

4. the younger from S 55° W, slight striation.»

16. On the north-western side of Suppats striae N 45° W were observed.

17. On the southern slope of Suppats there are agglomerates with structure lines running perpendicularly to the direction of the striae. Thin scars were seen from N 65° W or possibly S 65° E.

18. On Suppats a great number of striae of different sizes are seen. The narrowest come from N 65° W, the widest ones from N 25° W. The stoss-side is definitely upwards the valley. Every small outcrop has a distinct stoss-side towards Sjöfallet.

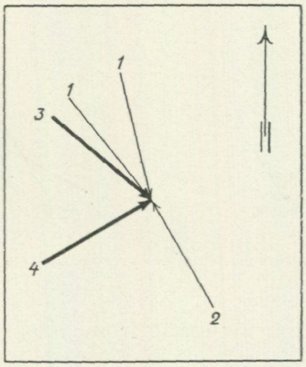

Fig. 6. Crossing striae on a small rock specimen from Kebnats.
Age relation 1—3 according to E Ljungner.

These various observations of the striae indicate greatly varying ice flows. Within the southern part, that in the Ultevis district, there are traces of a flow from SE (stoss-sides). It has not been possible to ascertain the connection between this and the more pronounced movement from approximately N 30° W. Most likely, however, the last-mentioned is the younger. In any case the flow from N 70°—80° W is the youngest and seems, too, to have been represented by a rigid and thin ice, very likely the final stage of the ice movement.

Within the Saltoluokta district, on both sides of Langas, the oldest movement traced is the one from N 20°—45° W, as adopted by Ljungner. Next there is a good stoss-side from S 35° E, well answering to the one from SE in the southern part. Then follows in the north N 55° W, and in the south N 30° W. Within the Saltoluokta district these directions are crossed by the direction S 50°—60° W, and in the south by N 70°—80° W. Thus it appears as if the Sarek Mountains in the west constituted the area from which the very last ice-flow emanated. This ice-cap was remarkably rigid and thus seems to have been fairly thin. Within the southern part of the area the flow was probably influenced by the surface forms of the country but nothing similar has been observed in the north.

The object of the investigation made was to locate the mother rock of the manganese ore more exactly than was possible by the aid of the insignificant outcrops. However, the investigation showed that the flow of the ice in the critical area, situated almost on the ice-shed, was very complicated. It is hardly possible to decide, by the aid of the material available, to what degree these flow directions influenced the boulder transport. It seems reasonable that the picture of the distribution will be fairly diffuse. The following observation by O. Ödman is an indication of the direction of the ice transport. It is striking that the surface of the outcrops are found on the E and SE sides of the hills. In Central Sweden, where the site of the ice-shed in relation to the country need never be discussed, the outcrops always lie on the north side of the hills. If this knowledge is applied in the present area the main part of the material must have been transported towards NW. However, the majority of the boulders are instead lying SE of the outcrops. This shows that it was the first or the second or these two ice-movements in conjunction that caused the main transport. An extensive accumulation of manganese-bearing boulders is, however, now found around the hill Vuojtur. It is not possible to disprove that these boulders may have come from a hitherto unknown source in the NW, but this possibility seems so unlikely that it may be left out of consideration. These boulders may thus have been transported from SE in exactly the opposite direction to the one formerly mentioned. This ice-flow from SE seems to have been fairly insignificant, at least judging from the traces it left. Therefore, it is possible that the rock or the ore-bearing part of the rock from which the boulder accumulation just mentioned may have been broken off, only in a later stage was within reach of the assaults of the ice. This is by no means unlikely since the spreading out of the boulders must occur continuously, with new parts of rock being exposed by erosion.

The distribution shown by the boulders is interesting also from another point of view. The flow of the ice in this part was always changing. It is thus very remarkable that the spreading out of the boulders shows such a distinct and uniform picture. A diffuse distribution over the entire area might have been expected.

The boulders shown in Pl. 1 cause further reflections. They form groups scattered throughout the distribution area. It should be noted that this distribution is not due to any differences in the search for boulders. The entire area from the vicinity of Murjek to S of Porjus has been well searched. It is thus possible to state that the picture of the distribution on the map corresponds well with the conditions in nature and their appearance remains to be explained. It is also of a certain interest that different types of boulders are accumulated into groups without any scattering. Several of these boulder groups were so distinct that during the course of the work they were given local names. Typical examples (Fig. 3), are *e. g.*, the conglomerate boulders NW of Murjek, the molybdo-scheelite-bearing piedmontite boulders 3 km NE of Rakten (p. 49), and the braunite boulders at Tjålme (p. 40). According to our present experience, the picture of such a concentrated distribution usually indicates that the source of the boulders is close by.

If the boulder groups had not been lying in a row in the direction of the ice-flow, it would have been natural to assume that they represented different sections of erosion in the ore-bearing bedrock. Another explanation is then possible, viz. that enormous sheets of morainic material were moved as units with the ice (Lundqvist 1943, p. 21). Examples of similar conditions are known from Skåne (Holst, 1903), where mighty layers of chalk have been moved by the ice. In the same direction points the study of the boulder content on the geological map sheets Karlstad and Forshaga, where zones richer in Älvdal porphyries alternate with zones poor in these rocks. This appears only when the boulder maps are drawn. Similar phenomena, although the zones rich in Älvdal porphyry here run about perpendicular to the direction of the ice-flow, are found on the map sheets Smedjebacken and Avesta (Lundqvist 1946, p. 71). All these relations together make it appear fairly likely that entire morainic areas were transported as units by the ice. It must, however, be admitted that so far we do not know very much about these problems.

The above account is essentially of interest as it illustrates the methods followed in prospecting. Starting with the first erratic boulder in the vicinity of Vuotnajaure, the region was prospected with the aid of geological and geophysical methods. The first mineralization was also located mainly owing to the discovery of an outcrop. But for this discovery it is uncertain whether it would have been possible to obtain a correct picture of the narrow mineralized zone only by using geophysical means. It is of importance in a case like this to start the drilling in the right spot. Considering the small and narrow mineralization, the difficulty of this task is easily understood. The difficulties of this prospecting enterprise were to a large extent caused by the fact that the mineralization is situated just within the zone of the ice-shed. It cannot be denied that we still know very little about the ice-shed and its movements. Ljungner (1943) made a good start in studying these problems and showed how complicated the process has been, but these investigations must be extended to larger areas. This is certainly justified and may quite unexpectedly yield practical results since our knowledge of the ore deposits in these parts of the country is still most unsatisfactory.

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Explanatory Notes to Plates 1—4.

On the plates (and in the text) Swedish and Lapp names have not been translated into English. Most of them are taken from the Ordnance Survey maps but some of the names now on the plates were created and used locally during the prospecting. The following list gives in English translation some of the Swedish (S) and Lapp (L) names and terms.

Älv (S)	River
Bäck (S)	Brook
Jaure (L)	Lake
Jokk (L)	Brook
Nedre Manganravinen (S)	Lower Manganese Ravine[1]
Övre Manganravinen (S)	Upper Manganese Ravine[1]
Nordhårås (S L)	North Hårås[2]
Sörhårås (S L)	South Hårås[3]
Sel (S)	Still-flowing part of river
Sjö (S)	Lake
Tjålme (L)	Sound
Vare, varats (L)	Hill or mountain

Plate 1 is reproduced from the general map of Sweden in scale 1 : 400,000, only some minor topographic details having been erased in order to facilitate the reading.

The topographic pattern of Plate 2 has been compiled from the Ordnance Survey maps and Plates 3 and 4. In some places the topography is incorrect, but the errors are believed to be insignificant. The form lines are arbitrary and only denote the main contours of the landscape.

The topography of Plates 3 and 4 was constructed in connection with the geophysical survey during the compass traverses. The base line systems were laid out with a tube but all distances were measured with the aid of a tape only. The accuracy is, however, sufficient for the present purpose.

[1] Geologically speaking they are lateral drainage channels of late Quaternary age, formed by melt water between the hill slope and the edge of an ice remaining in the valley.

[2] Local name. Called Åråsvare (796 m) on the general map of Sweden in scale 1 : 400,000.

[3] Local name. Called Hårås (772 m) on the Ordnance Survey map in scale 1 : 200,000.

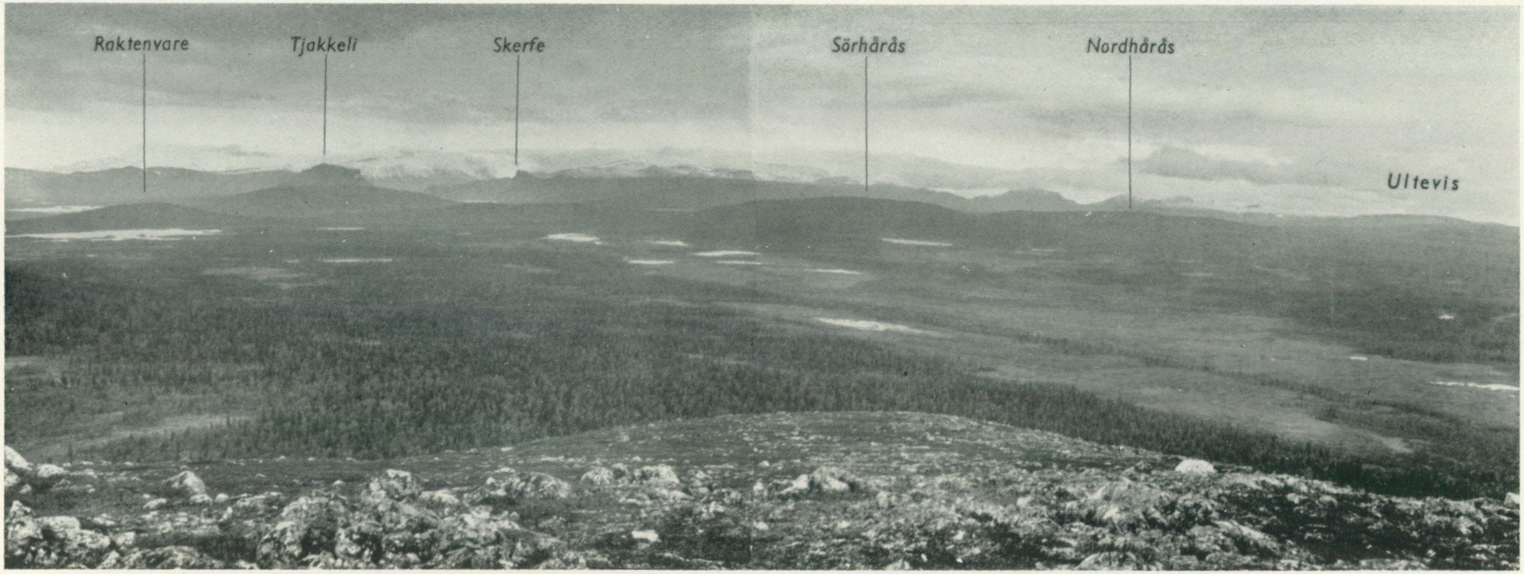

Fig. 3. View from SE of the central and N parts of the Ultevis district. Sarek Mountains in the background.

Fig. 4. Tuff agglomerate with small angular fragments. Black spot in centre is hematite replacing the groundmass. Drill core, Stuor Njuoskes. Nat. size.

Fig. 5. Southern part of the Ultevis plateau from Kuorpavardo in the SE. Stuor Njuoskes barren hill to the right in middle foreground, Stankajokk valley to the left.

Fig. 6. Stuor Njuoskes from Nordhårås. Manganravinerna are marked by horizontal lines near top of hill.

Fig. 7. Nedre Manganravinen on Stuor Njuoskes with exposures in the upper tuffitic series.

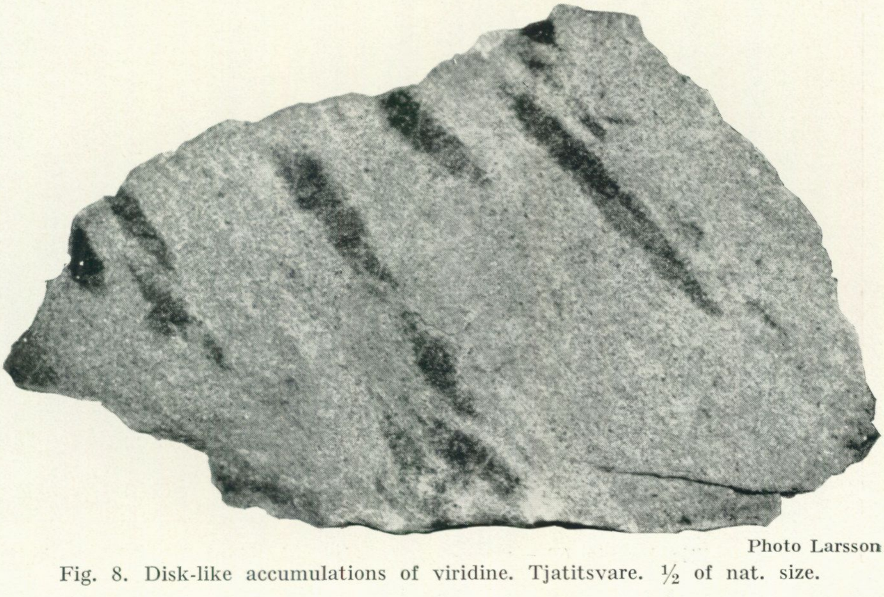

Photo Larsson

Fig. 8. Disk-like accumulations of viridine. Tjatitsvare. ½ of nat. size.

Photo Larsson

Fig. 9. Garnet-scapolite skarn in greenstone. Stankajokk. Nat. size.

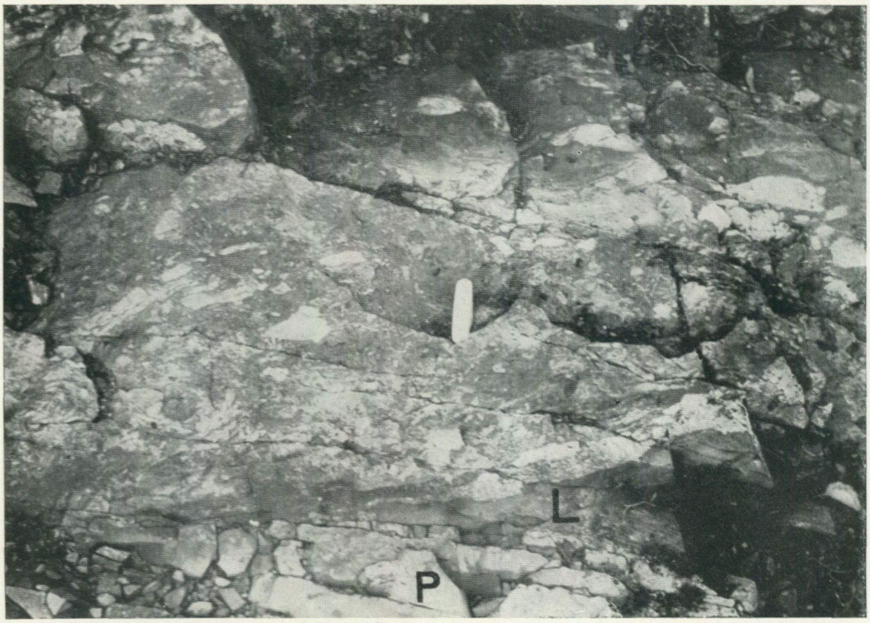

Fig. 10. Jaspilitic breccia (P = porphyry, L = leptite). Stankajokk. Pocket-knife gives scale.

Photo Larsson

Fig. 11. Garnet-banded tuffitic leptite. Juoråive. Nat. size.

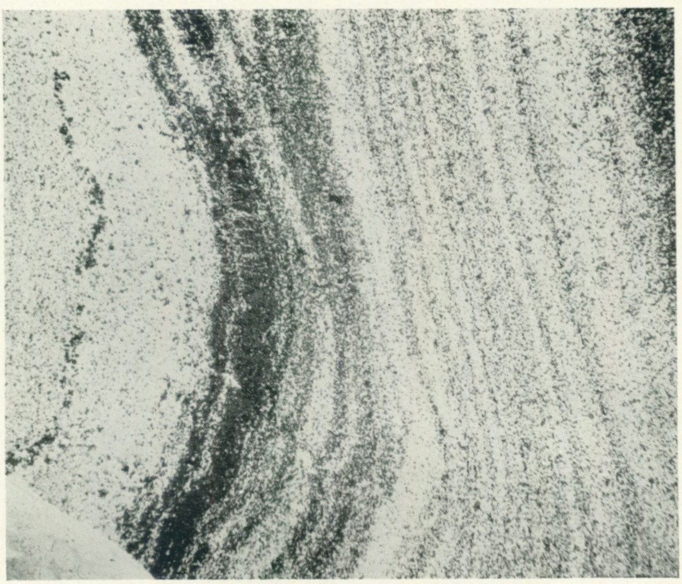

Fig. 12. Micro-photo of above. Garnet in dark bands. Thin section, 6 ×.

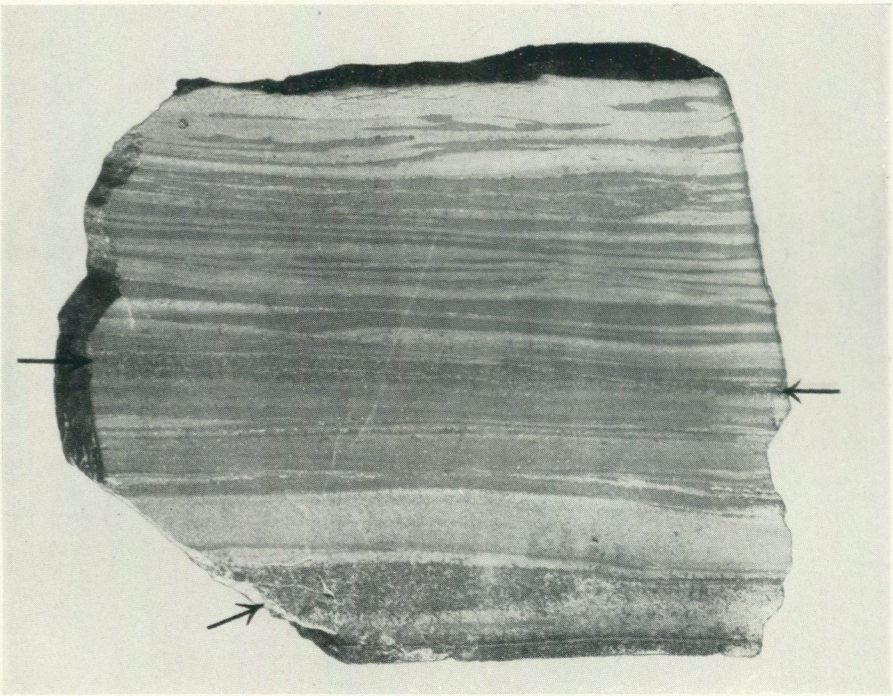

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Fig. 13. Hematite-banded tuffitic leptite. Arrows indicate layers of garnet. Stankajokk. Nat. size.

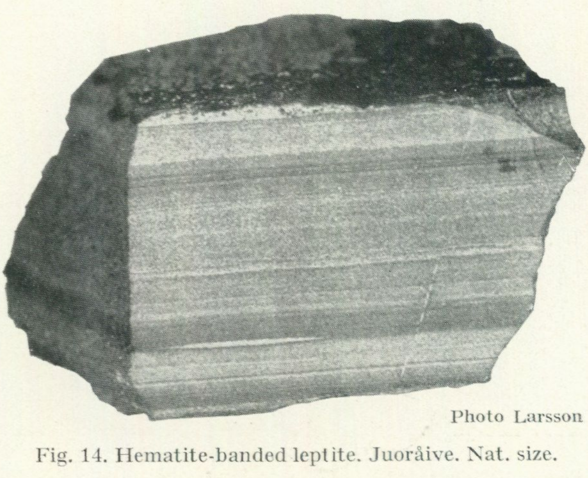

Photo Larsson

Fig. 14. Hematite-banded leptite. Juoråive. Nat. size.

Photo Larsson

Fig. 15. Tuff agglomerate with small angular fragments. Stuor Njuoskes. Nat. size.

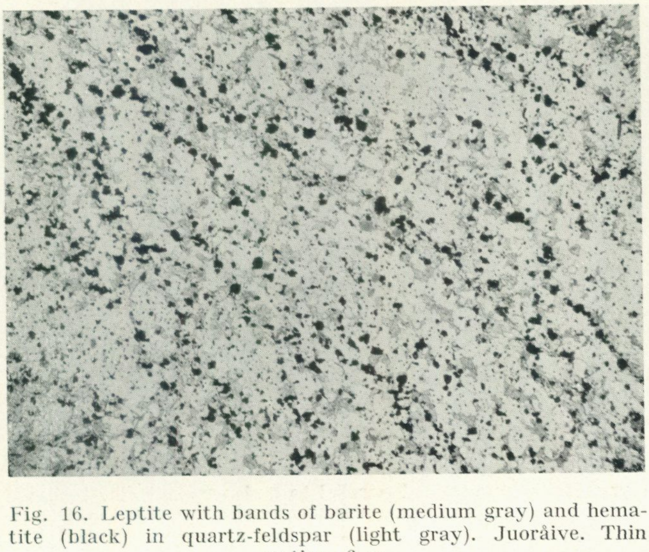

Fig. 16. Leptite with bands of barite (medium gray) and hematite (black) in quartz-feldspar (light gray). Juoråive. Thin section, 6 ×.

Fig. 17. Banking in the porphyry. Stankajokk, near Ultevis cabin.

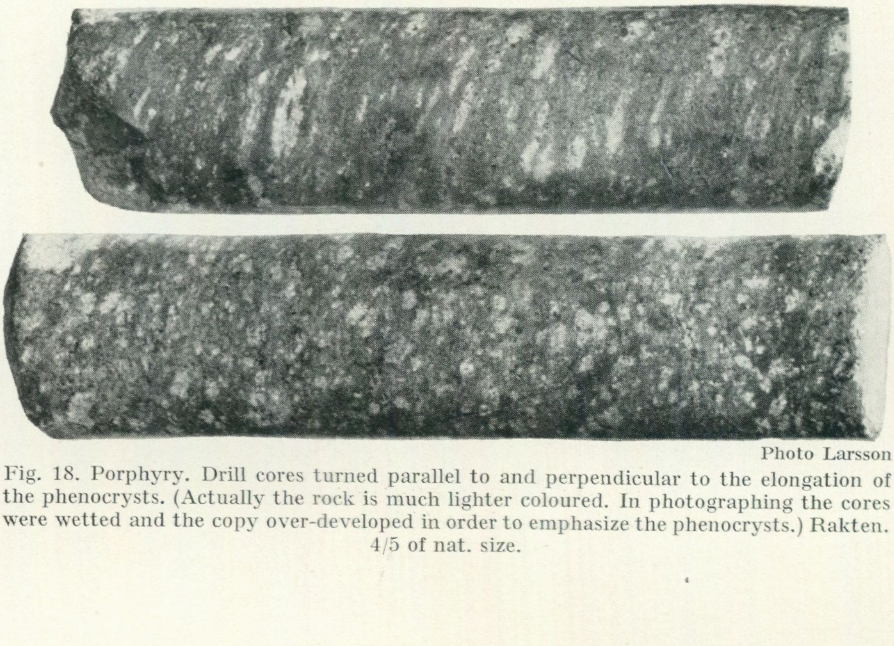

Photo Larsson

Fig. 18. Porphyry. Drill cores turned parallel to and perpendicular to the elongation of the phenocrysts. (Actually the rock is much lighter coloured. In photographing the cores were wetted and the copy over-developed in order to emphasize the phenocrysts.) Rakten. 4/5 of nat. size.

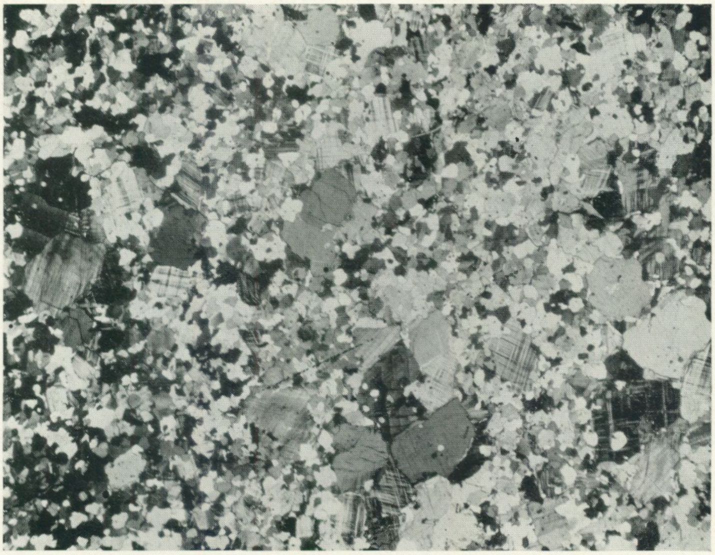

Fig. 19. Recrystallized leptitic porphyry with granulated phenocrysts of microcline. Sörhåräs. Thin section, Nic. +, 6 ×.

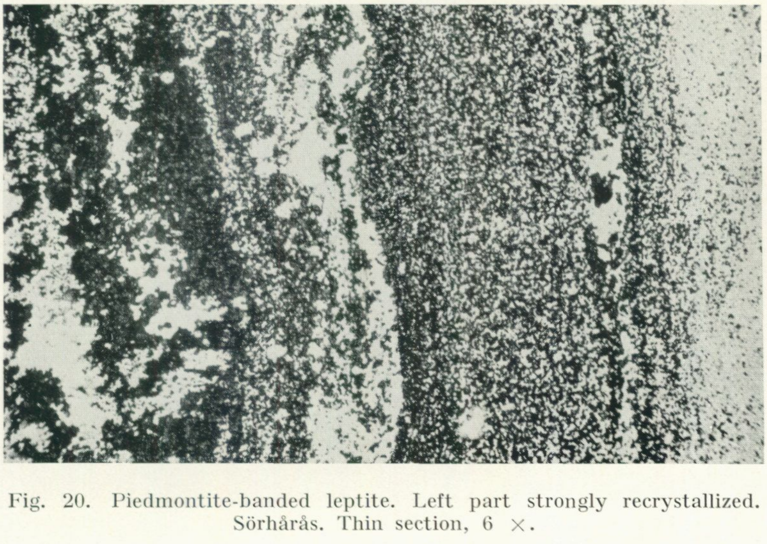

Fig. 20. Piedmontite-banded leptite. Left part strongly recrystallized. Sörhåräs. Thin section, 6 ×.

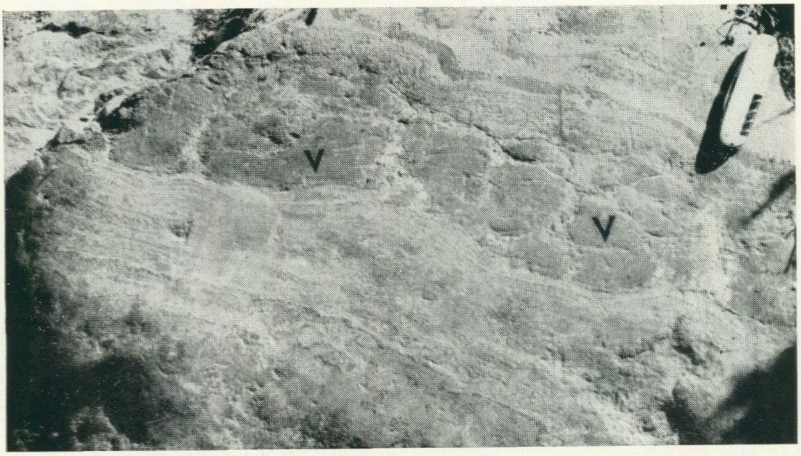

Fig. 21. Nodular bands of viridine (V) in banded tuffitic leptite. Tjatitsvare.

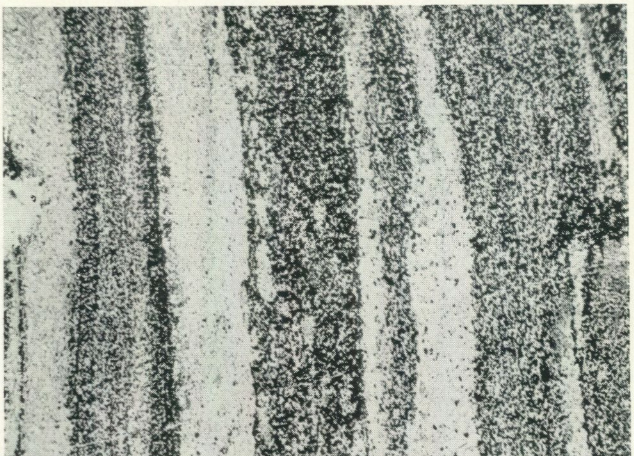

Fig. 22. Banded hematite ore. Quartz is white. Stankajokk.
Thin section, 6 ×.

Fig. 23. Bixbyite cut by veinlets of hematite. Nordhårås. Polished section, 42 ×.

Fig. 24. Bixbyite cut by veinlets of braunite (dark gray), hematite (white), and gangue (black). Nordhårås. Polished section, 150 ×.

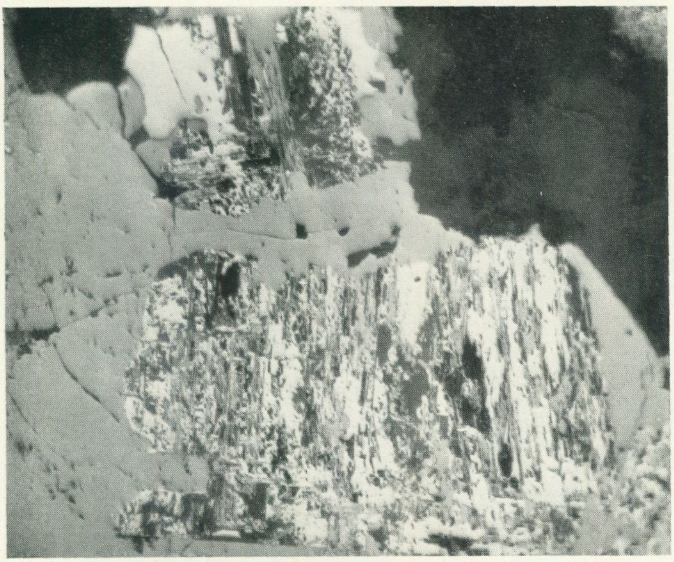

Fig. 25. Bixbyite completely decomposed to a lamellar intergrowth of hematite (white), braunite (medium gray), and gangue (dark gray). The intergrowth rests in braunite. Tjatitsvare. Polished section, 150 ×.

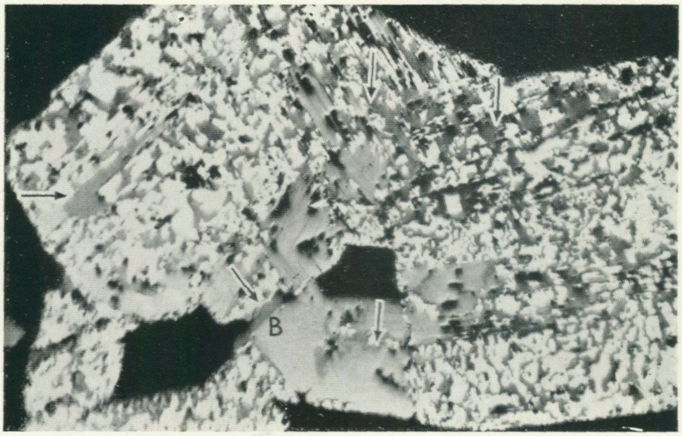

Fig. 26. Bixbyite (B) partly decomposed to hematite (white) and braunite (medium gray,arrows point at some places with braunite). Braunite is sometimes lamellar in bixbyite.Tjatitsvare. Polished section, oil immersion, 250 ×.

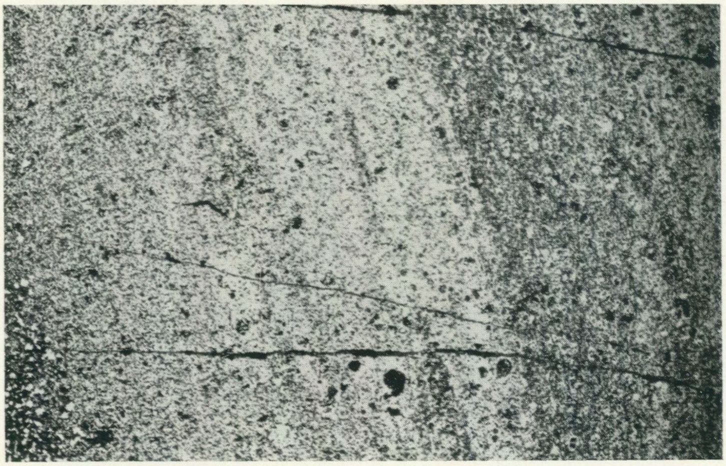

Fig. 27. Manganese ore layer in tuffitic leptite. Stankajokk. Polished section, 6 ×.

Fig. 28. Manganese ore breccia in porphyry. N foot of Sörhårås. Pocket-knife gives scale.

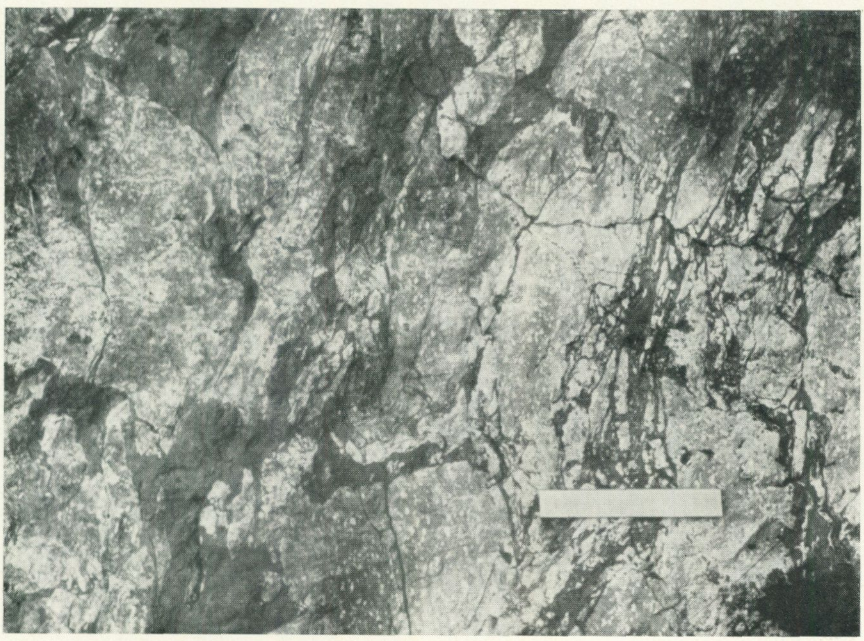

Photo S. Gavelin

Fig. 29. Same as Fig. 28. Note phenocryst spots in the porphyry. Ruler = 17 cm.

Fig. 30. Hollandite ore, chiefly fine-grained, coarser in places. No hematite. Gangue is black. Stuor Njuoskes. Polished section, 12 ×.

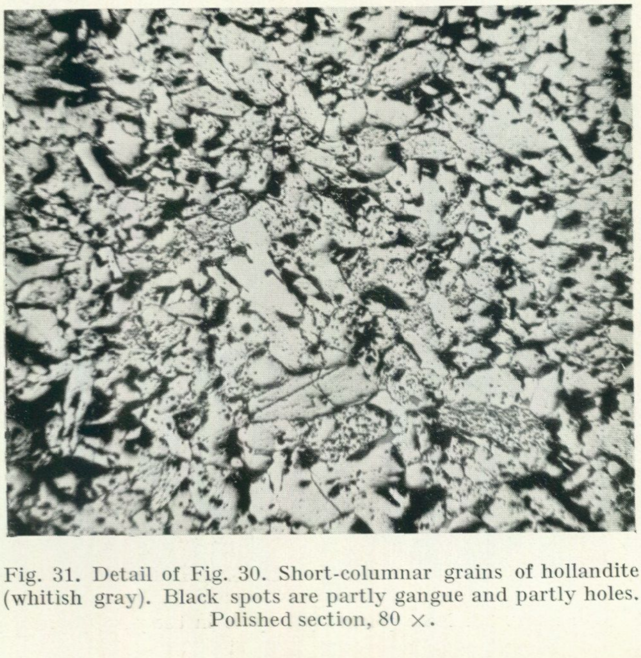

Fig. 31. Detail of Fig. 30. Short-columnar grains of hollandite (whitish gray). Black spots are partly gangue and partly holes. Polished section, 80 ×.

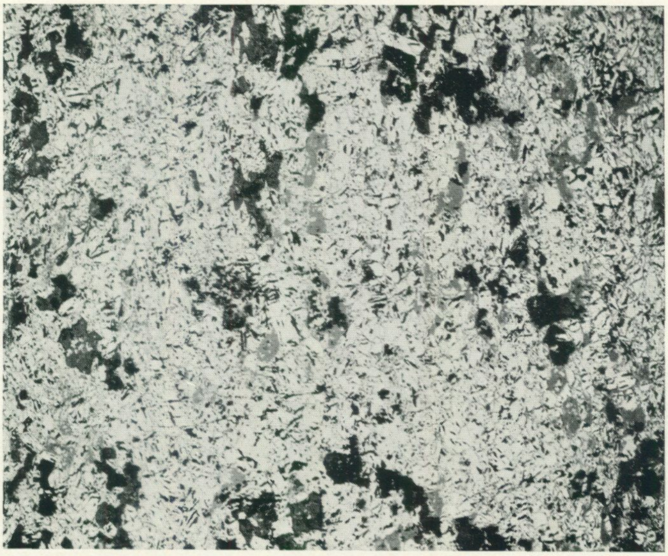

Fig. 32. Hollandite ore (hollandite = light gray, braunite = medium gray, gangue = dark gray, black.) Tjatitsvare. Polished section, 12 ×.

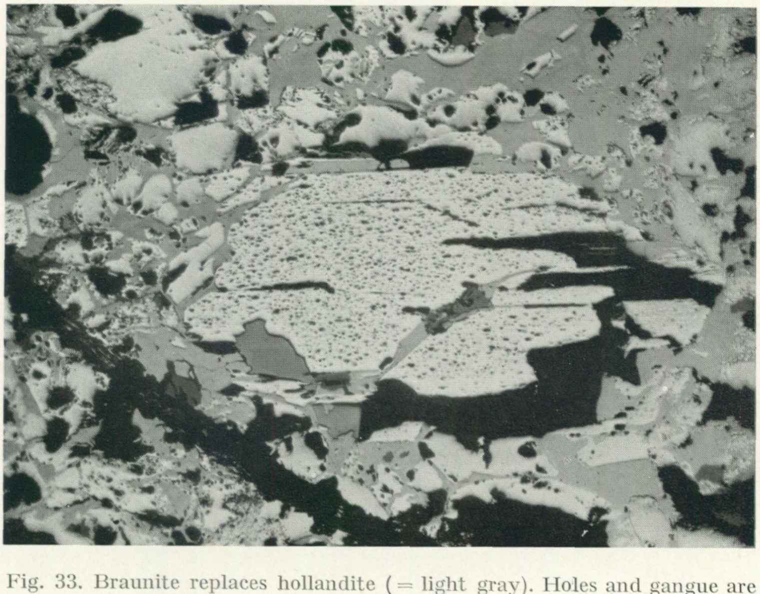

Fig. 33. Braunite replaces hollandite (= light gray). Holes and gangue are black. Note weak colour differences in braunite. Tjatitsvare. Polished section, 150 ×.

Fig. 34. Chalcedony veins and replaces feldspar (bottom) and quartz (top). The mottled appearance of the chalcedony is due to the spherulites. Tjatitsvare. Thin section, Nic. +, 6 ×.

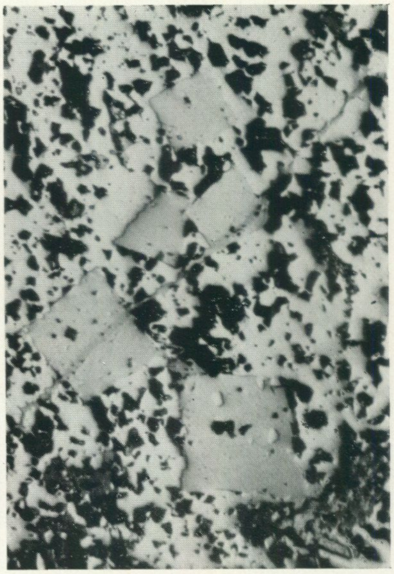

Fig. 35. Bixbyite crystals in hematite-hollandite ore (very little hollandite). Veinlet of braunite cuts the ore. Stuor Njuoskes. Polished section, 70 ×.

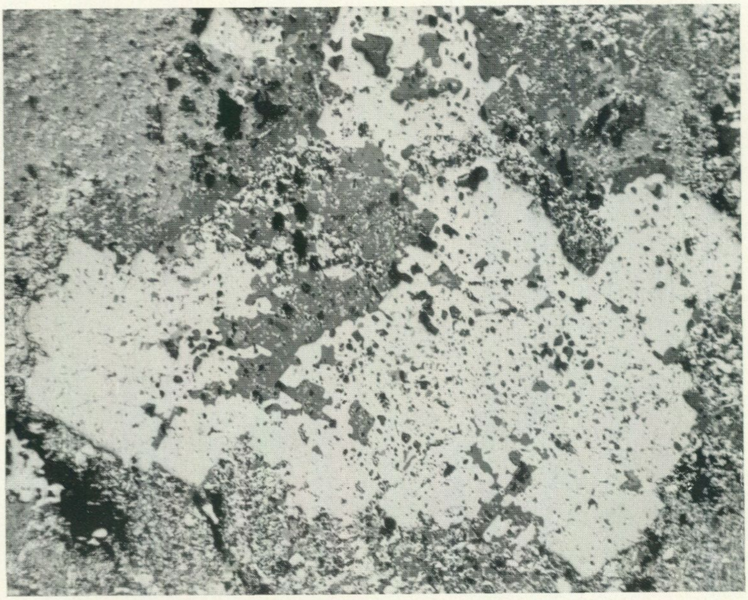

Fig. 36. Bixbyite porphyroblasts in lean hollandite ore. Stuor Njuoskes. Polished section,42 ×.

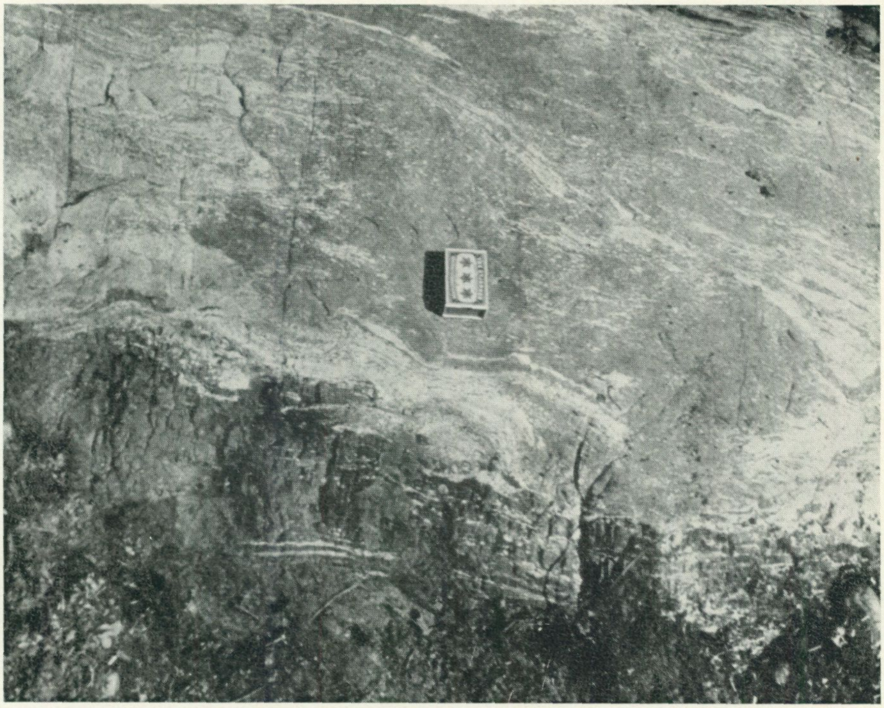

Fig. 37. Streaky lenses of braunite-hollandite ore (medium gray) and piedmontite (black) in limestone (light gray). Rakten.

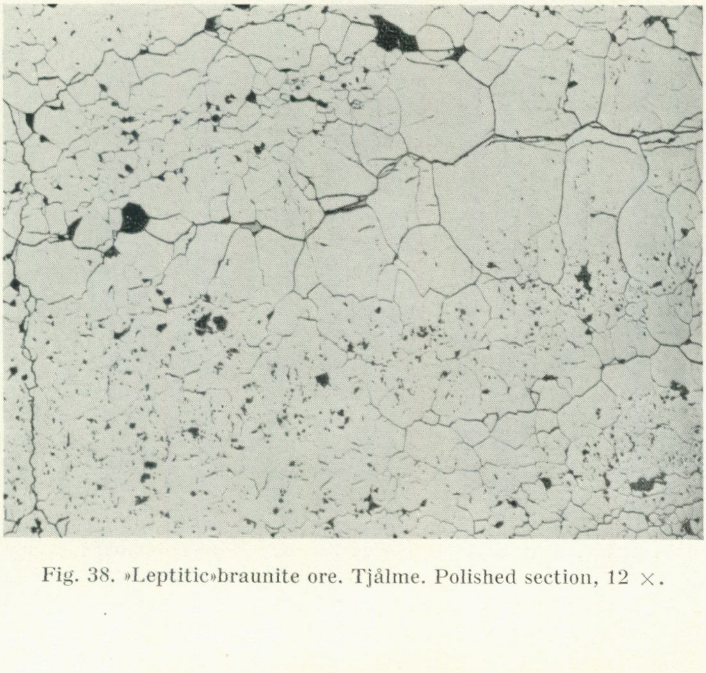

Fig. 38. »Leptitic»braunite ore. Tjålme. Polished section, 12 ×.

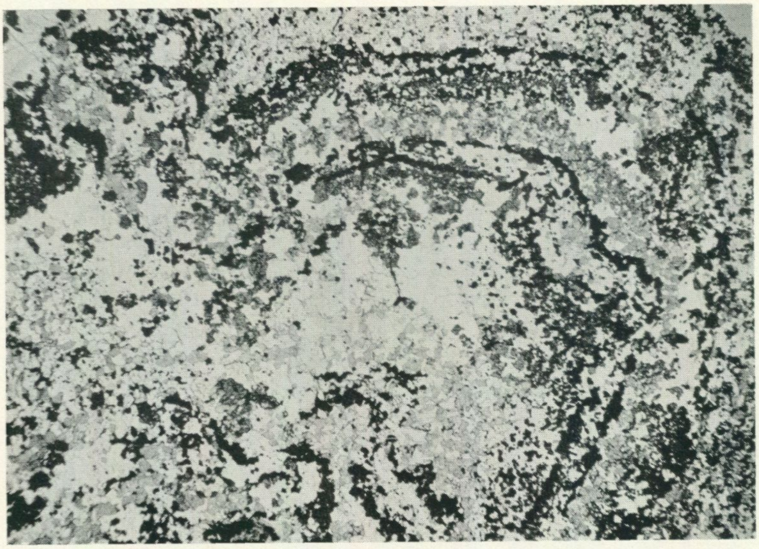

Fig. 39. Leptite, banded with hematite (black), viridine (dark gray), the questionable ortho-pyroxene (medium gray), and garnet. Tjatitsvare. Thin section, 6 ×.

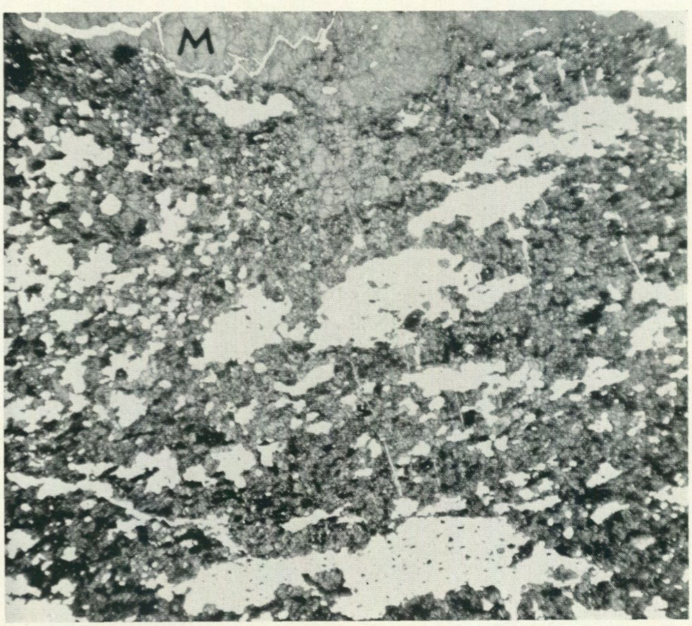

Fig. 40. Piedmontite rock with molybdo-scheelite (M). Piedmontite = mottled, light and dark gray. Quartz is white. Boulder locality 3 km NE of Rakten. Thin section, 7 ×.

Fig. 41. Bixbyite crystals in quartz-microcline vein. Two cubes modified by trapezohedrons. N foot of Sörhårås. Only slightly enlarged.

G. Lundqvist 1942

Fig 42. Ablation moraine S of Ranesvare. Exceptionally boulder-rich portion of the gently rolling hills.

G. Lundqvist 1942

Fig. 43. Ablation moraine S of Ranesvare. Portion partly with normal content of boulders and partly poor in boulders.

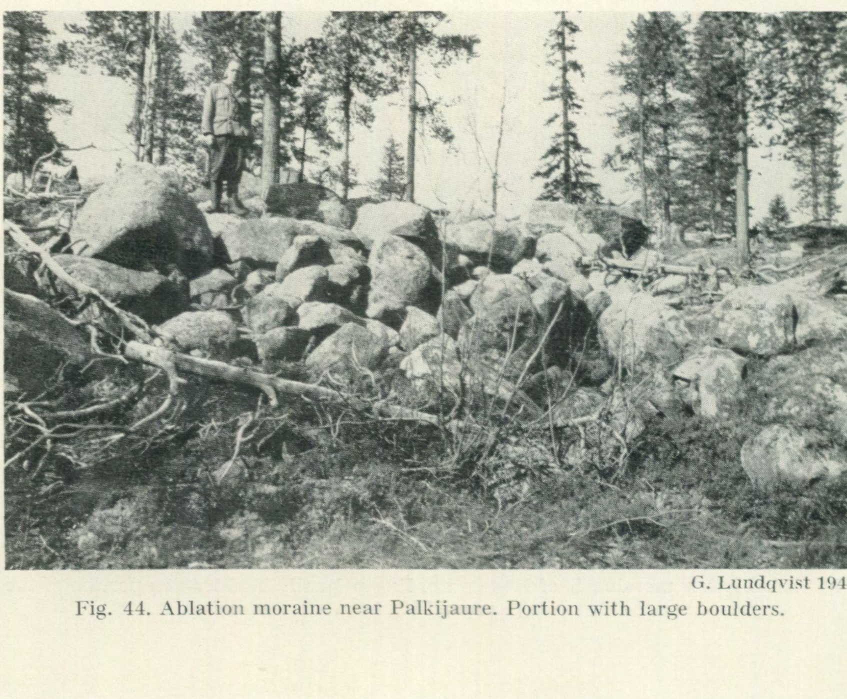

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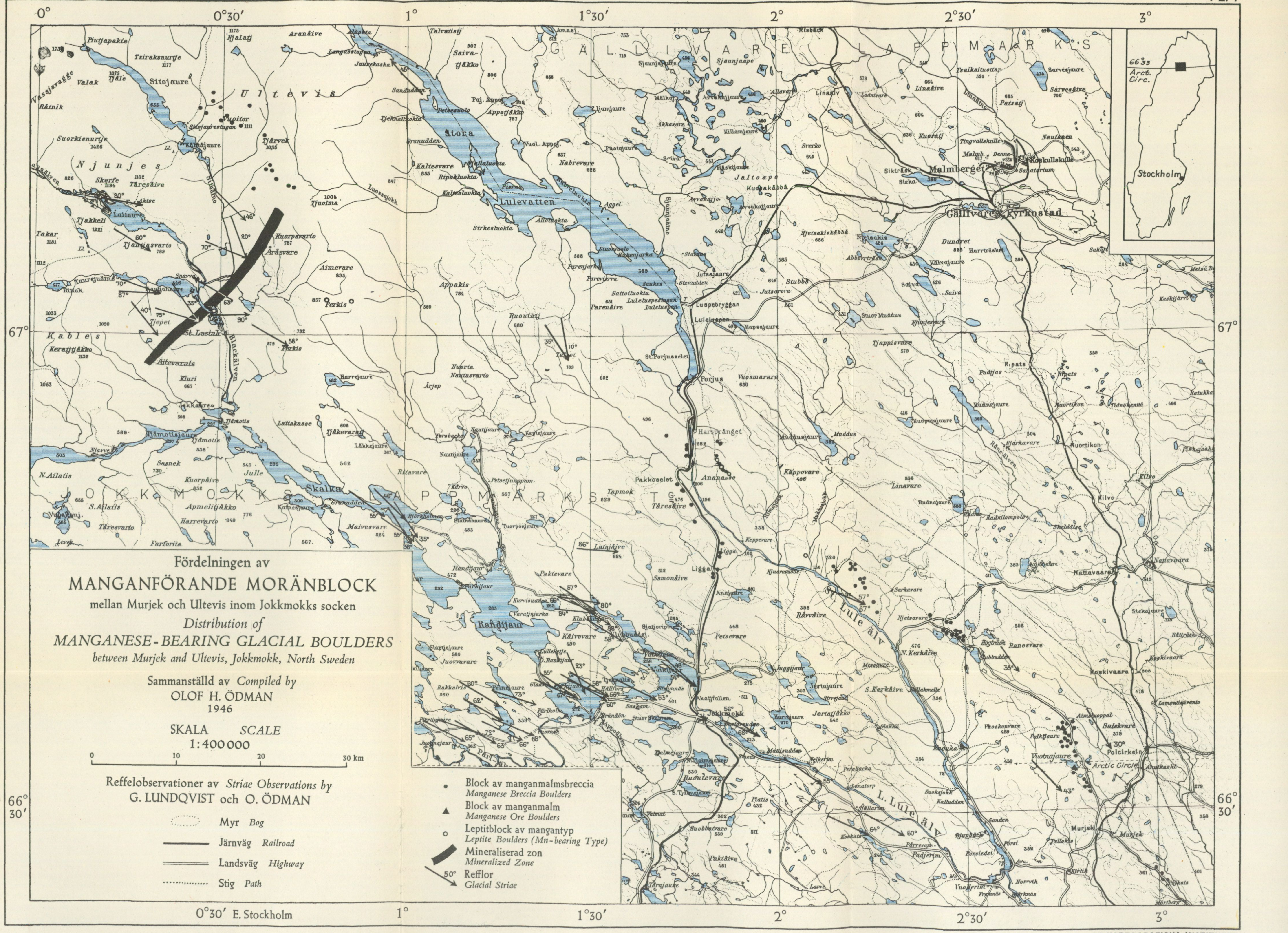
Fig. 44. Ablation moraine near Palkijaure. Portion with large boulders.



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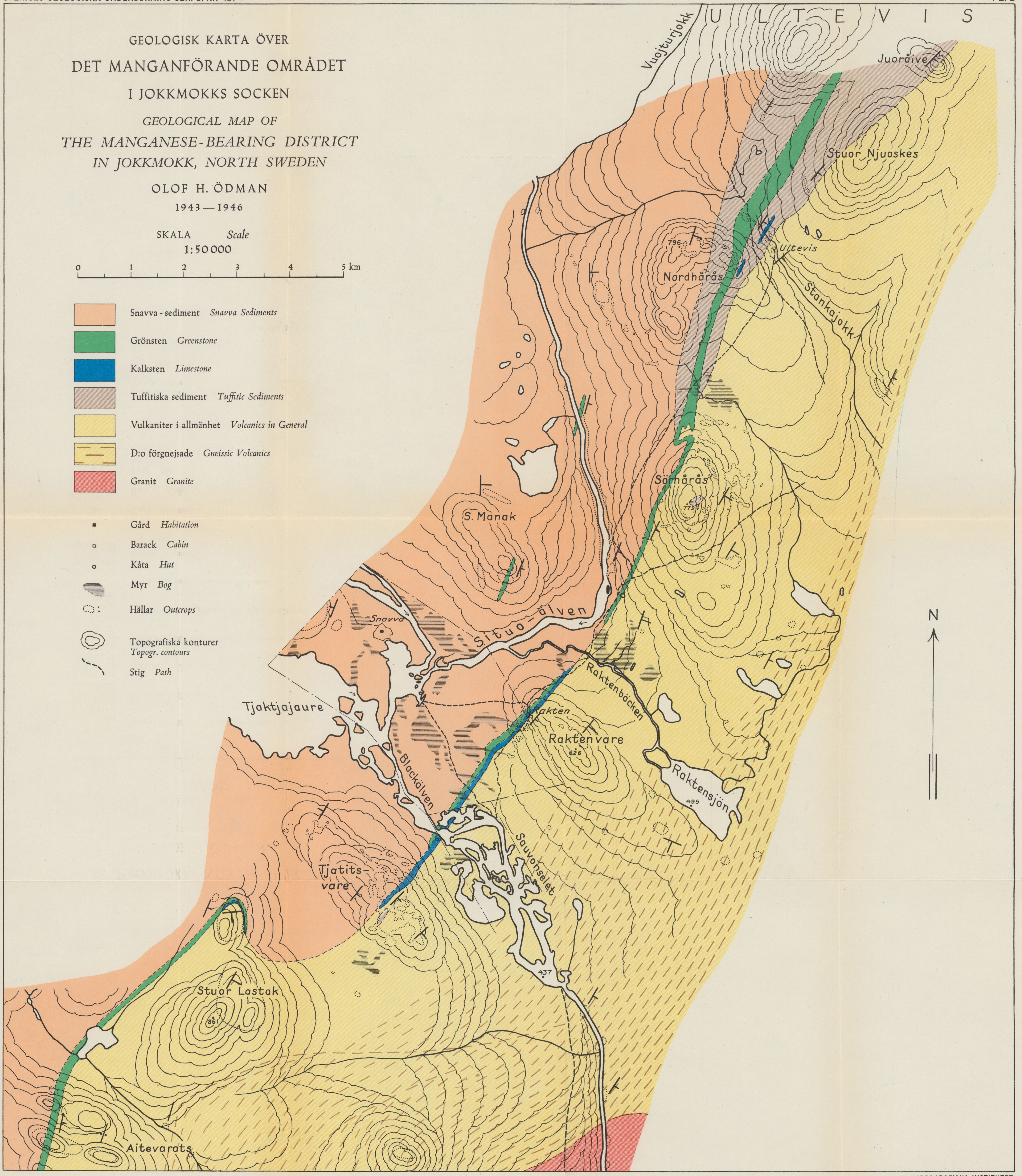

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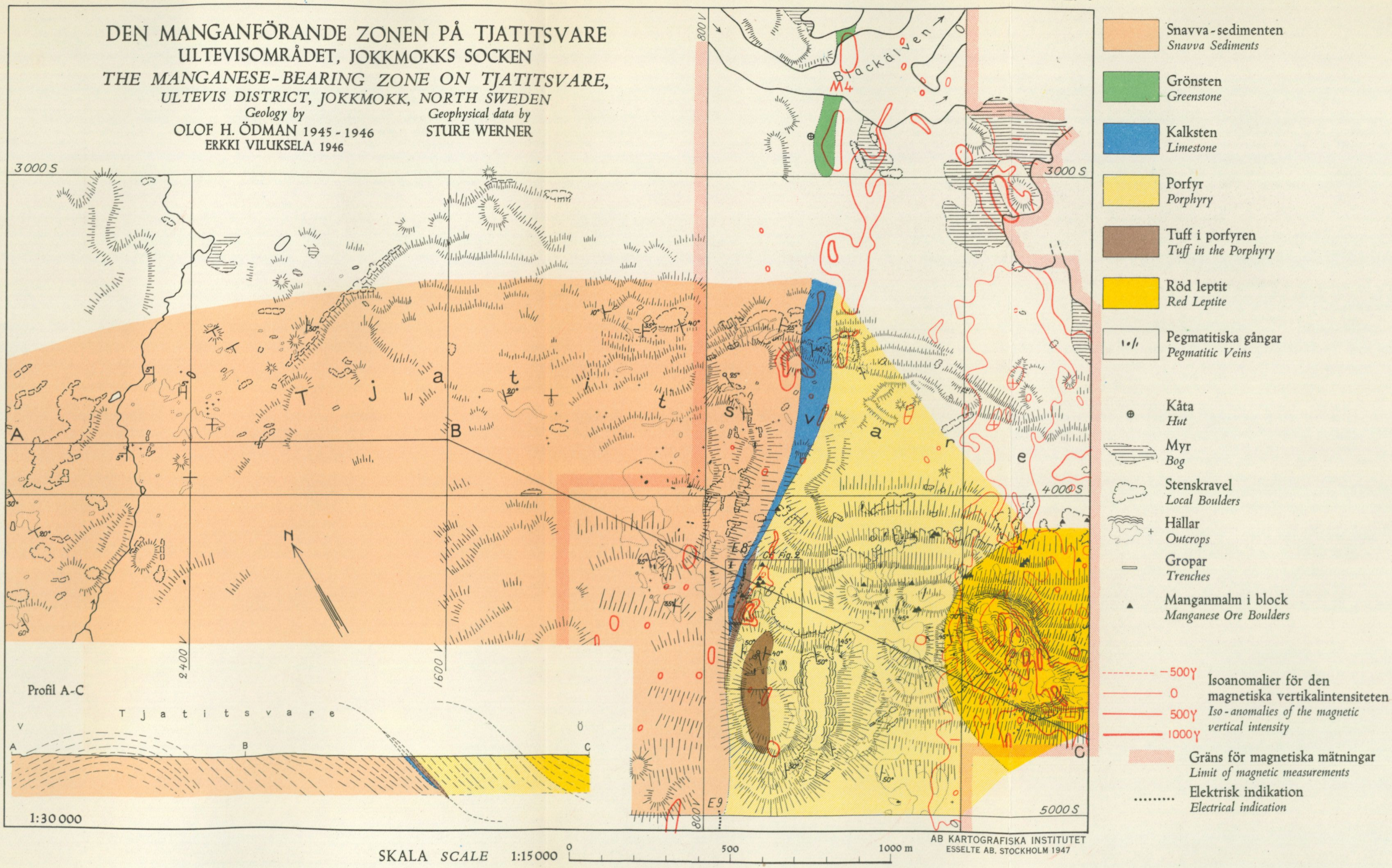
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