INTERNATIONAL GEOLOGICAL CONGRESS
XXI SESSION NORDEN 1960

THE CALEDONIAN MOUNTAIN CHAIN IN THE TORNETRÄSK – OFOTEN AREA, NORTHERN SCANDINAVIA

THE KIRUNA IRON ORE FIELD, SWEDISH LAPLAND

GUIDE TO EXCURSIONS NOS A 25 AND C 20

By
OSKAR KULLING AND PER GEIJER

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Literature: See references back Geijer's and Kulling's introductory notes.

Key map: see inside of back cover.

Excursion no. A 25: Aug. 6th—Aug. 13th, 1960.

Excursion no. C 20: Aug. 26th—Sept. 3rd, 1960.

Excursion leader:

Docent Oskar Kulling

Sveriges Geologiska Undersökning

Stockholm 50

Leader in Kiruna:

Mining engineer R. Westerlund

LKAB

Kiruna

General object of the excursions: Stratigraphy and tectonics of the Caledonides of Northern Scandinavia along the railway, crossing the Range (the Kiruna—Narvik railway), and along the highway on the southern shore of Ofot fiord. Additional object: General view of the Kiruna ore field. A Late-Glacial giant-boulder deposit of the Kärkevagge U-valley in the Torneträsk area.

The Kiruna iron ores

by

PER GEIJER

GENERAL GEOLOGICAL SETTING

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

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

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

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

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

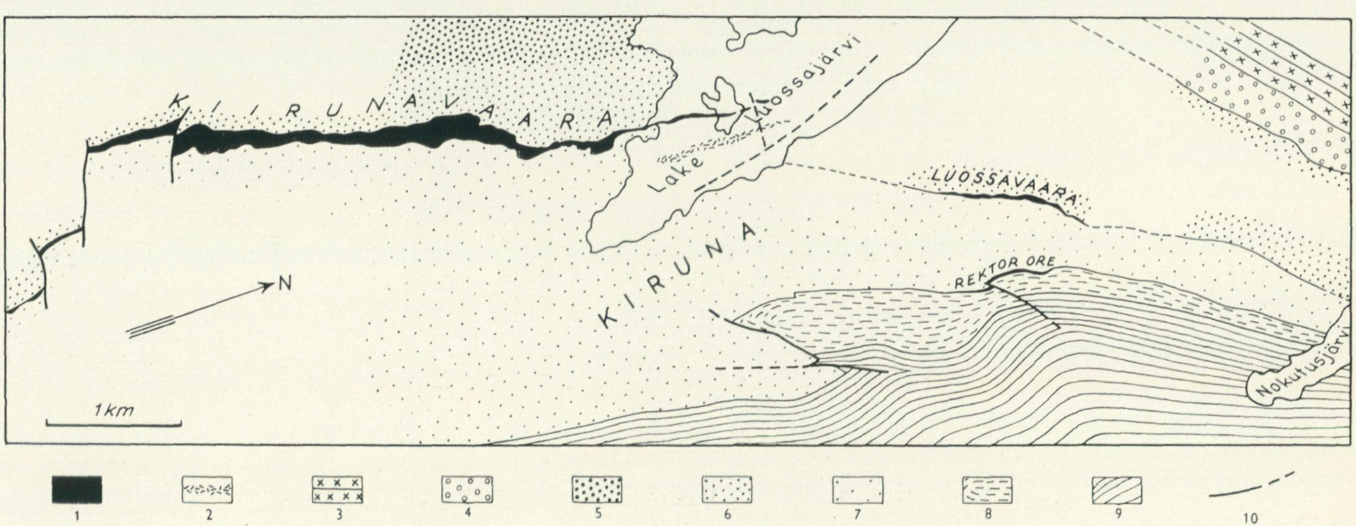


Fig. 1. Sketch map of the surroundings of the iron ore deposits at Kiruna.

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

Conditions of field study

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

The foot-wall unit

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

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

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

Of porphyries there are two main types. One is a grey rock with tabular feldspar phenocrysts, generally not numerous. Its groundmass is made up chiefly of feldspars in broad laths mostly about 0.1 mm in length and arranged at random; also its other constituents are the same as in the syenite, and the bulk composition is like that of the latter. It may be noted that texture and grain size are comparable to those of proved extrusives of a syenitic composition, as the rhomben porphyries of the Oslo region. Sometimes there appear in this porphyry vesicle fillings of one or several of the minerals actinolitic hornblende, magnetite, apatite, titanite. These nodules are surrounded by a narrow, light-coloured halo. Through increasing frequence of such bodies a transition is effected to a rock in which they may make up even half the volume; then the haloes have coalesced and the rock mass, apart from the nodules, consists only of feldspars and is pink-coloured throughout. While the nodules often have the character of typical vesicle fillings, in other cases they are less distinctly set off from the groundmass ("embryonal nodules"). In bulk composition there is no general difference between rocks with or without nodules, showing that the latter have been formed as local concentrations in the crystallizing eruptive, but in varieties very rich in nodules there must have been at one stage an excess of the nodule-forming substances.

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

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

The hanging-wall unit

The thickness of this unit is greatest in the south, on Kiirunavaara and eastwards, where it may perhaps surpass 1 200 m. The probability of some amount of faulting, and uncertainty about the actual dip in the eastern part, preclude a more precise estimate. On Luossavaara, again, it is about 400 m, and northeastwards from there it gradually decreases further. The whole of this unit is, in spite of local variations, homogeneous with regard to the general nature of the rock. This is a porphyry with feldspar phenocrysts, mostly isometric and red-coloured, in a dense groundmass generally red, or dark from finely distributed magnetite. The phenocrysts are perthitic, with the albite component predominant, and the groundmass is made up of alkali feldspar and quartz, in rhyolitic proportions. Among other constituents, magnetite is the most common one. In texture the groundmass is very often poikilitic, occasionally spherulitic, and else presents a very fine-grained aggregate with irregular grain boundaries, probably a slightly coarsened devitrification texture. Fluidal banding occurs, and "buttonholes" chiefly filled with quartz.

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

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

	III	IV	V	VI
Q	27.91	23.56	23.38	14.68
Or	26.27	17.89	12.86	16.21
Ab	33.19	48.99	52.68	54.25
An	1.39	1.95	4.26	4.46
C (Al_2O_3)	1.02	—	0.20	—
P	1.21	2.82	1.70	3.56
M	8.31	4.39	3.18	4.99

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

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

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

The main ore bodies of Kiirunavaara and Luossavaara

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

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

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

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

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

B	about	66	percent	Fe,	< 0.1	percent P
C_1	»	65	»	»	0.1—0.4	» »
C_2	»	63	»	»	0.4—0.8	» »
D	»	58	»	»	1.75	» »

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

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

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

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

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

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

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

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

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

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

The foot-wall contact on northern Kiirunavaara, once very well exposed, has proved especially important for the understanding of the ore body's place in the sequence of geological events (fig. 2). Beside the foot-wall unit and the ore there occurs, in this part, a system of porphyry dikes in the foot-wall. This porphyry is similar to the other units in the character of its feldspar, intermediate in quartz content between the foot-wall and hanging-wall units, carries diopside like the former and is texturally similar, also in the shape and size of the feldspar phenocrysts, to the latter. About 10 such dikes are known. None have been found to cut the hanging-wall rock. But one has apparently, when reaching the contact with the latter, spread out as an intrusive sheet along this contact. This body has later been broken up by the ore body, large slabs of porphyry being enclosed in the latter and further penetrated by veinlets of ore rich in apatite and hornblende. Northwards the ore injects a spur, in part showing "stratified" ore, obliquely into the foot-wall. This spur grades into a system of ore veins in the contact zone between the foot-wall unit and the overlying dike porphyry, running for a distance of about 500 m and then

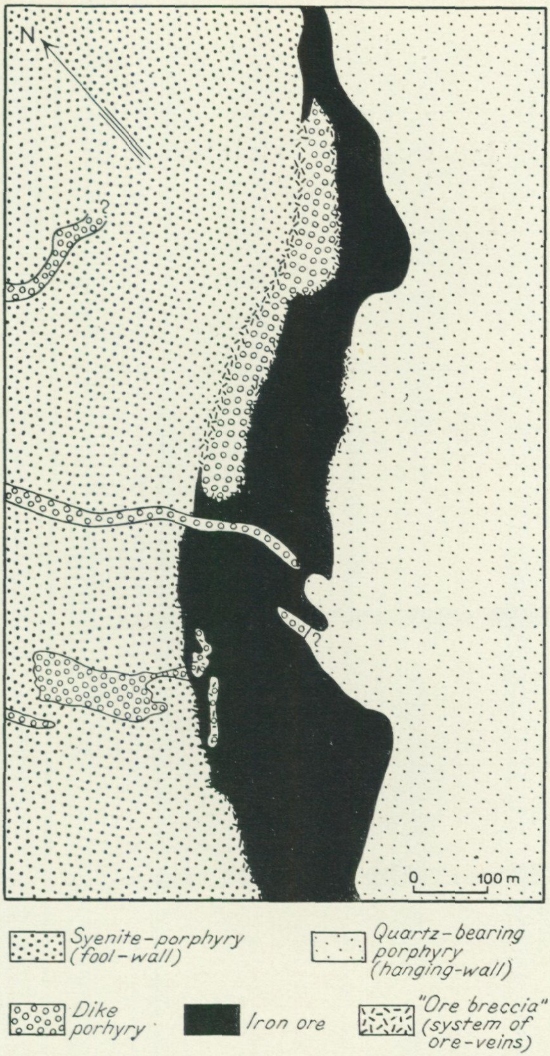
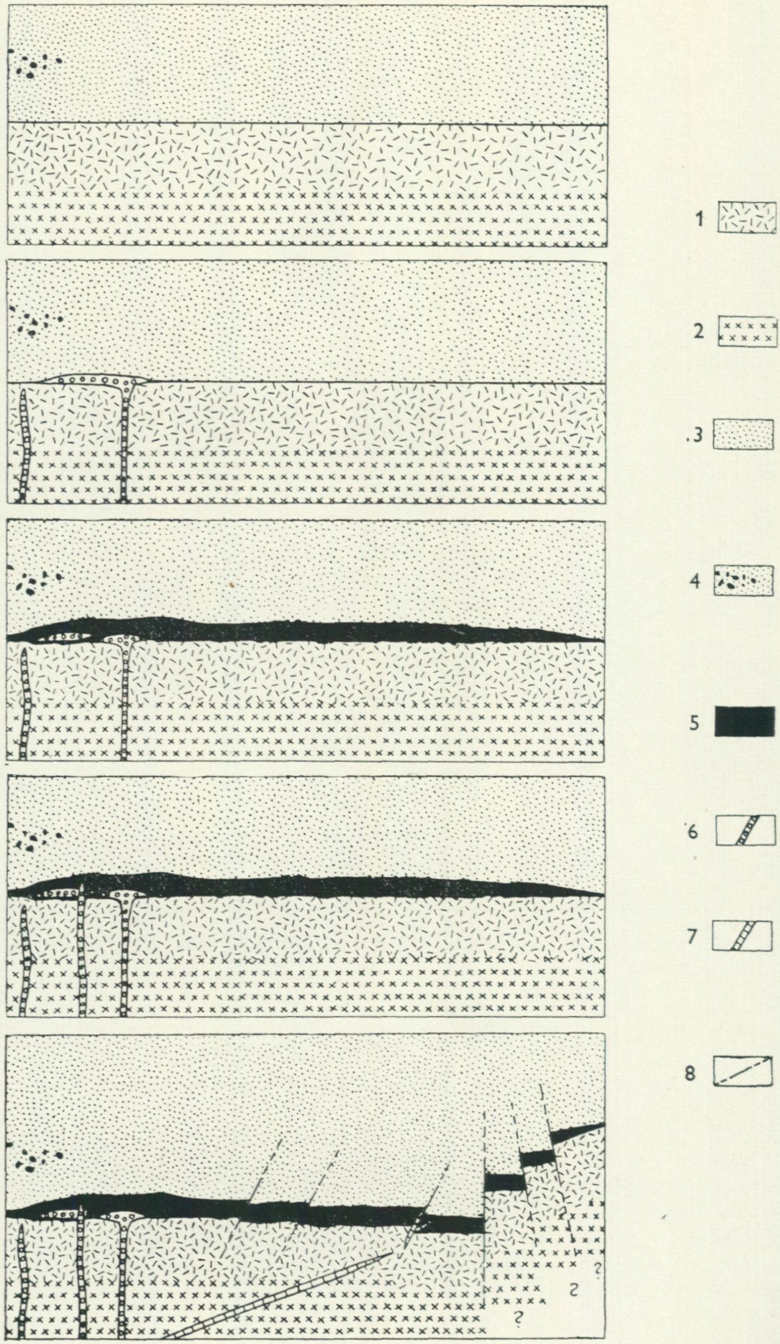


Fig. 2. Northern end of Kiirunavaara. Adapted from Geijer 1910.

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

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


1
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a couple of "horses" of albite rock that appear to represent altered inclusions of porphyry.

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

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

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

The latest events in the geological history of the ore mountains, before the weathering, were faulting and apparently accompanying granophyre intrusions. These are known only on Kiirunavaara. Its ore body is cut by a number of faults, generally striking about N. W. and probably always with a greater horizontal than vertical displacement. The largest granophyre dike runs in a N.—S. direction in the foot-wall unit. Other dikes of the same composition, in part with a felsitic groundmass, cut the ore body in its southern part. These dikes show no apparent affinity to the ore-bearing porphyries. In fig. 3 the most important stages in the geological evolution of the deposit are diagrammatically illustrated.

Rektor and Hauki ores

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

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

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Fig. 3. Diagrammatic section through Kiirunavaara, illustrating stages of its early geological history. From Geijer 1919.

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

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

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

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

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

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

Origin of the ores

As aptly formulated by Stutzer (1907), "all earnest observers" have reckoned with a close genetic connection between the ores and the associated porphyries. The first important contribution was by Bäckström (1898, 1904), who emphasized the evidence of the vesicle-fillings in the foot-wall porphyry, which show that minerals that normally are the first to crystallize in an igneous rock, here occur as the latest element. Their deposition was thought to be due to volcanic after-action, the material having been transported as gaseous compounds, chiefly chlorides and fluorides, and a similar origin was, in general terms, attributed also to the ore bodies. A somewhat more precise variation of this interpretation is represented by De Launay's pneumatolytic-sedimentary hypothesis (1903), rather ingenious with regard to the facts then known, but soon, by better exposures, proved inapplicable. Already in 1898, another hypothesis had been presented by Högbom, who drew attention to certain analogies with iron ores associated with syenitic rocks in the Urals, and concluded that there exists a group of magmatic non-titaniferous iron ores, analogous in origin to the titaniferous ones but connected with rocks of syenitic nature instead of with gabbroic types. Högbom clearly reckons with differentiation *in situ*. Stutzer (1907), who produced strong evidence for a magmatic origin of the ores, especially by noting illuminating details in the distribution of magnetite and apatite (compare above), regarded the ore as "eine gewanderte magmatische Ausscheidung", a conclusion confirmed by later investigations. Stutzer's characteristic of the ore body as a dike is less fortunate, as the rock series most probably occupied an approximately horizontal position at the time of the ore intrusion; an intrusive sheet or a sill would seem a more appropriate designation.

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

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

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

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

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

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

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

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

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

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

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

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

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

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On the Caledonides of Swedish Lapland

by

OSKAR KULLING

The Swedish Mountains is broadly speaking the same as the Swedish portion of the Scandinavian Caledonides. The Lapland Mountains constitute the northern half of the Swedish Mountains. The southern part of the Lapland Mountain is named the Västerbotten Mountains, the northern part the Norrbotten Mountains.

A monograph on the Caledonides of the Västerbotten Mountains has been published in 1955 by O. Kulling (Geol. survey of Sweden, Ser. Ca, Nr 37). The corresponding monograph on the Norrbotten Mountains geology is wanting. O. Kulling, however, is leader of the Geological Survey mapping of the Norrbotten Mountains.

The representation of the Caledonian bedrock of Lapland on the geological map of Sweden of 1958 is for the most part founded on general field researches of the four last decades. After the above-named monograph of the Västerbotten Mountains was printed some mapping revisions in the southeasternmost border of the mountains were performed by B. Asklund. For some boundaries in that part of the geological map of Sweden are the responsibility of Asklund. Beside the results from the Geological Survey mapping of the Norrbotten Mountains results have been obtained from the southernmost part of the mountains (compiled by N. Marklund) and put at my disposal by the Boliden Mining Company. The map-contributions from the Kebnekaise area by H. Johansson as well as the one from the Sulitelma area by G. Kautsky may also be mentioned.

During the Caledonian diastrophism a powerful transport of rock-masses took place from the Scandinavian branch of the Caledonian geosyncline area towards the southeast. The rock-masses advanced over parts of the old Fennoscandian shield adjacent to the geosynclinal area. Relics of these rock-masses now constitute the Swedish Mountains, situated along the national boundary to Norway. According to recent investigations the rock-masses appear as a number of flat-lying, dissected and often rather complicated built up nappes. Of these nappes the lower ones are transported a comparatively short way, the middle ones have a more westerly root-zone than the lower nappes, and the upper nappes have started from the very geosyncline.

The bedrock of the autochthonous portion of the mountain chain and of its lower nappes are only little metamorphosed. The metamorphic alteration grows stronger in every superposing nappe, and in the upper nappes i.e. the ones from the geosyncline, the metamorphism increases towards the lower part of every nappe.

In Scandinavia the Cambro-Silurian deposits of geosynclinal origin, which is the same as the metamorphic Cambro-Silurian, are named the Western Cambro-Silurian. The Cambro-Silurian deposits on the old Archean shield to the east of the geosyncline are named the Eastern Cambro-Silurian, and in the Scandinavian zone of the Caledonides they are situated in the lower nappes, or as autochthonous rocks. With few exceptions the overthrust rock-masses in the eastern part of the Scandinavian Caledonides do not rest on Archean or late pre-Cambrian bedrock but on Eastern Cambro-Silurian. Whether any of these nappes once advanced on to Archean bedrock east of the Eastern Cambro-Silurian to any extent is hardly to be found out.

In his paper of 1955 Kulling divides the Västerbotten Mountains bedrock into a series of tectonic units. The lowest one is, of course, the autochthonous Eastern Cambro-Silurian to the far east of the mountains. In Västerbotten these sediments are of Cambrian and Ordovician age. In the southernmost part of the eastern marginal zone there are thrust Eastern Cambro-Silurian sediments. According to B. Asklund they belong to the Föllinge Nappe, of which they form the northern part. The nappe has a wide distribution in Jemtland. The upper part of the eastern marginal zone of the Västerbotten Mountains is divided into two nappes: The Blaik Nappe is the lower one, and the Stalon Nappe the upper one. Both of them are to a great extent built up of quartzite and arkose, so-called sparagmite. Slate to shale is furthermore a frequent member of the Blaik Nappe. Minor components in both of the nappes are conglomerate, tillite and dolomite. Igneous rocks of Archean age constitute the lower part of each nappe in some restricted areas. The eastern part of the Blaik Nappe is often called the Ström quartzite Nappe. The sediments of the Blaik Nappe are of sericite-chlorite facies. The sediments of the Stalon Nappe belong to a great extent to the biotite-epidote facies. In its lower parts and towards the west the rocks grad into garnet facies.

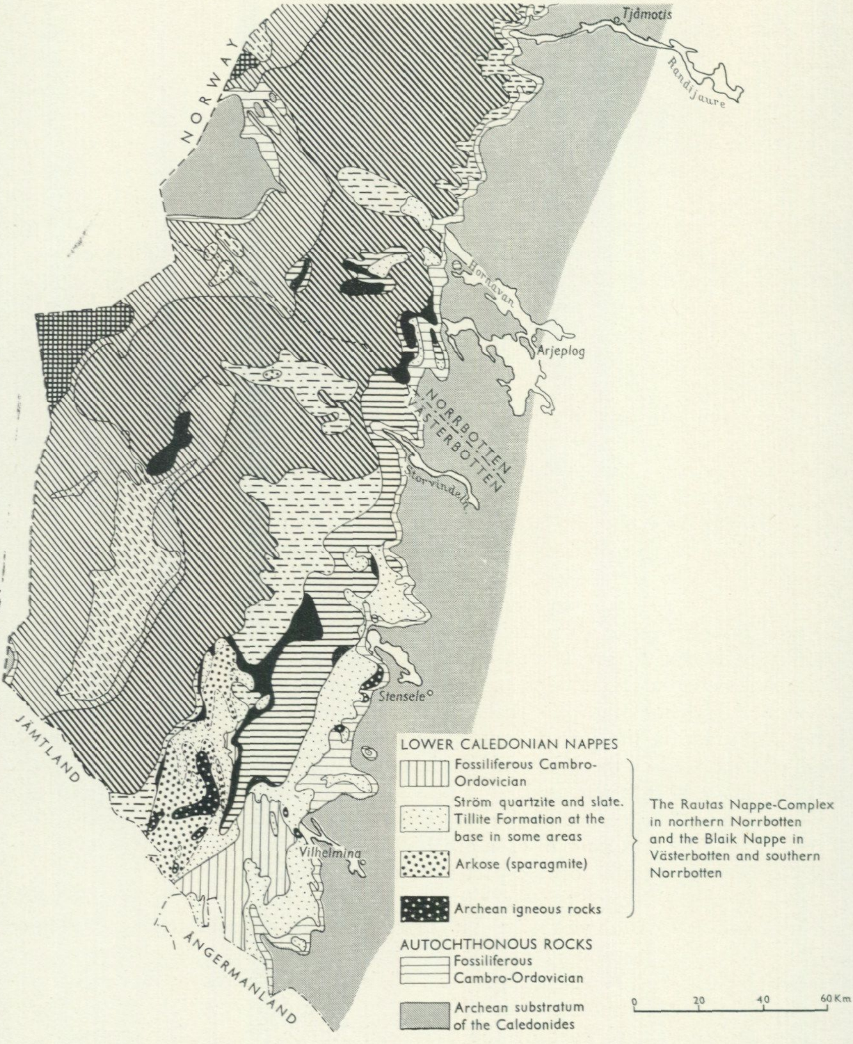
The rocks of the eastern marginal zone of the Västerbotten Mountains plunge to the west under the great Seve-Köli Nappe, that forms the main part of the Västerbotten Mountains proper and is composed of a great many kinds of low and high metamorphic rocks. Scattered finds or Ordovician and Silurian fossils are made in the low metamorphic sediments, that are, broadly speaking, usually designated as the Western Cambro-Silurian. No fossils of Cambrian age, however, have been discovered.

The northwestern corner of the Västerbotten Mountains is occupied by the Rödingsfjäll Nappe of more highly metamorphosed rocks, and situated above the low metamorphic part of the Seve-köli Nappe.

In the Seve-köli Nappe there are some windows where the underlying bedrock appears. In the Ammarnäs Inlier the principal sedimentary rocks are phyllite, graywacke and arkose. The inlier is situated in the northeastern part of the Västerbotten Mountains proper and is possibly a partly different composed western portion of the Stalon Nappe. In the Bångfjället Inlier, located in the central part of the Seve-köli Nappe, the main constituent is granite and syenite of Archean age and bears relation to the Archean igneous rocks in the lower part of the Stalon Nappe.

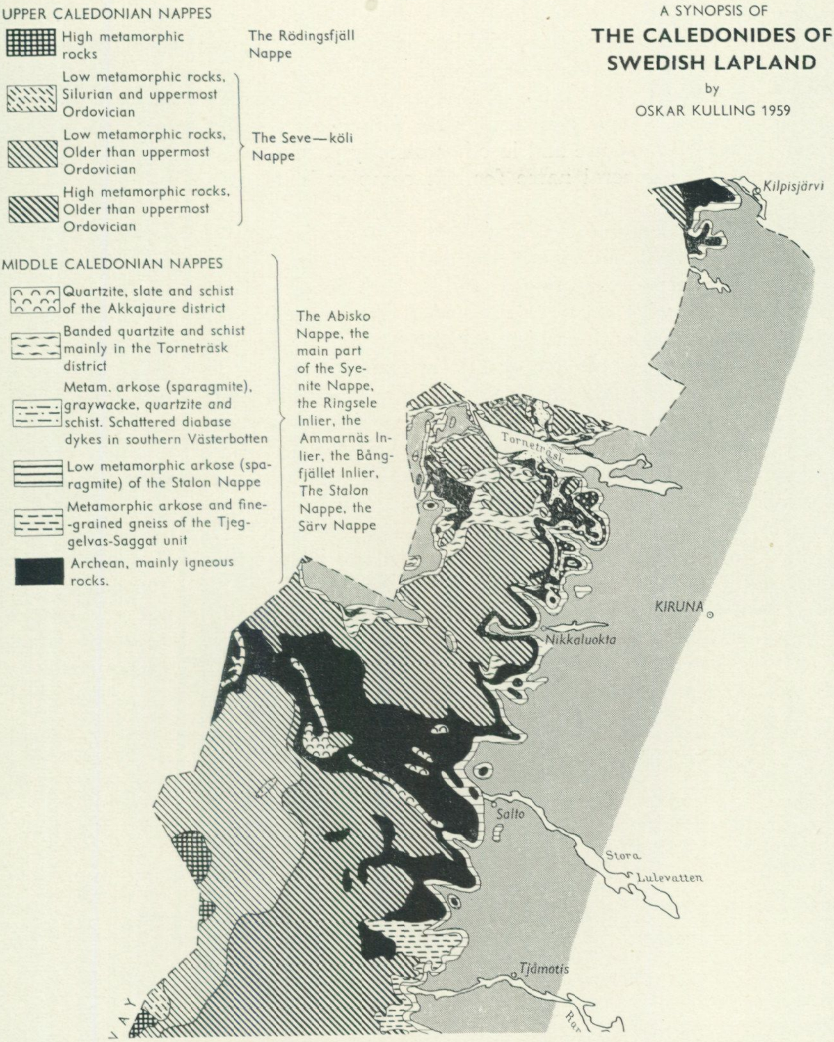
After this brief outline of the bedrock of the Västerbotten Mountains we now turn to the bedrock of the Norrbotten Mountains and especially the Torneträsk area in their northern part.

Starting from below we must point out that the Cambro-Silurian of Eastern Facies, in Västerbotten composed of Cambrian and Ordovician formations, in Norrbotten is only built up of Cambrian beds, and for the most part beds of only Lower Cambrian age. This applies to both autochthonous and thrusted



units. Tillite and varved shale may be noted in the very basal portion of the sedimentary sequence, mostly built up of sandstones and shales with some minor intercalations of limestone and pebbly beds. The sedimentary series quoted often starts with an arkosic basal conglomerate. The old designation of the sedimentary series along the thrusted masses in the eastern marginal zone of the Norrbotten Mountains is the Hyolithus Zone or the Hyolithus Series, as specimens of Hyolithes (Hyolithus is an earlier manner of writing) was the first fossil discovered in the sediments themselves. The fossils were collected by Fr. Svenonius in 1882 to the north of Lake Tjeggelvas.

Fig. 4.



In the Torneträsk area a thrusted unit with quartzite, slate and some minor intercalated limestone with fossils of the uppermost Lower Cambrian is called by the author the Luopakte Nappe. The only locality where fossils have been found in this unit, is the northeast corner of Mt Luopakte to the south of the eastern part of Torneträsk. Thrusted units with quartzites, slates and dolomites with attached basement of Archean chrystalline rocks, mainly of granite and syenite composition, are observed in the Torneträsk area and also in some other easterly districts of the Norrbotten Mountains. The Archean igneous rocks are to a great portion cataclastic, the sedimentary rocks often schistose. During a short stay in 1930 in the southeastern part of the Torneträsk area, along Lake Rautasjaure, Kulling observed and figured highly imbricated thrust-masses of the above-mentioned bedrock. See the section, fig. 8. In 1950 he referred to it as the Rautas Complex. Recently he remapped that little known district and demonstrated the wide distribution of the complex around Lake Rautasjaure and in other easterly parts of the northern Norrbotten Mountains. The general name for this complex is the Rautas Nappe-Complex.

The Stalon Nappe of the Västerbotten Mountains crosses the boundary into the Norrbotten Mountains. In southern Norrbotten its portion of Archean igneous rocks increases. In middle and nothern districts of the Norrbotten Mountains there are wide areas of thrusted Archean granite-syenite rocks, more or less cataclastic, below the schists of the Seve-köli Nappe. This Archean bedrock complex, however, is often only briefly mapped. In the Torneträsk area such Archean rocks lie above the Rautas Nappe-Complex, and constitute together with overlying "hard schists", that is tectonically banded quartzites, sericitic schists, dolomite rocks, etc. the Abisko Nappe of the author. In the middle parts of the Norrbotten Mountains the greater part of the so-called Syenite Nappe is to be placed in the Abisko Nappe.

As in the Västerbotten Mountains the Seve-köli Nappe dominates in the Norrbotten Mountains, and in some restricted areas to the west of the latter badly preserved fossils of possibly Middle and of Upper Ordovician age have been discovered. In the Torneträsk area of the northern mountains of Norrbotten, however, only the lowermost part of the Seve-köli Nappe is present.

In the Västerbotten Mountains the Rödingsfjäll Nappe rests on the Seve-köli rock complex. In the southern half of the Norrbotten Mountains

	The Västerbotten Mountains and the southernmost part of the Norrbotten Mountains	The Torneträsk area as a representative part of the northern Norrbotten Mountains. Compare figs. 5—6.
The Upper Caledonian Bedrock (Nappes)	The Rödingfjäll Nappe The Seve-köli Nappe	 The Lowermost part of the Seve-köli Nappe
The Middle Caledonian Bedrock (Nappes)	The Ammarnäs Inlier, the Bångfjället Inlier and the Stalon Nappe	The Abisko Nappe
The Lower Caledonian Bedrock (Nappes and autochthonous beds)	The Blaik Nappe/eastern part of it = the Ström quartzite Nappe/ "The Föllinge Nappe" = = Thrusted Eastern Cambro-Ordovician The autochthonous Eastern Cambro-Ordovician	The Rautas Nappe-Complex The Luopakte Nappe The autochthonous eastern Lower Cambrian
	Archean substratum	Archean substratum

there are three small areas of more highly metamorphosed rocks extending to the east from the Norwegian side of the national boundary, and are locked upon by the author as representatives of the Rödingsfjäll Nappe.

The preceding brief synopsis on the rock complexes of the Lapland Mountains is shown in the table, compare also the map, fig. 4. The rock complexes are subdivided into the upper, the middle, and the lower Caledonian rock units.

There are several nappes with Eastern Cambro-Silurian facies above the autochthonous sediments of the same facies, recorded to the south of Västerbotten, in Ångermanland and Jemtland. According to P. Thorslund the Föllinge Nappe is the fourth from below. The table above does not intend to show the absolute correlation between the "Föllinge Nappe" and the Luopakte Nappe, only that in the districts mentioned both of the named thrusted sedimentary units of Eastern facies are superposed on autochthonous fossiliferous beds. That is an example.

The Archean substratum

Along the eastern margin of the Västerbotten Mountains the Archean substratum of the Caledonian Chain is composed mainly of granite rocks of the Refsund Croup and of the Sorsele Croup. Along the Norrbotten Mountains a great many kinds of highly metamorphic sedimentary and volcanic rocks of various Archean formations together with Sorsele granite, Lina granite and its allied perthite-granite and syenite rocks build up the substratum of the Caledonian bedrock.

In the western parts of the Lapland Mountains there are five windows, where the Archean substratum of the Caledonian bedrock is exposed, viz.: 1. the Rombak-Sjangeli window on both sides of the national boundary to the west of Torneträsk, 2. the Kuokel window on the western shore of Torneträsk, 3. the Singis window, a very small one, to the southwest of the Kebnekaise Mountains, 4. the Nasa window, crossing the national boundary in the southwestern corner of the Norrbotten Mountains, and 5. the Västerbotten part (= easternmost part) of the Börgefjell window.

The Archean bedrock of the above-named windows is for the most part of granitic composition. In the windows to the west of Torneträsk, however, there are also some schists, partly with basic volcanic intercalations. These supercrustal rocks are older than the surrounding granite.

Along the margins of all these windows there are remnants of lightly disturbed autochthonous beds of sandstone and shale, western outcrops of the Hyolithus Series. No fossils, however, have been obtained from these western sediments. One may point out that the scattered occurrences of alum shale in the upper parts of these sediments strongly support the opinion of their Cambrian age. The windows with outcropping Archean bedrock represent anticlines. Specially the anticlines in the national boundary zone are very pronounced and large. The bedrock in the upper part of the Nasa window is rather tectonized.

Both in the windows and along the eastern mountain margin the Archean bedrock is for the most part quite fresh up to the boundary of the superposed sediments. In some areas, however, the bedrock quoted is weathered to a depth of some metres below the very boundary.

The Sito tillite Formation. The formation rests on Archean bedrock or is separated from it by sandy to arkosic beds. Laminated shale, possibly of real varved shale origin, is observed in connection with the tillite. The thickness of the Sito Formation is often a few to some ten metres. Tillite rocks are observed both in the autochthonous sequence and in thrusted units.

Up to now the Sito tillite has been found only in Norrbotten parts of the Lapland mountains. The tillite rocks have been considered representatives of the Varanger ice age (Kulling 1942 and 1951) or Varangerum. In the legend to the 1958 Sweden bedrock-map another name, the Varegium, has been introduced by B. Asklund. This term covers not only the Varangerum glacials, but also all sedimentary beds superposed on the very glacials, as far as the base of the lowest bed with real Lower Cambrian fossils. Thus the above-named Ström quartzite is included in the Varegium of Asklund. The author prefers to keep to the name of 1942, distinctly restricted to the old glacials.

The Eastern Cambro-Silurian. In the table of the introductory synopsis "the Föllinge Nappe" of Eastern Cambro-Silurian sediments was mentioned. This nappe-unit, if it is a real tectonic unit, is chiefly a Jämtland—Ångermanland nappe and is consequently dealt with by B. Asklund in the description of the Southern Swedish Mountains.

The sedimentary sequence of the Eastern facies starts with a basal sandstone formation almost devoid of fossil remains. Its name is the Laisberg sandstone or the Laisberg Formation and it lies on the Archean substratum or on the Sito tillite Formation. The Laisberg sandstone can be followed from the national boundary north of Torneträsk along the Lapland Mountains marginal zone to the Lake Malgomaj district in middle Västerbotten. The basal bed of the formation is often an arkose or a real basal conglomerate. In some districts sandy shales of the formation are obviously rich in mica, probably emanating from comparatively adjacent exposures of pre-Cambrian mica-bearing rocks.

Of the four Scandinavian Lower Cambrian faunal zones, viz. 4. Zone with *Strenuella linnarssoni* Kiaer, 3. Zone with *Holmia kjerulfi* (Linrs.), 2. Zone with *Volborthella tenuis* Schmidt and *Platysolenites antiquissimus* Eich., and 1. Zone with *Discinella holsti* Moberg, are the three upper ones clearly established in the east border zone of the Lapland Mountains. Lenses and thin beds of fossiliferous limestone with fossils of Zone 4 are specially noted in autochthonous shales on Mt Luopakte to the south of Torneträsk and in Aistjakk at Lake Storlaisan, both localities in Norrbotten. Also in a thrusted unit in the named Mt Luopakte Zone 4 is found. Fossils of Zone 3 are known from some localities in Västerbotten and fossils of Zone 2 have a wide distribution both in the Norrbotten and the Västerbotten parts of the Mountain border zone. The Hyolithes shale itself belongs to Zone 2. It is possible, that the lowest Zone, no. 1, of which no real fossils are reported from Lapland could be established in the lowest autochthonous beds, called the Laisberg sandstone Formation above.

The fossiliferous Lower Cambrian beds are for the most part composed of shales, marly shales, sandy shales, and sandstones. Pebbly conglomerates, phosphorite conglomerates and limestones are only occasionally met with.

The main facies of the Middle and Upper Cambrian is alum shale. Other kinds of shale and sandy shale to graywacke are also present. The stinkstone bearing alum shales which are rich in fossils are mainly distributed in the southern part of the Västerbotten Mountains border. As alum shale of more northern districts is poor in fossils, possibly lacking fossils, the age of these alum shales is more or less uncertain. The following Middle and Upper Cambrian faunal zones are established in southern Västerbotten up to north of Lake Storuman in the north.

The Middle Cambrian is represented by the Zone with *Paradoxides pinus* of the *Paradoxides ölandicus* beds, and the four zones: *Ptychagnostus gibbus,* Zone with *Tomagnostus fissus* and *Ptychagnostus atavus, Hypagnostus parvifrons,* and *Ptychagnostus punctuosus* of the *Paradoxides paradoxissimus* beds, and at the top the *Paradoxides forchhammeri* beds. The Upper Cambrian is represented by the Zone with *Agnostus pisiformis,* Zone with *Olenus,* the two subzones with *Peltura scarabaeoides* and *Parabolina longicornis* of Zone with *Peltura* and *Sphaeropthalmus.*

From the preceding list it is clear that many zones and subzones of Scandinavian Middle and Upper Cambrian are up to date not identified in the alum shale sequence of Västerbotten. The areas with alum shale are for the most part covered by drift. The fossils collected and examined are mainly from stinkstone erratics in till. Thus future investigations possibly may add new zones to the above-named ones and fill upp some of the zonal gaps in the list presented.

The Ordovician of Eastern facies, only met with in the southern part of the Västerbotten Mountains border zone, has a more southerly distribution than the above-named Middle and Upper Cambrian. The most northerly locality of Ordovician sediments is noted from the vicinity of Lake Skikkisjö to the north of Lake Vojmsjön. The lowermost Ordovician strata belong to the Ceratopyge beds, their lower part being the Ceratopyge alum shale and their upper part the Ceratopyge limestone. Of the following Lower Didymograptus beds only Zone with *Isograptus gibberolus* and Zone with *Phyllograptus densus* is up to date recorded at scattered localities. The next faunal zone is the Limbata limestone. On Mt Baktoberget to the south of the southeast corner of Lake Malgomaj the limestone is exposed in an old quarry. Regarding the fossiliferous Eastern Ordovician it may also be mentioned that graptolites, viz. *Climacograptus* and leptograptide remains of possibly Middle Ordovician age are collected from a black shale in a remote district in southernmost Västerbotten. In the very part of Västerbotten where the Eastern Ordovician fossils were discovered, there are large districts with bedrock of gray and black shale, graywacke and dark sandstone. The whole little known and very badly examined sedimentary sequence is looked upon as Ordovician.

The fossil-bearing Eastern Cambro-Ordovician strata of Lapland, if they crop out at all, appear below the thrusted masses in the eastern scarps of the Mountain border or are exposed along rivers and brooks in the otherwise drift-covered more or less plain areas of the same border zone. In these circumstances it is hard to divide the Eastern Cambro-Ordovician into true autochthonous beds and in thrusted ones. The author's brief survey is insufficient for that. The undisturbed Cambrian beds in the very eastern Mountain margin, subjacent to thrusted Lower or Middle Caledonian Bedrock units, are the only verified autochthonous ones. Alum shales are met with in the Blaik Nappe part to the west of Lake Malgomaj. The wide district of Cambro-Ordovician shales with graywacke- and quartzite intercalations to the southwest of Lake Malgomaj may be a downfolded part of the last-named Nappe complex. The author once (1942) described fossiliferous, probably Cambrian beds, resting on true Ström quartzite in the middle of this district.

The Ström quartzite — Långmarkberg tillite — Sparagmite sequence of the Lower Caledonian bedrock is the predominant stratified series of strata in the southwestern part of the Blaik Nappe. The Sparagmite Series is composed of arkoses and more of less feldspar-rich sandstones of red to greenish grey colour, real quartzites, pebbly conglomerates and sandy slates. Above this lowermost series of rocks follows the Långmarkberg tillite Series with real tillites with scratched boulders and with varved slates. The author has divided the Series into two formations (Kulling 1942 and 1955), the lower one of dark grey colour with material of possibly eastern origin, and the upper one of reddish to light grey colour with material of a wholly different composition, and pointing to southerly to southwesterly sources. The varved slates of the last named formation possibly got their clastic material from a floating ice-tongue, advancing in a northerly direction. The Långmarkberg glacial beds are supposed to be equal in age to the above-named Sito tillite Formation of the Norrbotten Mountains. Both of them constitute traces of the worldwide Varanger ice age (cf Kulling 1934 and 1951) in the Swedish Caledonian Mountains. The Ström quartzite Series both in the above-named southwestern district of the Blaik Nappe and in the more eastern occurrences of the same nappe along the eastern boundary of the Mountains is mainly composed of white to light grey quartzites, sandy slates and reddish to greenish grey slates. Arkosic quartzites are of secondary importance, and carbonate rocks are seldom met with.

As pointed out in the preceding synopsis the protruding units of the Rautas Nappe-Complex in northern Norrbotten are looked upon as a northern part of thrusted Lower Caledonian bedrock. The sediments in the complex are of the same quartzite-slate composition as in the Ström quartzite Series.

The Middle Caledonian Bedrock

The southernmost part of this bedrock is called the Stalon Nappe, the name proposed by Kulling in 1940 for the Middle Caledonian Bedrock of the Västerbotten Mountains marginal zone. The main constituent of the unit is sparagmite with intercalated or basal coarse conglomerate. The material of these conglomerates is composed of mainly Archean igneous rocks. In the upper part of the nappe unit tillite rocks and light coloured quartzites are noticed, supposed to be equal in age to the tillite of the Långmarksberg glacials and the quartzite of the Ström clastics. The lowermost part of the nappe is in the south and in some restricted parts of its eastern border zone built up of Archean igneous rocks, in the south mainly of highly-schistose greenstones, possibly to a great extent of volcanic origin, and in the east of syenite rocks. In the east the sparagmite often goes down to the very base of the nappe. To the west the metamorphism increases and the sparagmite grades into mica-schistose feldspar-rich schists, arkose rocks in mica-schist facies.

The Archean igneous rock portion of the Stalon Nappe is larger in the southern part of Norrbotten than in Västerbotten. This is so not only in the eastern or Mountain margin part of the nappe, but also in the two windows of the nappe to the west of the margin and situated within the Seve-Köli Nappe.

The Ammarnäs Inlier in the northeastern part of the Seve-köli Nappe of the Västerbotten Mountains was mentioned in the introduction part of this paper and has also been referred to. In the district between Lake Sädvajaure and Lake Hornavan the so-called Rinsele Inlier appears in Seve-köli Nappe milieu. The bedrock of the inlier was built up of arkoses (sparagmites), quartzites, graywackes and slates and bears comparison with both the bedrock of the Ammarnäs Inlier and the Stalon Nappe bedrock in the south.

The next part of the Middle Caledonian bedrock makes up the easternmost part of the thrusted masses from the north of Lake Hornavan to the mountains north of Lake Saggat. This Tjeggelvas-Saggat Unit is designated on the map of 1958 as sparagmite rocks. In reality the unit is composed not only of arkosic rocks with conglomerate intercalations but also of a lot of fine-grained gneisses and other rocks, up to date insufficiently surveyed and only to a limited extent examined. The age of the different types of rocks is pre-Cambrian but otherwise uncertain.

The northern continuation of the unit just discussed is the thrusted syenite and granite complex including "the Syenite Nappe" of A. Hamberg (1910). In his report on the Caledonian High Mountains of Sarek Hamberg states that the Syenite Nappe is superposed on "eastern Siluric facies", that is on the Hyolithus Series, and plunges to the west under "the Amphibolite Nappe", Hamberg's name for the easternmost part of the above Seve-köli Nappe, where amphibolite rocks predominate. On the 1958 geological map of Sweden the syenite and granite complex has a wide distribution, and in the broad Akkajaure district runs to the west and crosses the national boundary. Towards the north the thrusted Archean bedrock continues in the eastern part of the Norrbotten Mountains and reaches the Torneträsk area. The main part of "the Syenite Nappe" is looked upon by the author as belonging to the Abisko Nappe. As mentioned above, (see for instance the table of the introduction and the Torneträsk map, fig. 5) the Rautas Nappe-Complex also includes Archean igneous rocks in its lower part. From the Torneträsk area such thrusted igneous rocks can be followed to the south, to the northeast of Kebnekaise High Mountains. Some ten kms south of Mt Kebnekaise small remnants of such thrusted units were noticed during current geological mapping. These are not wholly registered on the 1958 geological map of Sweden. In the wide area of thrusted Archean igneous rocks of the Akkajaure district there are several occurrences of quartzitic and argillitic sediments superposed on or involved in the igneous rocks, runnning for the most part WNW—ESE or parellel with the axes of the dominant cross-folding. The metamorphic transformation of the sediments in the southeast is not very prominent but increases to the northwest. Thus the eastern shaly type changes to the northwest to sericitic schist, often with a pronounced tectonic banding. The bedrock of the above-named thrusted Archean is mainly composed of granite-syenite rock. But anorthosite, gabbro, porphyry, fine-grained gneiss and schistose sediments are also to be found. As to the sediments spoken of, some conglomerates and quartzites of the Archean Sjöfall Series are referred to. The big iron ore deposits of Mt Ruotevare in the mountains northwest of Lake Saggat belong to the thrusted Archean. The ore bodies are irregularly delimited segregations in anorthosite. From anorthosite transitional types of rock appear to the potash felspar syenite and to granite of the Mt Ruotevare area. According to A. Gavelin the whole sequence of rocks constitutes a magmatic stratified body. Some sixty km:s NNW of Mt Ruotevare the author has noticed anorthosite and allied igneous rocks with some small titaniferous iron ore lenses as members of the Archean thrust-masses. Further to the northwest in the far west districts of the Norwegian coast zone, in Lofoten-Vesterålen, there are deposits of titaniferous iron ores, situated in anorthosite-gabbro-syenite of possibly the same age as the named Norrbotten occurrences, representing a connecting link between thrusted igneous rocks on the Swedish as well as the Norwegian side of the national boundary.

At the time of the international geological congress in Sweden in 1910 three different hypotheses of tectonics and the origin of the actual thrusted igneous masses were discussed. A. Gavelin (1910, 1915), based on a survey of the Mt Ruotevare and adjacent areas, claimed that all the named igneous rocks were of Caledonian age. A. Hamberg (1910) looked upon the cataclastic and thrusted syenite-granite of the Sarek High Mountains to the north of the Ruotevare district as a flat-lying nappe unit with bedrock of supposed Archean age. P. J. Holmquist (1910) with experience from the Torneträsk area interpreted the cataclastic igneous rocks as representing a lot of parautochthonous Archean unites, each with Archean basement rock with superimposed "Silur", that is with a sandstone-shale sequence of the Hyolithus Series-type.

The Archean age of the granite-syenite thrust masses or more accurately the age of such rocks in the southernmost part of the Norrbotten Mountains was verified in 1934, when the author came upon localities of the complex where coarse conglomerate, upwards grading in and followed by arkose of the pre-Cambrian Sparagmite Series, overlies the granite-syenite body. Later on, such sediments on thrusted Archean were found in the lower part of the Västerbotten Stalon Nappe and described in the author's monograph of 1942.

The opinion of Holmquist, that every thrusted part of cataclastic Archean is parautochthonous and goes down in the autochthonous substratum of the surveyed part of the Torneträsk area, however, is contradicted on his own geological map. During the last decade G. Kautsky (1946, 1947 and 1953) sticks to Holmquist's opinion with material gathered from some scattered small areas of the Lake Akkajaure district. Kautsky says that the napplets sometimes are so thin that six to seven can occur in one mountain section, everyone with granite in its lower part and overlain by a sequence of arkose, white quartzite, grey-blue quartzite and slate, the last named with intercalated graphite shale and graywacke. Later, he reduced the parautochthenous nappes, called the Akka Complex, first to about eight in number, and finally to about three big nappes. Kautsky's map of 1953 does not show the distribution of his three Akka Nappes, as his mapping was restricted mainly to the district along the national boundary. Thus G.

Kautsky's opinion on the structure of the bedrock of the Akkajaure district varies, and his knowledge of its problems is restricted to the above-named boundary Zone and to some places on the shore of Akkajaure. The present author does not admit such terms as the Akkajaure Complex or the Akkajaure nappes.

The Caledonian bedrock in the northernmost part of Norrbotten, the bedrock of the so-called Pältsa district, was mapped by the author in 1956. The Middle Caledonian bedrock of the district, superposed on the Hyolithus Series and upwards followed by the Seve-köli schists, is designated as fine-grained gneiss and cataclastic granite of Archean age. On the 1958 geological map of Sweden this Middle Caledonian unit is incorrectly coloured as "Grey sparagmites outside the large western nappes". Regarding sparagmites, the author may call attention to another manifestation of inconsistency of the map-legend. Thus sparagmite and its granitic basement are shown as occurring both outside the large western nappes as well as in them. In the legend to the map, however, sparagmites are confined to "Rocks outside the large western nappes". The terms of the map-legend mainly refer to the bedrock of the Southern Swedish Caledonian, and is compiled by B. Asklund. See Asklund's comments to the map.

Before finishing the paragraph on the Middle Caledonian Bedrock the author would like to comment on the western boundary of the Stalon Nappe in Västerbotten and southernmost Norrbotten. The boundary on the Sweden map of 1958 is not in accordance with the author's opinion. The diapthoritic greenstones in the lower part of the Stalon Nappe crossing northwestern parts of Lake Malgomaj —Lake Vojmsjön district were mapped by the author northwards to west of Lake Storuman, and a petrographic description of the greenstones published in a monograph (1942). For instance: the description names the actual rocks as the Ullisjaure greenstones, referring to some type-rocks on Lake Ullisjaure. On the map of 1958 the Ullisjaure area to the west of Lake Storuman is coloured as grey sparagmite. And in a district to the west of the Ullisjaure area the western continuation of the greenstones is designated on the new map as amphibolite of the western nappes. To the west of the northern part of Lake Vojmsjön a major thrust boundary is shown crossing the Ullisjaure greenstones, and similar mica-schists are on the map placed both below and above the mentioned major thrust boundary. According to the author the west boundary of the Stalon Nappe may be drawn east of the high mountain amphibolites where, on the map, the so-called hardschists i. e. tectonically banded schists occur.

The Upper Caledonian Bedrock

This bedrock, as stated in the introduction, is divided into a lower part, the Seve-Köli Nappe, and an upper part, the Rödingsfjäll Nappe.

The Seve-Köli Nappe makes up the major part of the Lapland Mountains. Its name indicates that the nappe is composed of low metamorphic as well as high metamorphic schists. The former name for the lower metamorphic mountain schists is the Köli schists, and for the high metamorphic schists the Seve schists. The mountain schists are built up of a great many kinds of sediment with intercalated volcanics and intrusive igneous bodies. The high metamorphic rocks predominate in the eastern part of the nappe and form the real high mountains of Lapland. The low mountains and the undulating plateaus in the westernmost part of Lapland are mainly composed of low metomorphic bedrock. Migmatite rocks are on the whole restricted to the lowest part of the nappe in the Västerbotten Mountains. In the Norrbotten Mountains such rocks are sparse and only restricted to some thin zones. The stratigraphy of the higher metamorphic rocks is hard to make out as leading stratigraphical zones are often wanting.

The interpretation of the stratigraphy of the lower metamorphic rocks of the Seve-köli Nappe is based on the occurrence of some characteristic sedimentary and volcanic rocks, or more accurately termed, on some associations of strata. The best guiding association is a limestone superposed on a light coloured, pure quartzite or quartzite conglomerate, the Slätdal-Vojtja association. A characteristic graywacke to graywacke conglomerate, the Gilliks clastics, representing a formation in the sequence below the above-named, strengthens the interpretation of the stratigraphy in question. In 1925 the author discovered determinable fossils in two formations situated in the central part of the lower metamorphic rocks of the Västerbotten Mountains. The older of these two formations is the above-named Slätdal limestone of the uppermost Ordovician. In the Eastern facies this fossiliferous limestone is parallelised with the Dalmanitina beds and equal in age with the upper part of the Ashgillian. The younger fossiliferous formation is a slate, the Broken slate, with graptolite fossils of Lower Silurian age or more exactly the zone of *Cephalograptus comata* and the zone of *Petalograptus folium* of Middle Rastrites beds, equal in age with the upper part of the Middle Llandovery. Up to date these two formations are the only ones in the Western Cambro-Silurian of the Swedish Mountains, where the age of the formations is paleontologically well-dated. A stratigraphy of the Western Cambro-Silurian of Central Västerbotten, with the two dated formations included, was worked out by the author and published in 1933. New evidence of stratigraphical value was brought to light during subsequent surveys in other parts of the western Cambro-Silurian of Lapland. Thus, the fossiliferous Slätdal limestone, the Vojtja conglomerate, and the Gilliks clastics were discovered in southern and middle parts of the western Norrbotten Mountains, and the stratigraphy of the Central Västerbotten bedrock extended downwards in many districts. Some names used in the 1933 years stratigraphy have been substituted by others in order to avoid a mere local meaning. The stratigraphy now valid for the Western Cambro-Silurian of the Lapland Seve-köli nappe is the following: The Viris Series, the Lövfjäll Series and the Broken Series of Silurian age, the Slätdal-Vojtja Series, the Gilliks Series, the Seima Series, the Ro Series, and the Pieske Series of Ordovician or most probably Ordovician age. To these series one may add the Keddåive Series below the Pieske Series in some Norrbotten parts of the bedrock. The Fjällfjäll Series in the southwestern part of the Västerbotten Mountains and exposed in the Fjällfjäll-Ljusfjäll anticline may also be mentioned as belonging to the bedrock below the Ro Series. Because of possibly great stratigraphical gaps above the Fjällfjäll Series its position in relation to other sub-Ro Series rocks is somewhat uncertain. A short description of the rocks and the distribution of the named series is now given.

The Viris Series, the youngest sedimentary unit of the Western Cambro-Silurian of Lapland, is mainly built up of a light grey fine-grained feldspathic sandstone with some detrital fragments of slate. Its name, the Viris quartzite, refers to its distribution around Lake Virisen in the central part of the Västerbotten Mountains. The Viris Series is restricted to the Virisen area and to some occurrences to the north of it, up to Lake Björkvattnet. In a restricted area at the boundary between Västerbotten and Norrbotten Viris quartzite is also reported. In the lower part of the Viris quartzite Series coarse quartzite conglomerate is observed. In another part of the Virisen area conglomerate of the same type occurs in environments of sandy phyllite to calcareous phyllite of the subjacent Lövfjäll phyllite type. Interdigitations of Viris quartzite and Lövfjäll phyllite are also met with. Though not proved, the separate conglomerate occurrences are looked upon by the author as belonging to one and the same stratigraphical bed, the Gimja conglomerate, and registering a gap in the stratigraphical succession.

The Lövfjäll Series in the central part of the Västerbotten Mountains is predominantly composed of the so-called Lövfjäll phyllite, that is, grey, fine-grained calcareous phyllite with intercalations of slate, sandy calcareous phyllite to calcareous quartzite. Graywacke beds, sometimes with current bedding and graded-bedded slates, occur. Some thin beds of chlorite schist are noticed and may indicate tuffaceous strata. The Lövfjäll Series builds up the south-north running syncline in the central part of the Västerbotten Mountains from north of Lake Kultsjön in the south to north of Lake Björkvattnet in the north. The center of this syncline is the Viris quartzite. In the above-mentioned area on the Västerbotten—Norrbotten boundary Lövfjäll phyllite occurs as substratum of the Viris quartzite of that area. Also the Gimja conglomerate was found by the surveyer N. Marklund. In more northerly parts of the Lapland Mountains, specially in the Lake Ikisjaure district, the probable northern equivalent of the Lövfjäll Series is mainly more or less calcareous slate with greenstone beds. The material collected from the named Norrbotten areas has only been very briefly examined.

The Broken Series. This series of grey to black slate in its upper part and light grey quartzite in its lower part has only been examined in detail in the Lake Broken area situated to the north of Lake Virisen. The only locality with upper Middle Llandovery graptolites up to now is to be found in the vicinity of Lake Broken. The Broken slate succession contains some intercalations of slaty graywacke beds. The Broken quartzite is often calcareous. In districts outside the central part of the Västerbotten Mountains it is hard to verify which slates and quartzites are equal in age to the Broken sediments.

The Slätdal-Vojtja Series. Its constituents are dark slate, fossiliferous limestone, Slätdal limestone, with a fauna rich in corals of uppermost Ordovician age, and at the bottom quartzite conglomerate, the Vojtja conglomerate, and quartzite, the Vojtja quartzite. The conglomerate and quartzite register a very big transgression in the Caledonian geosynclinal branch of Scandinavia. The presence of the series was at first only verified in the central syncline of the western Västerbotten Mountains and in an area along the Västerbotten—Norrbotten boundary. Later the author came upon the fossiliferous Slätdal limestone and the Vojtja clastics in the Ikisjaure—Mavasjaure area along the national boundary and in an area to the east of Vastenjaure, both areas situated in western parts of the Norrbotten Mountains.

The Gilliks Series. The graywacke conglomerate, named the Gilliks conglomerate, and the above-named Vojtja conglomerate are quite different. The latter is a well-washed transgression conglomerate, the former, with its shaly matrix, is sometimes tillite-like, mostly unassorted, with rather heterogenous detrital material. The graywacke conglomerate from Mt Gillikstjåkko in the central part of the Västerbotten Mountains was directly followed by the Vojtja clastics. The wholly different composition of the two clastic formations points to a major stratigraphical break above the graywacke beds. Chloritic schists, looked upon as altered volcanic tuffs, were observed as intercalations in the named graywacke conglomerate beds in central Västerbotten. In all the Norrbotten occurrences of the Gilliks Series there are to be found a great many kinds of rocks, sediments as well as volcanics together with the graywacke sediments, both as intercalated beds and between the graywackes and the Vojtja clastics. The volcanics are mostly basic, the sediments are calcareous phyllite, slate and some minor limestone beds. From the southern part of the Västerbotten Mountains no graywacke conglomerate, occurring below the Vojtja clastics, has been reported, only some graywacke quartzite. The composition of the material of the graywacke conglomerate is remarkable. Na-granite and Na-keratophyre occur both as pebbles, boulders and big scattered blocks. Dark oolitic dolomite, light coloured dolomite and several types of sandstone are other components of the conglomerate material. The detrital material is of the same composition both in Norrbotten and in Västerbotten. In the Ikisjaure—Mavasjaure district of southern Norrbotten a stratified part of the graywacke conglomerate contains limestone lenses with fossils. The presence of *Halysites*-colonies among the badly preserved fossils points to a comparatively late Ordovician age for the graywacke beds. No real index fossils, however, have been met with. The source of material in the Gilliks clastics is probably wholly from the geosynclinal area, as the Na-granite and Na-keratophyre appear in lower parts of the geosynclinal strata, and the sedimentary block-material, well-preserved as it is, has no pre-Cambrian look. During surveys in the East Greenland and the North-East Land parts of the Caledonian Chain the author observed most kinds of sedimentary rocks mentioned above as block-material, as formations, laid down in the geosynclinal trough. The author's opinion is that the Gilliks clastics were deposited by turbidity currents travelling along the geosynclinal axe. The currents probably transported their material from some northern source.

As to the age of the Gilliks Series the author may add the following statement. In the western part of the Norwegian Trondhjem region (Th. Vogt 1945) the Ordovician Volla conglomerate is in several respects similar to the Gilliks clastics. Together with the late Th. Vogt the author visited some Volla conglomerate localities and made comparisons that strengthened his hypothesis. The Volla conglomerate lies on a black graptolite slate, the so-called *Dicranograptus* shale of the Norwegian Etage 4 b, that is of Upper Caradocian age. In the mentioned part of the Trondhjem region a wide-spread quartzite conglomerate occurs above the Volla conglomerate, separated from the latter by a feldspathic sandstone of varying grain size. This quartzite conglomerate, the Lyngestein conglomerate, may be equal in age to the Vojtja conglomerate of Lapland.

The Seima Series. In the central part of the Västerbotten Mountains basaltic volcanics with agglomerate beds lie below the Gilliks graywacke conglomerate. These so-called Seima lava beds form the upper part of the Seima Series. Keratophyre beds also occur. Below the volcanics shaly and sandy beds with some intercalated carbonate rocks predominate. As basal bed of the series pebbly conglomerate of some areas and a graywacke-slate of others is proposed. Possibly these layers are of more interformational than of real basal nature. The distribution of the named series in the Norrbotten Mountains cannot be discussed here, as field-work is still proceeding in the western parts of the mountains, where the series in question occurs. The Låtats pillow lava in the author's reports on the field work in these areas is considered to be of Seima age.

The Ro Series. In the lower part of the bedrock of the Central Västerbotten Mountains the author discovered in 1926 a conglomerate composed only of serpentinized peridotite. This conglomerate, the Rotik conglomerate, was deposited on a peridotite substratum. Later, light coloured dolomite and magnetite ore were very occasionally observed as pebbles of this serpentine conglomerate. The conglomerate sometimes grades into a fine-grained facies, sometimes into a sedimentary serpentine breccia. In other parts of southern Lapland quartzite conglomerate with or without sparse serpentine pebbles was met with. This conglomerates are also in the lower part of the geosynclinal sequence of strata. Most probably all the named conglomerate beds belong to one and the same formation and register a transgression in the geosynclinal area. Above the conglomerate beds sandy phyllite, slate and greenstone lava occur. The whole sequence is named the Ro Series and occurs below the Seima Series. A conglomerate of the same kind as the Rotik conglomerate has been reported from the southernmost part of the Norwegian Trondhjem region. This conglomerate, however, had intercalated fossiliferous beds. According to H. Hedström (1930) the fossils in the serpentine conglomerate suggested compararison with the Lower Ordovician Asaphus beds i. e. the Norwegian Etage 3 c β—γ, or the lower part of the Llanvirnian. The author in his monograph of 1933 on Central Västerbottens Mountains put forward the hypothesis that the Rotik conglomerate is equal in age to the Norwegian serpentine conglomerate. This view was based on the fact that the peridotite rocks of the Norwegian Trondhjem region seem to be restricted to one and the same level in the lower part of the geosynclinal stratification. The author held that the greater part of the ultrabasic magma forced its way upwards into the unconsolidated muds on the floor of the geosynclinal sea and came to rest there. Otherwise it is hard to give an acceptable explanation to the monomictic character of most of the serpentine conglomerates now discussed.

The Pieske Series below the Ro Series is the lowermost stratigraphic series that may be distinguished in most areas of the Western Cambro-Silurian of Lapland. Its most prominent member is the so-called Pieske limestone. Most of the limestones of the Lapland Monuntains on the 1958 Sweden map in both high and low metamorphic grades (with the exception of the above-discussed Slätdal limestone) are looked upon as representatives of the Pieske limestone Formation. In districts with peridotite and Pieske limestone the two are mostly associated with each other. Possibly both are of Lower Ordovician age and correspond to the Arenig beds of the British Caledonian branch. The

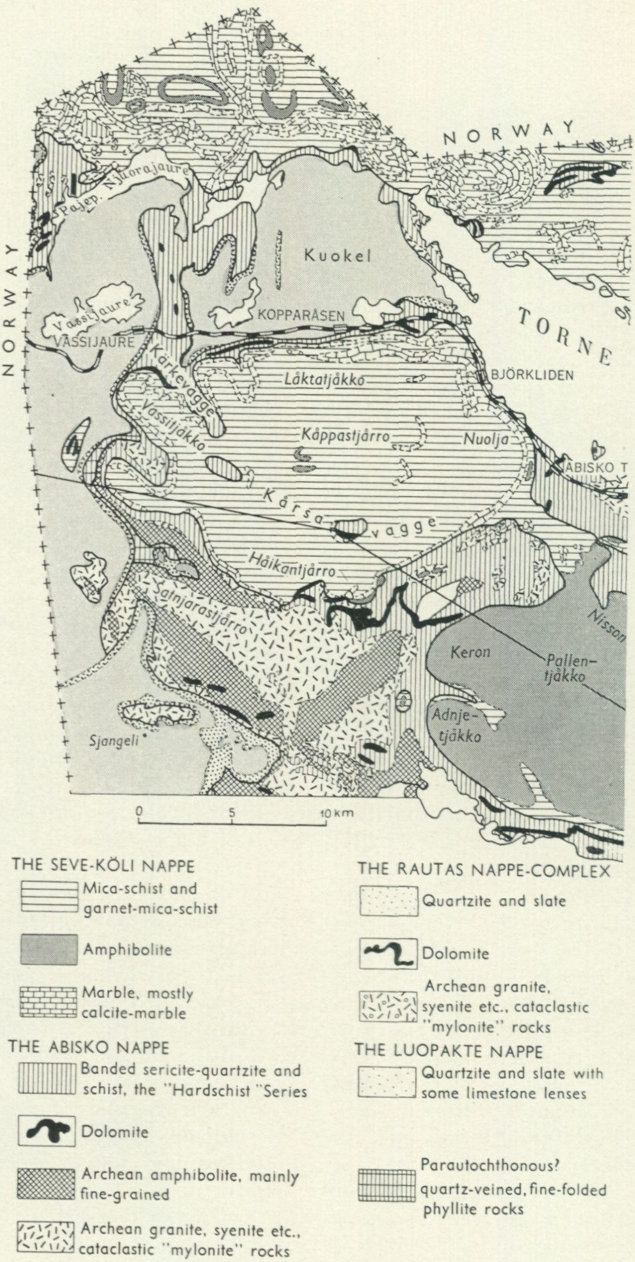
Pieske limestone makes up the upper part of the Pieske Series. In the middle and lower parts of the series there are sediments of varying composition as well as some volcanic rocks. Most of the rocks of the series are mica-schist. Graywacke-schists and conglomerate beds are reported from the lowermost part of the series. As to conglomerate beds the author may discuss such a conglomerate from the Norrbotten Virihaure district. The material in the conglomerate is mainly light-coloured granite. The conglomerate formation appears as feldspathic quartzite with granite conglomerate beds. Th. Vogt (1927) observed the granite conglomerate at the southeastern corner of Lake Virihaure. His opinion is that the granite material of the conglomerate is of Archean age. Above the conglomerate the fine-grained sediments of the Pieske Series are mica-schists of varying composition. In the superposed Pieske limestone small lenses of serpentine-schist occur in its lower boundary zone. G. Kautsky (1953) during his survey of the Sulitelma area came upon such lenses of serpentine-schist. Kautsky speaks of the limestone as of Upper Ordovician age. As Kautsky accepts the author's hypothesis of the Lower ordovician age of the ultrabasic serpentinized peridotite and has no fossils to support his opinion of Upper Ordovician age of the limestone, the present author holds to his stratigraphy.

T h e K e d d å i v e S e r i e s. In some scattered areas dark dolomite rocks appear below the sediments of the Pieske Series. Some twenty kms east of the southern part of the above-named Lake Virihaure, in 1948 the author came across such dark dolomite to dolomitic schist. The carbonate formation was followed about thirty kms to the south. Below and to the east of the dolomite rocks a sequence of somewhat quartzose mica-schists predominates. Amphibolite rocks are sometimes intercalated with the carbonate rocks and the subjacent mica-schists. To the east the big amphibolite body, the so-called Eastern amphibolites of the Eastern High Mountains, begins. Included in this amphibolite body scattered carbonate rocks and, of course, also mica-schists rocks are to be found. Both limestone, dolomite and magnesite occur among the carbonate rocks.

The Eastern amphibolite and high metamorphic schist often make up the lowest part of the Seve-köli Nappe. In some areas, specially in the western parts of the Torneträsk area of the northern Norrbotten Mountains, carbonate rocks of the Pieske limestone type and also of the Keddåive dolomite type make up the lowermost part of the Seve-köli Nappe.

T h e R ö d i n g s f j ä l l N a p p e. In the introduction to this paper the nappe is called the uppermost tectonic unit of the Lapland Caledonides. The Västerbotten part of the nappe builds up the high mountains along the national boundary around Lake Överuman. The name of the nappe proposed by the author in 1945 (Kulling 1948), refers to the boundary-peak Mt Rödingsfjället some twenty kms south of the lake. All the rocks of the nappe are highly metamorphosed. To the south of Lake Överuman the boundary between the rocks of the Rödingsfjäll Nappe and the lower metamorphic Seve-köli rocks below is well exposed. The main part of the Rödingsfjäll Nappe is on the Norwegian side of the national boundary where its high metamorphic schists to migmatite rocks and late-Caledonian granite bodies cover wide areas. Thick limestones and a great many ore deposits, inter alia the Dunderland iron ore deposits, may also be mentioned as constituents of this magnificent tectonic unit. On the Norwegian side of the national boundary the eastern boundary of these thrust-masses was located in 1951—52 (T. Strand 1953), but not however followed right up to the national boundary. On the bedrock-map of Norway of 1953 this unsurveyed part of the boundary line is shown as a dotted line up to Mt Olfjället on the national boundary, where the point of crossing was put at the disposal of director S. Föyn of the Geological Survey of Norway by the present author. In northwestern Västerbotten the rocks of the Rödingsfjäll Nappe are as follows: Migmatitized schists with some amphibolite intercalations, the latter possibly of volcanic origin, make up the lower part of the nappe. Above follows a limestone formation, and as upper part of the nappe, a garnet-mica-schist formation. In southern and middle parts of westernmost Norrbotten some minor thrusted rock-masses in the national boundary zone are looked upon by the author as erosional remains of the Rödingsfjäll Nappe protruding to the east from Norway. The southernmost part of these protrusions, located by the author in the high mountains south of Lake Ikisjaure, is composed of high-metamorphic schists. The northern protrusions, the ones of the Sulitelma high mountains, were surveyed by G. Kautsky (cf. Kautsky 1953) and spoken of by him as the Gasak Nappe. According to Kautsky, the lower part of the nappe is inverted and starts with a gneissic conglomerate, upwards grading first into a breccia and then into rocks, interpreted as weathered and fissured granite. Above this peculiar rock-complex follows an uninverted series of sedimentary and igneous rocks, starting with sandy schists with intercalations of dolomite and graphitic mica-schists, then volcanic rocks, staurolite-mica-schists with conglomerate beds, then mica-schists with lenses of marble and uppermost quartzose garnet-mica-schists. In Mt Sulitelma gabbro forms the crest of the peak and is superposed on a volcanic formation. No real basis for dating the several high-metamorphic rock units of the Gasak Complex exists. Kautsky, however, puts forth the idea that the gneissic conglomerate, referred to as the lowermost formation of the whole complex, may be equal in age to the Gilliks graywacke conglomerate of the author, and that the quartzose garnet-mica-schists, the uppermost formation of the Gasak Complex, may be interpreted as metamorphosed Vojtja quartzite. Also the other high-metamorphic sedimentary and volcanic formations of the Gasak Complex are interpreted by Kautsky as of Upper Ordovician age (cf. G. Kautsky 1953).

Do small erosional remains of the Gasak Complex exist in more northerly parts of the Norrbotten Mountains than the ones discussed above? Some forty to fifty kms to the north of Mt Sulitelma the author and G. Kautsky have both surveyed the bedrock and drawn geological maps of the area between Lake Vastenjaure and Lake Akkajaure. The editor of the 1958 Sweden map, director N. H. Magnusson, preferred to use a geological map of the district, compiled from both the available maps preferring most of the author's bedrock-lines, and most of the thrust-lines of G. Kautsky. As to bodies of the Gasak Complex in the district the author's map did not show any. On Kautsky's map and on the Sweden map three such isolated outliers are outlined. The author revised some parts of the actual district some years after the publication of Kautsky's map, and in a report to the director of the Geological survey ha gave new arguments as to why he did not accept Kautsky's ideas on the tectonics of the district. In his coming monograph on the bedrock of the Norrbotten Mountains the author will give his evidence for the solution of these and other Caledonian problems.



NORWAY
NORWAY
Pajep. Njuorajaure
Kuokel
Vassijaure
VASSIJAURE
KOPPARÅSEN
TORNE
BJÖRKLIDEN
Kårkevagge
Låktatjåkko
Vassitjåkko
Kåppastjårro
Nuolja
ABISKO T
Kårsavagge
Håikantjårro
Satnjarastjårro
Nisson
Keron
Pallen-tjåkko
Adnje-tjåkko
Sjangeli
0
5
10 km
THE SEVE-KÖLI NAPPE
Mica-schist and garnet-mica-schist
Amphibolite
Marble, mostly calcite-marble
THE ABISKO NAPPE
Banded sericite-quartzite and schist, the "Hardschist" Series
Dolomite
Archean amphibolite, mainly fine-grained
Archean granite, syenite etc., cataclastic "mylonite" rocks
THE RAUTAS NAPPE-COMPLEX
Quartzite and slate
Dolomite
Archean granite, syenite etc., cataclastic "mylonite" rocks
THE LUOPAKTE NAPPE
Quartzite and slate with some limestone lenses
Parautochthonous? quartz-veined, fine-folded phyllite rocks

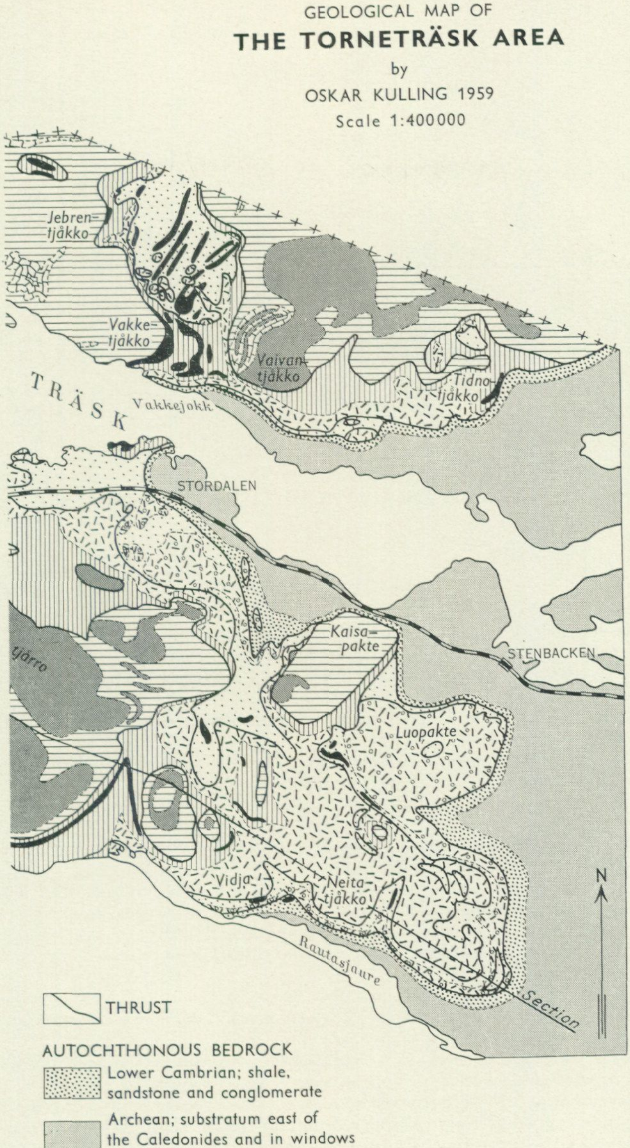


Fig. 5. Section, see fig. 6.

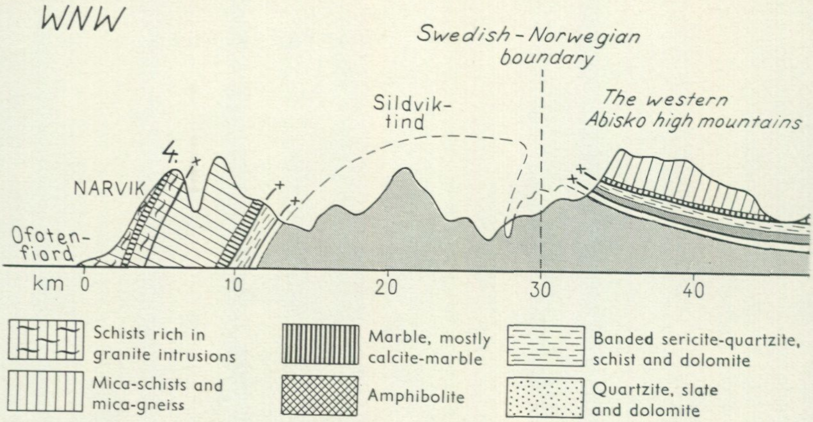


Fig. 6. Section across the Caledonides of the Torneträsk—Ofoten area, running from the eastern border of the Mountains at Lake Rautasjaure towards WNW to Ofoten fiord at Narvik. 1. The Rautas Nappe-Complex. 2. The Abisko Nappe. 3. The Seve-köli.

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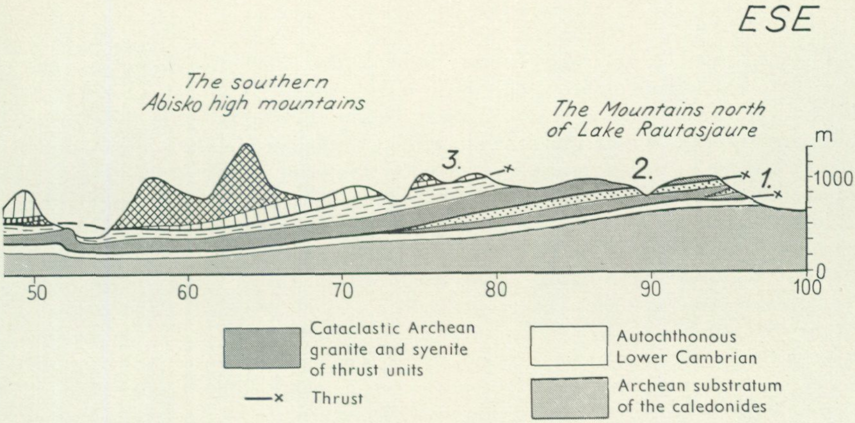

Nappe. 4. Lowermost part of the Håfjell unit (looked upon as a northern part of the Rödingsfjäll Nappe). The section is indicated on the geological maps of the Torneträsk area (Fig. 5) and the Narvik—Ofoten area (Fig. 25).

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Introductory notes on the Caledonides of the Torneträsk area

On the accompanying geological map of the Torneträsk area, fig. 5, the bedrock is divided into the following geological-tectonical units:

The Archean substratum east of the Caledonides and in windows of the same.
Autochthonous Lower Cambrian.
Parautochthonous? bedrock.
The Luopakte Nappe.
The Rautas Nappe-Complex.
The Abisko Nappe.
The Seve-köli Nappe. Compare also fig. 6.

The Archean substratum

On the map the Archean substratum of the Caledonides is not subdivided into geological units but is looked upon only as the foundation of the Caledonides.

In the Torneträsk area and in other parts of the Norrbotten Mountains the autochthonous sediments below the thrust-rocks used to be named the Hyolithus Zone or the Hyolithus Series. This Series in the Torneträsk area appears as a narrow zone along the Caledonian Mountain slopes, often almost covered by debris from the above-lying thrust-units, exposed in the scarps. In the east the sediments are nonmetamorphic, and fossils, markings on the bedding-surfaces and other structures of primary origin are well-preserved. In the west, in the windows, the sediments of the Hyolithus Series are slightly altered, and sericite covers the bedding-planes. No fossils have been discovered in these western sediments. In the east the Series is often one to two hundred meters thick. In the west only the basal sandstone with bottom conglomerate is usually present. It has a thickness of one to some tens of meter. The composition of the Hyolithus Series in the east is exemplified in the excursion-guide to Luopakte south of Torneträsk and in the excursion-guide to Vakkejokk north of the lake. There is quite a marked difference in composition of the Hyolithus Series to the north and to the south of the lake, well demonstrated in the two above-named excursion areas. From a general petrological point of view one may divide the Hyolithus Series of the Luopakte area into the following units: the Lower sandstone, the Lower shale, the Middle sandstone, the Middle shale, the Upper sandstone, the Upper shale and the Alum shale. In the Vakkejokk area the Lower shale and the Middle sandstone are absent or to a very great part absent, and a peculiar breccia formation has occupied their place. This breccia rock is called the Vakkejokk breccia and was discovered by the present author during a short stay in the Torneträsk area in 1930.

The Lower sandstone. On the base-levelled Archean substratum the sedimentation started with a well-defined conglomerate, or with an arkosic conglomerate. The lower sandstone itself is arkosic in its lower beds. The sequence is composed of fine-grained to coarse-grained grey, greenish grey and also whitish grey sandstone. Some layers with cross-bedded calcareous sandstone are noticed, particularly in the lower beds of the sandstone, see fig. 7. The thickness of the Lower sandstone is often of the magnitude of about ten m. Up to date no fossils have been discovered in it.

The Lower shale. In most sections this shale is only present as thin beds of shale to sandy shale, intimately connected to the Lower sandstone. To the north of Torneträsk the shale is almost absent, but small fragments to big lumps of shale, included in the Vakkejokk breccia, probably come from the Lower shale. In the northern slope of Mt Luopakte the Lower shale is about 12 m thick, phyllitic and with some intercalated sandstone beds.

The upper beds of the shale are exposed as the lowermost meter of the section II of Mt Luopakte, compare fig. 11, as fine-grained argillaceous sandstone and coarse shale. Small strings of fossil origin are noticed.

The Middle sandstone. Grey, greenish grey and yellowish grey sandstone, thick- to thin-bedded, of various grain-size and with some intercalated beds of shale to sandy shale characterizes the Middle sandstone. Spotted sandstone, so-called Leopard-sandstone, is noted. In the upper part of the sandstone fragments of shale, pebbles of mainly vein-quartz and, at places, small angular pieces

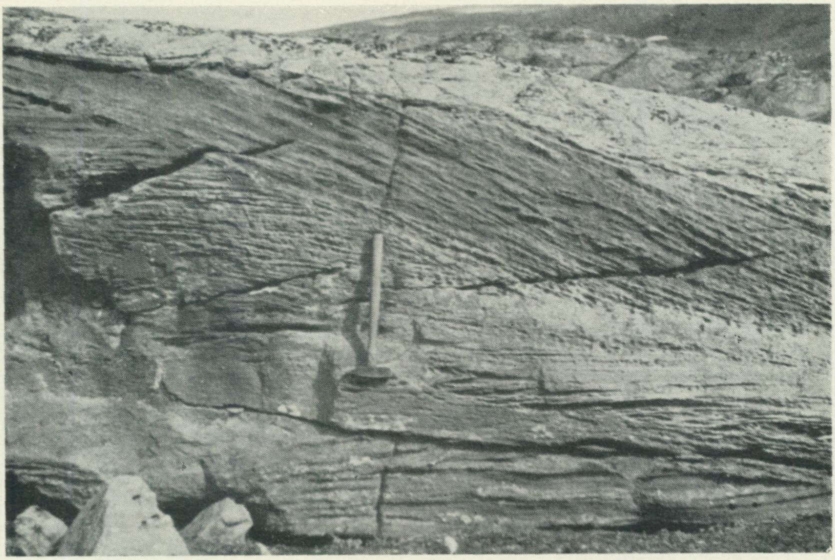

Fig. 7. Cross-bedding in calcareous sandstone immediately above the bottom conglomerate of the Hyolithus Series. About 5 km to the north of Sjangeli.

of Archean igneous rocks are present and indicate a stratigraphical break. No real conglomerate, however, is met with. To the north of Torneträsk the presence of the Middle sandstone is not verified. A great deal of sandstone material, present as boulders and fragments of the Vakkejokk breccia, points to a former distribution of probably the Middle sandstone in the area to the north of Torneträsk. In various levels of the Middle sandstone tracks of fossils are abundant on the bedding planes. A local erratic boulder of sandstone with *Monocraterion tentaculatum* Torell was found by the present author and by him referred to the Middle sandstone beds.

The Vakkejokk breccia. This formation is described in the Vakkejokk-area guide. The only probable traces of the breccia to the south of Torneträsk are the pieces of Archean igneous rocks, mentioned above as scattered small fragments in the upper beds of the Middle sandstone.

The Middle shale. To the south of Torneträsk this shale is superposed on the Middle sandstone. To the north of the lake the shale rests on the Vakkejokk breccia. The Middle shale is the "Hyolithus shale" of most earlier papers dealing with the Hyolithus Series of the eastern margin of the Norrbotten Mountains. The shale is a representative of the 2nd faunal zone from below of the Scandinavian Lower Cambrian. In the Torneträsk area the present author has collected the two zone fossils, *Volbortella tenuis* Schmidt and *Platysolenites antiquissimus* Eichw. in the lower part of the shale. *Platysolenites lontowa* Öpik was also found and some specimens of *Hyolithes* sp. and *Monocraterion* sp., the latter fossil appears in the lowermost sandy beds of the Middle shale.

The Middle shale is red to greenish red and light-grey. Some sandy beds and the thin fossiliferous beds in the shale are usually of a greenish grey colour. In some southern localities, near Rautasjaure, see the map, fig. 5, the Middle shale starts with half a meter of dolomitic sandstone. The thickness of the shale is usually 15 to 20 m.

The Upper sandstone. This sequence of sandy sediments, usually 50 to 60 m thick, is composed of a great many sandstone formations of variable grain-size, bedding-coarseness and colour. The bedding-planes of the sandstone formations are often covered with tracks of fossils and with other markings, i. e. ripple-marks. A great many types of fossil tracks are met with. Compare figs. 12 and 13. They will not be named or described in this paper. The upper sandstone of the Vakkejokk area may be referred to as representative of more northern facies than the one of the Luopakte area.

The Upper shale. This sequence of shaly sediments, 15 to 20 m thick, starts with a conglomeratic bed, partly conglomeratic dolomitic limestone. This lowermost bed is about one m thick. Phosphorite nodules of the bed and stromatolite structure of some types of carbonate rocks of the bed may be mentioned. Sparse fragments of Archean igneous rocks are noticed in the conglomerate bed. Sandstone, however, is the most common pebble-type of the conglomerate. The shaly beds are dark grey to greenish grey. To the north of Torneträsk most of the beds are silty and intercalated layers of sandstone are noticed. In the Luopakte area the uppermost part, 1.7 m thick, of the Upper shale is a grey, fossiliferous, calcareous shale, in its upper part passing over into impure limestone. In 1907, Professor J. Chr. Moberg discovered these fossiliferous beds and described their fauna, which is a representative of the 4th faunal Zone from below, of the Zone with *Strenuella linnarssoni,* of Lower Cambrian age. Compare the text to the Luopakte excursion.

Alum shale. This formation of very varying thickness is always schistose. Probably it is not wholly autochthonous. To a very large extent the thrust-masses have used the alum shale as sliding zone. The age of the alum shale is uncertain, but probably Middle Cambrian.

Parautochthonous? phyllite.

In the southwestern part of the Torneträsk area a formation of quartz-veined, fine-folded phyllite with slip cleavage is superposed on the sediments of the Hyolithus Series. In more southern areas, outside the Torneträsk area, such slip cleavage-phyllite lies as a formation between schistose alum shale and well-preserved real autochthonous sediments of the Hyolithus Series, and for that reason the named phyllite is looked upon as probably parautochthonous beds.

The Luopakte Nappe.

In the Luopakte area fossils are obtained not only from the autochthonous sediments, but also from a unit of thrusted sediments lying on them. This unit is composed of quartzite and slate with small fossiliferous limestone lenses included in the slate. During a stay at Mt Luopakte in 1950 G. Bexell, who took part in the present author's examination of the Mt Luopakte area, discovered the fossiliferous limestone, the fauna of which is referred by Bexell to the 4th Zone of Lower Cambrian. Thus this limestone is of the same age as the uppermost fossiliferous beds of the autochthonous sediments of the area. The following fossils are determined by G. Bexell, *Strenuella* cf *gripi* Kautsky, *Dielymella praecox* Cobbolds, *Bradoria* cf *nitida* (Wiman), *Indianites exigua* Cobbolds, cf *Heliconella rugosa* Hall var., *Lingulella* sp, *Obolus* sp, and *Hyolithellus* cf *micans* (Billings). The western extension of the Luopakte Nappe is somewhat uncertain, as its rocks are of about the same kind and metamorphic state as the sediments of the Rautas Nappe-Complex. Because of the fossil find in the sediments quoted the author gives a special name to the thrust-unit.

The Rautas Nappe-Complex

The Complex is composed of low-metamorphic sediments in its upper part and Archean crystalline rocks in its lower part. The main sedimentary constituents of the complex are grey and white quartzite, grey to dark-grey slate and light-grey to white dolomite. No fossils have been discovered in them to date. However, they are proposed to be of Cambrian age, probably Lower Cambrian. The Archean part of the Complex is mostly granite and syenite. Fine-grained gneiss and other crystalline rocks are also met with as members of the often cataclastic Archean rocks. The Complex often shows imbricate structure, compare fig. 8, demonstrating a highly imbricated part of the Complex in Mt Vidja to the north of the northwestern part of Lake Rautasjaure. On the general section across the Torneträsk area, fig. 6, the imbricate structure of the Rautas Nappe-Complex is not demonstrated. As is the case with the Luopakte Nappe the Rautas Nappe-Complex represents an eastern nappe, only observed in the eastern part of the Torneträsk area.

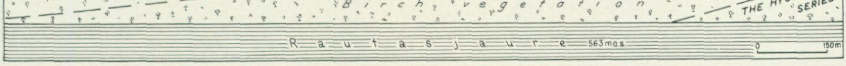

Fig. 8. The southern aspect of Mt Vidja to the north of Lake Rautasjaure. In the mountain scarp the imbricate structure of the sediments of the Rautas Nappe-Complex is well demonstrated. Black areas = white quartzite. Oblique striped areas = white dolomite. The rest of the sediments is composed of slate, sandy slate and dark-coloured quartzite rock. Grey areas = Cataclastic Archean igneous rocks, which crop out in the eastern slope and compose the crest area. The former one belongs to the Rautas Nappe-Complex, and the latter one forms the lower part of the Abisko Nappe.
Sandstone and shale of the autochthonous Hyolithus Series are exposed a short distance to the east of the figured section. From Kulling 1930.

The Abisko Nappe

As is the case with the Rautas Nappe-Complex the Abisko Nappe is composed of an upper sedimentary unit and a lower unit of Archean igneous rocks. The sediments are of middle metamorphic facies with a pronounced tectonic banding and are often called hard-schists. In the quartzose and slaty schists of the sequence yellowish white dolomite often appears as long lense-sharped bodies. The type of transverse deformation in the Abisko Nappe is exemplified in fig. 9. The metamorphism of the hard-schists, however, is always weaker than that of the superposed rocks of the Seve-köli Nappe. The Archean rocks of the Abisko Nappe are usually granite, syenite and fine-grained amphibolite (mostly in the western part of the Torneträsk area). Many other types of rock, partly of sedimentary origin, contribute to the lower part of the Nappe. Sometimes it is hard to keep apart metamorphic sediments connected to the Archean igneous rocks in the lower part of the Nappe from schists belonging to the hard-schist formation. The latter formation seems to be a metamorphic western facies of the quartzite-slate formation of the Rautas Nappe-Complex and like the latter is probably of Cambrian age.

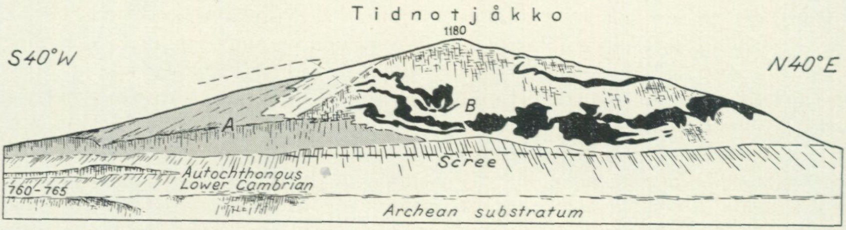

Fig. 9. Mt Tidnotjåkko from the southeast. The mountain constitutes the southeastern corner of the Caledonides north of Torneträsk. On the Archean granite substratum lies autochthonous Lower Cambrian sandstone and shale. Scree covers their upper part. The thrust-rocks of the mountain belong to the Abisko Nappe. A = Cataclastic Archean granite and syenite. B = Metamorphic, partly banded schists and quartzites with intercalated dolomite marble (black on the figure). The dolomite exemplifies the type of transverse deformation of the hard-schists of the Abisko Nappe. The dolomite folds are overturned to the northeast and torn into shreds. From Kulling 1930.

The Seve-köli Nappe

The three major constituents of this great nappe are mica-schist to garnet-mica-schist, amphibolite and marble, mostly calcite-marble. The distribution of the various rock units is clearly demonstrated on the geological map, fig. 5. On it and on the section across the Torneträsk area, fig. 6, it is apparent that the main amphibolite body lies stratigraphically connected with the marble formation in the lower part of the Seve-köli Nappe. Compared with the more southerly part of the Seve-köli Nappe, like those of Middle and Southern Lapland, the Torneträsk part of the nappe represents only the comparatively high-metamorphic lower part of the Seve-köli Nappe. However, such high-metamorphic members of the Seve-köli Nappe represented in more southerly parts of Lapland by migmatite, do not occur in the Torneträsk area, although zones with mica-gneiss and oligoclase-porphyroblast-gneiss are present in the lower part of the nappe.

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Introductory notes on the Giant-boulder deposit of Kärkevagge U-valley in the western part of the Torneträsk area

The Late-Glacial history of the Torneträsk area is treated mainly in two monographs, by O. Sjögren (1909) and by C. G. Holdar (1957). These two authors are representative for their time. Sjögren supports the idea, that the last land ice dwindled to nothing in the area to the east of the high mountains of Scandinavia. Holdar's argument is that the land ice receded towards the high mountains, where temperature and precipitation were sufficient to maintain a restricted glaciation, and he lays stress upon the presence of lateral drainage channels, deposits on some mountain slopes, formerly looked upon as strand-line deposits of Late-Glacial ice-dammed lakes. He finds evidence of his opinion in the fact that dead-ice fillings of the lower parts of the Torneträsk area slowly melted away. Thus, this disappearance of ice constituted the last stage of deglaciation.

Both Sjögren and Holdar discuss the giant-boulder deposits of Kärkevagge and the Late-Glacial history of the U-valley. Sjögren characterizes the boulder deposits of the valley, compare fig. 20, their nothern parts as end, lateral and medial moraines, and their southern and middle parts as mainly three giant end moraines. Holdar's opinion on the Kärkevagge U-valley is the following: During the initial glacial phase of Kärkevagge three glacier components must have contributed to its shape, namely the Kårsa glacier one km to the south of the southern corner of the valley, and two small mountain glaciers at the western side of the valley. His idea is also that during Late-Glacial time the three glacier components receded contemporaneously. According to Holdar, the giant-boulder deposits in the southern and middle part of the valley have been transported a very short distance on glacier ice or inclosed in it, and they have finally been gently deposited by the melting ice. On a sketch in his monograph (fig. 68), Holdar demonstrates his opinion on the transportation of giant-boulders on the shrinking Late-Glacial ice of Kärkevagge, the giant-boulders mainly supported from the upper part of the western scarp of the valley. As to the boulder ridges in the northern part of the mouth part of Kärkevagge Holdar mainly refers to the opinion of Sjögren and of other students of the deposits. This opinion supports the end moraine hypothesis for at least the northernmost of the moraine ridges. Holdar discusses the possibility that the other ridges of the area may be interpreted as "shear-plane moraine" ridges or as "Lehmmauern" ridges in the sence of P. Woldstedt. However, his conclusion is that such interpretations of the genesis of the deposits could not solve all problems connected with them. He finishes his discussion by saying that the habitus of the terraces, the eskers and other deposits of the area together with the direction of striae on outcropping bedrock point to great influence exerted on the deposits by a lateral lobe of the west directed Torne ice (of the Torneträsk—Vassijaure valley).

The present author's opinion is that the boulder ridges of the northern part of the Kärkevagge valley might be interpreted as a series of lateral moraine ridges of the shrinking Torne ice.

As to the giant-boulder deposit of the southern and middle parts of Kärkevagge the author's view is that, when the pressure of the land ice diminished and frost disrupture started in Late-Glacial time, old crevices widened in the outer zone and repeated boulder-slips, partly real mountain-slips occurred, specially from mountain-scarps in areas where the bedrock was rich in fissures. To the west of Lake Rissajaure at the southern corner of Kärkevagge, there is a marked big scar of the mountain scarp, compare fig. 20. The bedrock of this part of the mountain scarp is rich in crevices. Possibly an important part of the material of the giant-boulder deposit of the valley is derived from this scar. The boulder ridge across the valley on the threshold of Lake Rissajaure (compare fig. 23) is situated below the named scar and so to speak points to the scar.

The present author concludes these introductory notes by calling attention to the presence of a Post-Glacial big mountain-slip of the Torneträsk area situated about 35 km to the southeast of Kärkevagge, compare fig. 24. The outer margin of this slip lies about one km from its scar on the steep mountain slope. The boulders of the slip are of about the same shape and size as the ones of the Kärkevagge giant-boulder deposit. When inspecting this Post-Glacial slip the present author came to think of the Kärkevagge deposit. The similarities of structure of the two deposits strengthen his hypothesis of the mountain-slip origin of a greater part of the Kärkevagge deposit. The Late-Glacial ice of the valley took part in the re-arrangement of the slip-material. The Late- and Post-Glacial waters of the valley finally brought about the present state of the deposit.

Selected literature

SGU = Sveriges geologiska undersökning, Stockholm.

GFF = Geologiska föreningens förhandlingar, Stockholm.

Holdar, C. G. 1957: Deglaciationsförloppet i Torneträskområdet (Summary: The recession of land ice in the Torneträsk area) GFF. 79. pp. 291—528.

SJÖGREN, O. 1909: Geografiska och glacialgeologiska studier vid Torneträsk (Zusammenfassung 1909: Der Torneträsk. Morphologie und Glazialogie. GFF. 31) SGU. C. 219.

Introductory notes on the Caledonides of the Narvik-Ofoten area

Two modern solid rock maps, "Narvik" (Th. Vogt, 1950) and "Håfjellsmulden i Ofoten" (S. Foslie 1930), have been published from the Narvik--Ofoten area. The geological map "Narvik" covers the east part of the area, from the national boundary to Sweden in the east to the eastern part of Ofoten fiord in the west. The geological map "Håfjellsmulden i Ofoten" comprises the Håfjell syncline area to the south of the middle part of Ofoten fiord. The present author's general geological map of the middle part of the Narvik—Ofoten area, see fig. 25, is almost wholly based on the two above-named geological maps. As the present author's experience of the bedrock of the map-area is based only on observations performed during some days' stay there, he prefers not to draw the boundaries between the tectonic units of the area.

The eastern part of the Narvik—Ofoten area is composed of Archean bedrock, the northwestern Norwegian part of the Sjangeli-Rombak window. The Caledonian bedrock to the west of the window comprises broadly speaking "the Håfjell syncline" of S. Foslie. The substratum of Caledonian schists to the west of the syncline is composed of microcline granite-gneiss, the so-called "Bottom" igneous rock (bunn-granitt) of Norwegian geologists of supposed Archean age but with wholly Caledonian structure. These "bottom" igneous rocks have a wide distribution in the North Norwegian Nordland coast zone.

The Caledonian sequence of strata to the west of the Sjangeli-Rombak window is in many respects different from the one to the east of it. The Caledonian bedrock of the Torneträsk area on the whole corresponds only to the lower part of the bedrock of the Håfjell syncline. Also the mentioned sequences in the east and west differ from each other in some respects.

The "Basement conglomerate" of the map, fig. 25, may be looked upon as the western continuation of the Hyolithus Series of the Torneträsk area. In the "Basement conglomerate" formation there are arkosic conglomerates, arkosic quartzites and real quartzites. As the metamorphic alteration of the autochthonous sediments of the Torneträsk area increases from east to west, the Basement conglomerate formation to the west of the Sjangeli-Rombak window is slightly more metamorphic than the one immediately east of the window. Thus the Basement conglomerate beds are mica-schists with scattered biotite porphyroblasts. The Basement conglomerate beds are superposed by fine-grained sedimentary schists, constituting the lower part of the Rombak schist. According to Th. Vogt (1922) the Rombak schist is composed of a lower part, mainly biotite-schist, and an upper part, garnet-mica-schist. According to Vogt there is no tectonic boundary between them. This boundary occurs between the Rombak schist and the Basement conglomerate formation. Vogt's opinion is that the lower part of the Rombak schist corresponds to the so-called hardschist of the Torneträsk area. In the middle part of the Rombak schist a formation of thrusted Archean microcline granite occurs immediately to the north and to the south of Rombaksfiord but is wanting in other parts of the named zone. A thin quartzite formation is superposed on the granite to the north of the fiord. In a more northerly situated area the probable northern continuation of the quartzite formation lies on lower Rombak schist. Probably both the granite and the lense-formed bodies of quartzite are squeezed-out remains of formerly continuous formations. The author's opinion is that these formations, together with some adjacent metamorphic sediments of the lower part of the Rombak schist, represent the western continuation of the Abisko Nappe of the Torneträsk area.

The Rombak calcite marble, lying on the lower part of the Rombak schist, is the equivalent of the Calcite marble formation, constituting the lowermost part of the Seve-köli Nappe of the Torneträsk area. The Rombak calcite Formation increases in thickness to the north, and several intercalations of garnet-mica-schist occur in the calcite formation. Vogt on his "Narvik" map designates these intercalations of schist as Rombak schist. On the uppermost beds of the Rombak marble Formation lies the Narvik schist of Vogt. In the lower part of the Narvik schist there are several conformably intercalated amphibolite bodies. This lower Narvik schist with its amphibolite corresponds to the amphibolite and adjacent schist of the Seve-köli Nappe of the Torneträsk area. Thus, according to the present author the Rombak marble, the upper formations of the Rombak schist and at least the lower formations of the Narvik schist belong to the Seve-köli Nappe unit. A thin quartzite is noticed in the midst of this lower part of the Narvik schist.

The upper part of the Narvik schist of the Narvik—Ofoten area is composed mainly of injection gneiss with scattered larger and smaller bodies of trondhjemite and granite. Such rocks are not to be found in the upper part of the Seve-köli Nappe of the Torneträsk area.

In the injected upper Narvik schist may also be mentioned a continuous marble formation and an intermittent formation of sedimentary iron ore. Included in the schist in the area immediately southwest of the Narvik map area lies the big Raana norite body with some olivine rocks along its southwestern boundary, see the map, fig. 25.

To the west of the Raana norite field, in the Håfjell syncline area of S. Foslie, the injected schist with its marble formation and its sedimentary iron ore formation forms the lowermost unit. Foslie's name for the marble formation is the 'Melkedal limestone', and for the iron ore formation the 'Sjåfjellet iron ore Formation'. Foslie's stratigraphical sequence is from the Melkedal crystalline limestone upwards, the following No 1 to No 15. The thickness of the various formations are obtained from the least disturbed parts of the sequence south of the Ofoten fiord and are of interest for comparison purposes and as figures of giving the order of magnitude of thicknesses within the Caledonian geosyncline.

1.	30 m	The Melkedal limestone.
2.	400 »	Garnet-mica-schist with some pegmatite veins.
3.	10 »	The Sjåfjell iron ore.
4.	630 »	The Ballang schist-sequence. Garnet-mica-schists with several zones of bituminous schists, the Ballang schists, and some thick, basic igneous rock formations with intercalated microcline-rich gneiss, impregnated with Cu and pyrite ore material.
5.	20 »	The Elvenes conglomerate. At Elvenes its thickness is 75 m. The pebbles

are quartz-diorite, trondhjemite and quartzite rocks. The conglomerate formation is often called the conglomeratic, calciferous mica-schist. The Conglomerate formation divides the referred Håfjell sequence into a lower part of mica-schists with trondhjemite and granite intrusions, and an upper part without such intrusions, rich in marble formations.

6.	1 200 m	The Ballang limestone sequence. The major part of this sequence is calcite-marble. Four beds of dolomite-marble, a great many mica-schist beds, two quartzite beds and also thin amphibolite beds above and below the upper one of the two quartzite beds.
7.	270 »	Garnet-mica-schist.
8.	60 »	The Bö quartzite. In the west its thickness goes down to 25 m.
9.	630 »	Garnet-mica-schist.
10.	350 »	The Fuglevann limestone with intercalated mica-schist beds and in the schist two beds of sedimentary iron ore, the so-called Håfjell iron ore.
11.	850 »	Garnet-mica-schist with a thin marble bed in its middle part.
12.	170 »	The Hekkelstrand dolomite and limestone. The dolomite is a strongly dolomitic calcite-marble and lies in the upper part of the carbonate formation.
13.	100 »	Garnet-mica-schist.
14.	20 »	The Djupvik quartzite.
15.	400 »	Garnet-mica-schist with some thin calcite-marble beds. The schist is the uppermost formation of the Håfjell sequence to the south of Ofoten fiord.

The whole rock-sequence of the Håfjell syncline to the south of Ofot fiord from the Melkedal limestone upwards amounts to more than 5 000 (5 140) m in thickness. On the northern side of Ofot fiord the sequence of strata continues further upwards. On the above-mentioned Håfjell sequence lies injection gneiss and schist with granite intrusions, designated the Niingen schist by Th. Vogt. This uppermost high metamorphic unit is by all means a nappe, *the Niingen Nappe*, constituting the uppermost nappe of the North Scandinavian part of the Caledonides. The sequence of strata of the Håfjell area down to the base of the Narvik injection gneiss, *the Håfjell tectonic unit*, is by the present author looked upon as a northern part of his Rödingsfjäll Nappe, described from some parts of the national boundary zone of middle Lapland.

The Håfjell syncline to the south on Ofot fiord is very regular, with axes dipping northeast. As mentioned in the above stratigraphical table, the Håfjell area holds deposits of iron ore and of Cu and pyrite ores. Of the two formations of sedimentary iron ore the upper one, *the Håfjell iron ore*, is characterized by manganiferous zones, now mainly recrystallized to Mn-holding silicate rocks. The lower one or the Sjåfell iron ore formation lies about 3 000 m below the upper one and is practically free from Mn-holding zones, like the majority of other Caledonian sedimentary iron ore deposits in Northern Norway. Foslie's opinion is that the Sjåfell iron ore deposits at present are without practical interest. The Håfjell iron ore deposits, however, might hold valuable iron deposits. Of the Cu and pyrite ore deposits that of Björkåsen is the most well-known. Mining goes on at Björkåsen in the Ballangen area. The ore lies in the lower basic igneous rock formation of the Ballang schist sequence.

Thus, in the above remarks on the Caledonides of the Narvik—Ofoten area the present author has divided the bedrock into the following tectonic units, starting from below: 1. The Archean basement of the Sjangeli-Rombak window with some remnants of autochthonous sediments resting on it. 2. The western equivalent of the Abisko Nappe = banded lower Rombak schist and cataclastic Archean igneous rock and possibly the "Bottom" igneous rocks in the west. 3.

The western equivalent of the Seve-köli Nappe = the Rombak calcite marble, the upper part of the Rombak schist and the lower part of the Narvik schist with included amphibolite rock. 4. the bedrock of the Håfjell unit by the present author looked upon as a northern part of his Rödingsfjäll Nappe. 5. and as the uppermost tectonic unit the Niingen Nappe

After passing the big Sjangeli-Rombak anticline, the Seve-köli Nappe unit plunges to the west below the Håfjell unit and further to the west in the western part of the Ofot fiord area it has dwindled to nothing. The Seve-köli unit has apparently been torn from its root zone. The matter seems to be of great significance for the interpretation of the general structure of the Scandinavian Caledonides.

Selected literature.

NGU = Norges geologiska undersökelse, Oslo.

Foslie, S. 1949: Håfjellsmulden i Ofoten og dens sedimentaere jern-mangan-malmer (Summary: The Håfjell syncline in Ofoten and its sedimentary iron-manganese Ores). NGU 174. The geological map printed in 1930.

Vogt, Th. 1950: The geological map Narvik. Description wanted. NGU.

Route descriptions

First day (Aug. 7 and Aug. 27)

Excursion in the Kiruna iron ore field

Arrival in Kiruna in the afternoon. Bus to Kiirunavaara. Examination of the open-pit under guidance of the mine management. See the special paper on "The Kiruna iron ores" by Per Geijer. Evening free. Overnight stop in Kiruna.

Second day (Aug. 8 and Aug. 28)

Bus to Kojuvaara, where the boundary between Kiruna greenstone and Kurravara conglomerate is well exposed. In the greenstone pillow structure. In the conglomerate pebbles mainly of grey syenite porphyry with smaller number of epidote-altered porphyry, jaspilitic quartzite, greenstone, tuffite and iron ore. Layers poor in pebbles but sometimes with cross-bedding.

Bus to Sandstensberget. Quartzitic sandstone, belonging to the Vakko Series. Conglomeratic layers with pebbles of quartz-bearing porphyry and dark phyllite. Metamorphose of sandstone weak and clastic structure retained. Tension jointing.

If possible bus-visit to Luossavara summit. In clear weather fine view of the Caledonides in the west. Back to Kiruna. By train from Kiruna in the afternoon. Arrival at Abisko T. Stop at Abisko Tourist Station for four nights.

Third, fourth and fifth day (Aug. 9—11 and Aug. 29—31)

With regard to weather conditions the order of the three one-day tours from Abisko T, viz. the excursion to Luopakte, to Vakkejokk and to Kärkevagge, will be determined at the excursions.

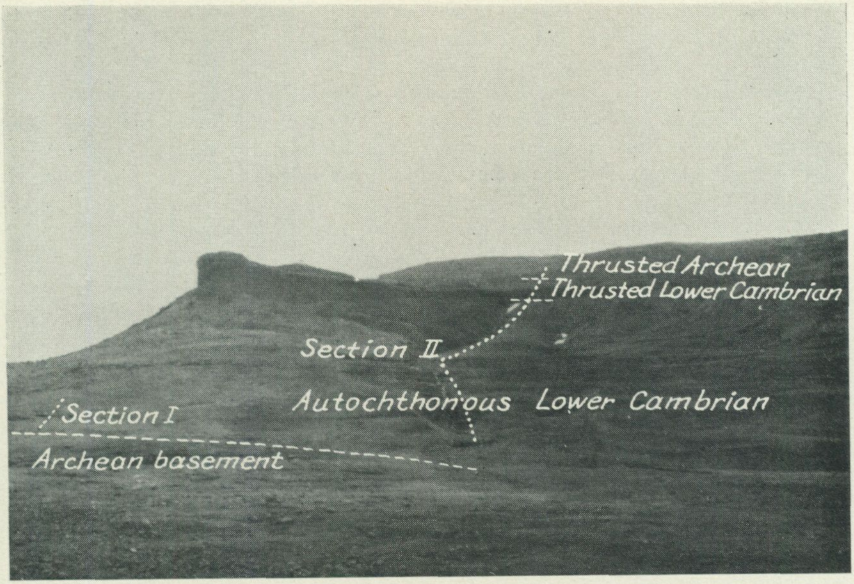

Fig. 10. The northern aspect of the northeastern part of Mt Luopakte with some geological boundaries and two sections located on it.

The Luopakte excursion

An early train takes us to Stenbacken, a railway station 64 km to the east of Abisko T. During the journey we get a good general view of the mountains to the north of Torneträsk and of the high mountains in the south.

Along a path, starting east of the Stenbacken station, we walk to the south up the birch-covered slope. After half an hour we arrive at the tree-limit, lying about 60 m higher than Stenbacken itself, or 445—450 m a. s. From here easy-walking mountain-heath prevails.

FIRST STOP: After 1 km to the SSW we stop and look around. One km to the south the characteristic northern aspect of Mt Luopakte appears and 6 km to the WNW Mt Kaisepakte.

On Mt Luopakte to the south, compare fig. 10, the visible crest lying above the scarp, is composed of Archean igneous rocks, granite to syenite, and by the present author referred to the lower part of his Rautas Nappe-Complex. The mountain scarp at the foot of the crest is composed of rocks belonging to the author's Luopakte Nappe. Grey and blue-grey quartzite are its leading sediments. Of secondary importance is slate with sparse limestone lenses with fossils. In the steep slope below the scarp schistose alum shale crops out, and this formation goes down to the base of the uppermost waterfall of the visible brook. From there and down to the base of outcrops along the brook the sediments of the so-called

Hyolithus Series are of primary character. In the lower part of Mt Luopakte's northeastern slope the Lower sandstone Formation of the Series and its Archean substratum of red syenite are exposed.

We can admire the scarp of thrust-rocks from Mt Luopakte towards the west and northwest up to Mt Kaisepakte. On the way both the above-named tectonic units have dwindled to almost nothing. The crest and the upper part of the scarp of Mt Kaisepakte are composed of crystalline schists of the Seve-köli Nappe.

A system of strand-line like Late-Glacial lateral drainage terraces on the eastern slope of Mt Kaisepakte is well visible.

Glancing to the north of Torneträsk we can see the high mountains of mica-schist and amphibolite of the Seve-köli Nappe. Below these we see the east-west running scarp, composed mostly of cataclastic Archean granite and syenite, by the present author referred to as the lower part of his Abisko Nappe. Only small remnants of the Rautas Nappe-Complex separate the Archean of the Abisko Nappe from the sediments of the Hyolithus Series, badly exposed in the birch-covered slopes below the named scarp.

We start again and walk about one km in a SSE direction to the base of the Hyolithus Series, well exposed in a little ledge in the lowermost part of the northeastern slope of Mt Luopakte.

SECOND STOP: The Archean substratum of the sediments is composed of deep-red syenite in the last paper of O. Ödman on the Archean of Norrbotten designated as a member of the Late-Orogenic Karelian intrusive rocks.

As pointed out in a preceding paragraph the Luopakte section was worked

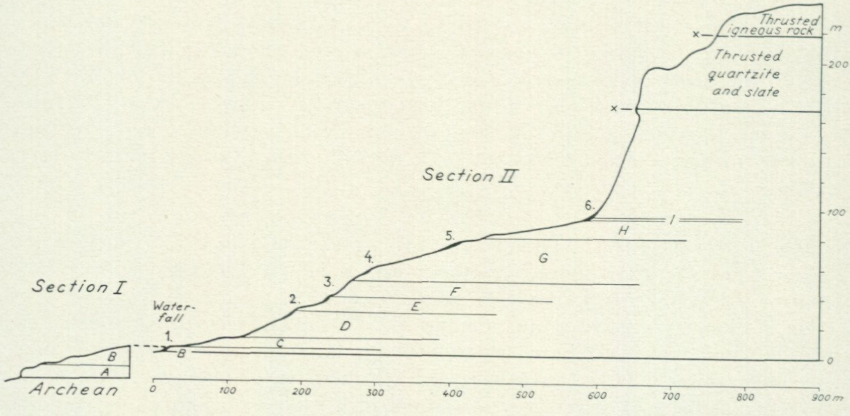

Fig. 11. The subdivision of section I—II of Mt Luopakte, compare fig. 10. A = the Lower sandstone. B = the Lower shale. C = the Middle sandstone. D = the Middle shale. E—F—G = the Upper sandstone. H—I = the Upper shale with bottom bed and top bed (I) included. J = Alum shale. Above the alum shale the Luopakte Nappe with quartzite and slate, and on these sediments the lowermost part of the Rautas-Nappe-Complex with Archean igneous rock, mainly granite and syenite.

out by J. Chr. Moberg some fifty years ago (1908) and is up to now the best known section through the Hyolithus Series of the Norrbotten Mountains. The locality, where we now find ourselves is, by Moberg and the present author, designated as the lower part of section no. I. On the syenite lies 0.2—0.3 m thick arkosic conglomerate. Some of its pebbles seem to be so to speak immersed in the syenite, pointing to a weathering in situ of the uppermost part of the syenite at the time of deposition of the pebble material. The Lower sandstone, *A* of the Mt Luopakte section, fig. 11, is 8 to 9 m thick and subdivided into several beds, the lowest of them is arkosic. We also notice beds of calcareous sandstone with current-bedding.

In order to obtain a continuous exposure across the following formations of the Hyolithus Series we turn to the west and advance some hundred m to the base of the exposure along the little brook, that descends from the crest of the scarp.

THIRD STOP: According to Moberg, the Lower shale formation, *B* on the section, on the Lower sandstone, is 11.7 m thick, somewhat phyllitic, with intercalated, thin layers and lenses of sandstone. Moberg's statement is based upon data from section I. The brook-section which is section II by Moberg and the present author, starts with the uppermost part of the Lower shale, compare fig. 11, and is composed of fine-grained, argillaceous sandstone and coarse shale. Moberg mentioned the occurrence of small, dark but shining strings like theca-free graptolites on the surface of the beds. Such fossils are not uncommon.

FOURTH STOP: We then ascend along the brook through the Middle sandstone, *C* on the section. The Middle sandstone is about 8.5 m thick. Moberg divides it into seven units, each unit with some special characteristics according to colour, bedding and grain-size. An argillaceous shale, one m thick, is intercalated in the upper part of the sandstone. In the uppermost part of the sandstone, "1.67 m thick", a somewhat conglomerate-like appearance is caused by the presence of small, angular fragments of shale, often with baryte crystals included. Scattered pebbles of rounded vein-quartz and more exceptionally small fragments of Archean granite are also met with at about the same level. This admixture in the sandstone points to a stronger influence from an adjacent shore and denotes a masked break in the sequence of strata. On the bedding planes of the Middle sandstone fossil-tracks are abundant. Mud-cracks occur. The boundary bed towards the superposed Middle shale is a dolomite sandstone of greenish grey colour, containing scattered phosphorite nodules. In a local erratic boulder of whitish grey sandstone with lenses and cakes of shale the present author har collected a *Monocraterion tentaculatum* Torell, the boulder probably emanating from a middle part of the Middle sandstone.

FIFTH STOP: We pass upwards to the next unit, to the Middle shale, *D* of the section. The shale is about 18 m thick, mainly of a reddish colour. Thin beds of greenish to greenish red colour occur. The lowermost bed of the shale, one m thick, is light green with sandy intercalations. Moberg has collected specimens of *Monocraterion* in such sandy beds. The middle shale is fossiliferous. Moberg mentions finds of *Platysolenites antiquissimus* Eichw. about 4.75 m above the bottom of the shales, and at an altitude of about 5 m a *Hyolithus* sp. The present author has collected a great many specimens of *P. antiquissimus* and also some specimens of *Volbortella tenuis* Schmidt. These two species are the zone-fossils of the second faunal zone from below of the Scandinavian Lower Cambrian. The shale with fossils of this faunal zone is the most wide-spread geological unit of the whole Hyolithus Series of Norrbotten and the first discovered fossils in the Series, namely the Svenonius' find of specimens of Hyolithes in 1883 at Mt Ramanvare immediately to the north of Lake Tjeggelvas, is from this "Hyolithus shale". From the same shale formation at the southern corner of Mt Tidnotjåkko on the northern side of Torneträsk the present author has collected a specimen of *Platysolenites lontowa* Öpik, known from the Lower Cambrian blue claystone at Kunda in Esthonia.

SIXTH STOP: We move up to the following Upper Sandstone sequence, divided by Moberg into eight formations. The present author has reduced the Sandstone sequence to three formations, E, F and G.

E. Greenish grey sandstone, 8.30 m. thick, thin-bedded, with thin intercalations of shale. Some calcareous beds are noticed.

F. Light yellowish grey, thick-bedded sandstone, 11.6 m thick, with sparse phosphorite nodules. In the lowest part of the sandstone cakes of shale and small pebbles of quartz are noticed.

G. Mostly grey to yellowish grey sandstone, about 28 m thick. Its upper part, about 5.5 m, is dark grey and "blue quartz"-like. The bedding-plane of the sandstone sequence is rich in structures, produced by organisms, as trails and burrows. Several such types of structures are discovered. Compare figs 12 and 13 as examples. In the sandstone series repeated beds with lenses and cakes of shale occur, also beds with coatings and seams of black claystone on the bedding planes. Beds with "Leopard-sandstone", brown-spotted sandstone, are also noticed.

SEVENTH STOP: We advance upwards to the lower part of the Upper shale, *H* and *I* on fig. 11.

H. Is composed of two formations, a partly conglomeratic dolomitic limestone, 0.7 m thick, and superposed on it a 15.5 m thick greenish shale formation, in its weathered parts of a somewhat dark-red colour. The dolomitic limestone is impure, with scattered phosphorite lenses and nodules. It is partly of stromatolitic structure. The pebbly conglomerate on the limestone has rounded and cake-formed pebbles of phosphorite, blue-grey quartzitic sandstone and some scattered fragments of Archean igneous rocks. The conglomerate thus registers the presence of an adjacent continental area and an interformational break in the sedimentation, followed by sedimentation of mud, spread out from the receding continental shore.

EIGHTH STOP: We ascend across the remaining part of the reddish shale to the base of the uppermost waterfall of the brook. Here Formation I crops out. It is composed of grey, thick-bedded and calcareous fossiliferous shale with a fauna of Zone with *Strenuella linnarssoni* Kiaer, the uppermost of the four

Figs. 12 and 13. Types of fossil-trails on the bedding-planes of the Upper sandstone of Mt Luopakte.

faunal Zones of the Lower Cambrian. The fossiliferous beds are 1.7 m thick. Its uppermost 0.15 m is almost an impure limestone. The most common fossil of formation I is *Ellipsocephalus Nordenskiöldi* Linrs., the zone fossil and *Obolus* sp. is also met with. — The beds of Formation I form the uppermost stratigraphical unit of wholly autochthonous beds in this area.

Above the formation with the fauna of uppermost Lower Cambrian lies schistose alum shale, J of the section on fig. 11. According to Moberg, the alum shale is about 72 m thick. The schistose structure in the lower examined part of the alum shale dips to the west. The schistosity of the beds and "mylonitic" zones in some lower part of the alum shale point to movements of the sequence of black shale. Thus the alum shale sequence may be looked upon as a parautochthonous unit. In the alum shales no traces of fossils have been discovered. Scattered nodules of pyrite but no stinkstone-lenses have been noticed.

As no time is left for visiting the thrust units of the area we return to Stenbacken station and take the train to Abisko T. Descending across the examined section we could make short stops at some localities for collecting re-inspecting purposes.

If the thrusted units above the alum shale sequence of Mt Luopakte the Luopakte Nappe, and the lower part of the Rautas Nappe-Complex, are to be inspected, it will be convenient for us to walk a short distance to the west up to the western part of the scarp of thrust-rocks above the alum shale and then without undue hard work, ascend to the mountain plateau above the northern scarp. Beside the named quartzite, the main constituent of the Luopakte Nappe is slate with some thin intercalated beds and lenses of fossiliferous limestone. At present it is somewhat uncertain whether igneous rocks form the basal part of the nappe at places or not. In a locality at the northeastern corner of the scarp the above-named representatives of the faunal Zone four of Lower Cambrian were discovered in 1950. Unfortunately no special paper on the fossil fauna has been published to date.

In the northeastern part of Mt Luopakte the Luopakte Nappe is about 50 m thick. The western extension of the nappe is little known and may not be discussed for the present.

The crest of the protruding northeastern part of Mt Luopakte is composed of cataclastic Archean granite and syenite, looked upon as the lower part of the Rautas Nappe-Complex. The upper part of the last-named Nappe-Complex, the banded quartzitic rock of the summit of Mt Luopakte lies too far away to be examined in connection with an excursion mainly devoted to the stratigraphy of the Hyolithus Series. The present author has no personal knowledge of the summit-rocks.

The Vakkejokk excursion

Our destination this day is the Vakkejokk area to the north of Torneträsk and about 15 km to the east of Abisko T. Our principal purpose is to examine the curious Vakkejokk breccia and other formations of the Hyolithus Series to the north of Torneträsk.

After an early breakfast we walk one km to the north, to the tourist station harbour. From there we go by tourist-boat to the mouth of Vakkejokk. During our journey, about one hour long, we can view the rocky mountains arond the lake.

To the west the Western Abisko high mountains rise as a huge block with an undulating crest. The mountain-block is dissected by deep U-valleys. The upper part of the Western Abisko high mountains is composed of flat-lying mica-schist and below the schist rests a formation of mainly calcite marble, the latter the lower part, and the former the upper part of the Seve-köli Nappe of the mountains.

To the south the Southern Abisko high mountains stick up as a collection of amphibolite peaks. The amphibolite with its intercalated and underlying mica-schist constitutes an eastern part of the Seve-köli Nappe of the Torneträsk area. To the north of Torneträsk the relationship between bedrock-composition and geomorphology is not so pronounced as on the other side of the lake, but is nevertheless to be found. Marble and mica-schist are the main constituents of the low mountains to the north of the western part of the lake. Amphibolite is the principal rock of Mt Vaivantjåkko and adjacent peaks in the east, thus immediately east of the day's excursion area around Vakkejokk.

To the west of Mt Vaivantjåkko the white rocks on the eastern slope of Mt Vakketjåkko are dolomite. Together with adjacent grey and black schists, the dolomite forms the upper part of the Abisko Nappe of the area. The lower part of the nappe and moreover the Archean substratum of the named sediments is visible from out on the lake, for instance at Vakkejokk, where the bedrock at the uppermost waterfall is composed of cataclastic Archean acid igneous rocks. Excursion members are to be guided up to the top of the fall. From this place the scarp of Archean rocks runs about 15 km to the ESE and E.

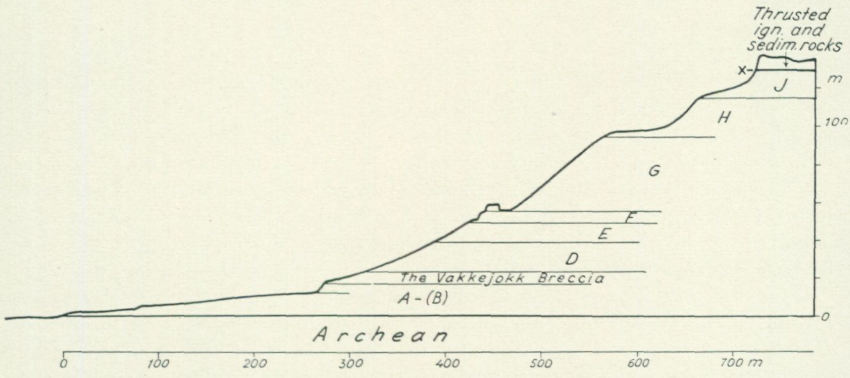

Fig. 14. Section across the Hyolithus Series along Vakkejokk to the north of Torneträsk. The subdivision of the Series is about the same as in the section at Mt Luopakte, compare fig. 11. A (—B) = the Lower sandstone, possibly with some remnants of the Lower shale. C = the Middle sandstone of Mt Luopakte is wanting. The Vakkejokk breccia of the section is only found as a well-defined formation to the north of Torneträsk. D = the Middle shale. E—F—G = the Upper sandstone. H = the Upper shale. J = Alum shale. Above the alum shale follow thrusted Archean igneous rock and sedimentary rock.

We arrive at the mouth of Vakkejokk and start southwards along the eastern side of the stream. On the whole the units of the Hyolithus Series to the north of Torneträsk are related to the ones on the southern side of the lake. However, several differences occur, the most pronounced of which is a continuous breccia formation included as a member of the sequence of strata to the north of Torneträsk, but wanting or almost wanting on the southern shore of the lake. Other differences of the stratification on both sides of the lake, exemplified by the Luopakte section and the Vakkejokk section, may be mentioned during our prolonged walk along Vakkejokk.

FIRST STOP: The Archean granite substratum of the Hyolithus Series crops out in the stream about 330 m from the stream-mouth. The granite is light grey and fine-grained. 50 m to the north the basal part of the Lower sandstone, *A,* is visible in a flat outcrop in the stream. Its granite substratum is to be seen only at extremely low water and then, only as a small ridge sticking up from below the basal sandstone bed. The sandstone is of an arkosic type and holds scattered pebbles of granite and quartz. In an exposure 5—6 km to the ESE a well developed basal conglomerate of the Lower sandstone is present. The section on fig. 14 starts at the base of the Lower sandstone and runs up to the waterfall mentioned above, including the thrusted Archean rock.

SECOND STOP: About 70 m further to the NE a new exposure of the sandstone starts, extending some 30 m to the NE, to a bend in the stream. The sandstone is blue-grey to grey, well stratified, thick-bedded, with coarse gritty beds in its upper part. A disconformity in the stratification is noticed on the western side of the stream.

THIRD STOP: There are no outcrops along the stream for the next 150 m, up to the base of a little waterfall. The upper half of the waterfall-wall is composed of the Vakkejokk breccia. Below the breccia, which is about 6 m thick, lies a sequence of arkosic sandstone, gritty sandstones and sandy shales. The boundary between the breccia and its substratum is undulating. The breccia seems to lie pseudoconformably on its substratum. The author has made a detailed survey of the breccia and its superposed and subjacent sedimentary formations from Vakkejokk and about 7 km to the ESE. During the whole distance the breccia appears as a body of somewhat varying thickness but always resting on the Lower sandstone, *A,* and upwards followed by the Middle shale, *D.* Scattered sections across the Hyolithus Series east of the detailed mapped area show the presence of the breccia another 7 km away, always with the same position in the sedimentary sequence. However, the boundary against the substratum of the breccia is sometimes very uneven, compare fig. 17. Unfortunately, the boundary between the breccia and the overlying sediments is seldom exposed.

The breccia itself is of a very peculiar composition and shows a series of different types. Its main component is Archean granite of about the same type as the granite of the substratum of the Hyolithus Series to the north of Torneträsk. Next to the Archean crystalline components of the breccia are sandstone and shale, the latter often furthermore forming the matrix of some types of breccia. In other types both the angular boulders and their matrix are of granite material. Such breccia may also be found as boulders in breccia with shale matrix. Rounded granite boulders inclosed in pure or almost pure shale form another type of the breccia. This unit in its turn may be enclosed in breccia of a more common type. Scattered big boulders of Archean rocks in the breccia seem to be in a state of just slipping apart at the very moment of becoming fixed in their breccia milieu. Such a situation is visible in outcrops in the stream bed at low water. In order to widen our knowledge of the structure and behaviour of the breccia complex, three sketches and two photos, all from the area to the east of Vakkejokk, have been reproduced. Compare figs. 15—19. Fig. 15 demonstrates the boundary between a tillite-like type of breccia and its substratum of well-bedded sandstone. Fig. 16 is a sketch of the boundary zone between a brecciated and a non-brecciated part of the Vakkejokk unit, composed exclusively of fine-grained Archean granite. Fig. 17. At the locality about eight km to the east of Vakkejokk the typical breccia is very thin, only about one m thick, and shows a peculiar, interfingering contact with its substratum of sandstone. The shale with included boulders situated on the real breccia may or may

Fig. 15. The picture shows the Vakkejokk breccia lying on well-stratified sandstone. The material in the breccia is mainly fine-grained granite of Archean age. From the area to the east of Vakkejokk.

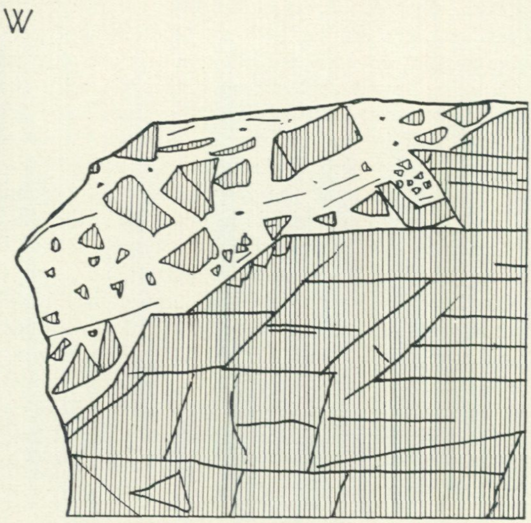

Fig. 16. Sketch of the boundary zone between a well-developed breccia part and a non-brecciated part of the Vakkejokk breccia composed of fine-grained Archean granite. The figured wall is 3 m high. From a locality about 1/2 km east of Vakkejokk. From Kulling 1930.

not be included in the Vakkejokk breccia sensu stricto. Fig. 18 shows a facies of the breccia, where boulders of granite lie included in crumpled shale. Fig. 19 demonstrates the boundary zone between typical Vakkejokk breccia and a folded upper part of the subjacent sandstone. At other localities of the breccia big isoclinal-folded units of sandstone are involved in the breccia and form integrating parts of it. Last but not least it must be mentioned that hundreds of

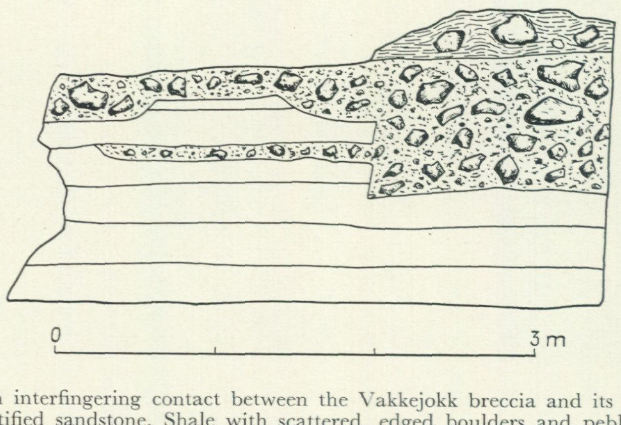

Fig. 17. An interfingering contact between the Vakkejokk breccia and its substratum of well-stratified sandstone. Shale with scattered, edged boulders and pebbles lies on the well-defined breccia. About eight km to the east of Vakkejokk.

Fig. 18. The Vakkejokk breccia. Small to large boulders of fine-grained Archean granite lie involved in shale. From the area to the east of Vakkejokk.

meter long units of slightly brecciated granite occur in the breccia, i. e. as the lower part of the breccia formation and on its substratum of sandstone.

In 1930, during a stay at Vakkejokk, the present author discovered the breccia and proposed a tectonic origin for it. He noticed that the breccia at a locality about half a km ESE of the breccia-outcrop at the stream shows the boundary conditions, demonstrated in fig. 16, to the subjacent, somewhat cracked Archean granite. However, subsequent examination demonstrates that this "basement granite" does not belong to the autochthonous basement Archean of the area but lies on the Lower sandstone. This "basement granite" thus constitutes the lowermost part of the breccia formation. After geological mapping of the area to the north of Torneträsk in 1951 and 1952 the author could verify that the Vakkejokk breccia behaves as a formation, almost conformably intercalated between the Lower sandstone and the Middle shale of the Hyolithus Series, in this position running more than fourteen km to the east.

According to the present author's experience of structures of thrusted units in the Lapland Mountains no nappe shows such structures as are met with in the Vakkejokk breccia now demonstrated in the field with figures and elucidatory comments. The thrusted units sometimes have been intricated in a most complicated way as has been exemplified in fig. 8 but no tillite-like breccia, extending for several km like a conformable formation has been met with in other Mountain areas. The author has visited no section of the Vakkejokk breccia where

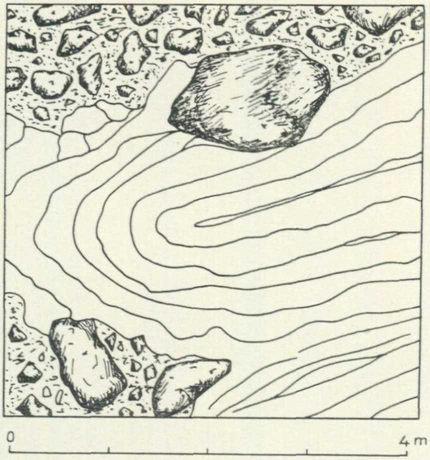

Fig. 19. The Vakkejokk breccia. Sketch of the boundary zone between the breccia and folded sandstone. Downwards the folded sandstone goes over into flat-lying sandstone. From the area to the east of Vakkejokk.

the rocks at its lower boundary show tectonisation, and no material of the breccia is cataclastic. Several types of the Vakkejokk breccia are tillite-like. However, taken as a whole the breccia formation is different in material and structure from any normal tillite formation of ground-moraine character.

The old Archean land-surface on which the Lower sandstone formation of the Hyolithus Series was deposited, was in all probability base-levelled and of peneplain-type. During the subsequent stage of geosynclinal evolution it is possible that the adjacent geanticlinal zone also became more pronounced and upheaval of land occurred. From the slopes of such an area we may suppose a disastrous combination of rockslide and mudrush. Thus both the cracked uppermost part of the Archean bedrock and the sedimentary deposits on it may have been thrown down into the adjacent, low-lying parts of the geosynclinal border area, in its rush incorporating weak sediments, i. e. the upper part of the previously deposited Hyolithus Series.

From the preceding general introduction it is clear that the Vakkejokk breccia problem must be the object of further examination and debate. The problem is hard to solve by wholly actualistic lines.

In this connection the author may call attention to a fact, mentioned during the Luopakte excursion. For scattered, small, sharp-edged fragments of Archean granite have been noticed in the upper part of the Middle sandstone formation (subjacent to the Middle shale formation). These lie at the very place in the stratigraphical sequence of the Luopakte area where traces of the Vakkejokk breccia are to be supposed.

Another fact may be mentioned. Breccia-rocks, interpreted as tillite, have been discovered at a great many localities in the Hyolithus Series of the Norrbotten Mountains. They are situated at the base or in the lowermost part of the Series. The present author has named them the Sito tillite and supposed them to be equal in age with the Långmarkberg tillite Formation in southern Lapland and northern Jämtland. This Långmarkberg Formation is deposited on the Sparagmite arkose Formation and followed by the Ström quartzite Formation. The Långmarkberg tillite Formation shows every sign of a glacial origin with the presence of ice-scratched boulders and pebbles and varved shale with erratics. In the Sito Formation, however, no ice-scratched material has been found up to date. The material of all the examined occurrences of the Sito Formation shows a composition of somewhat monotonous character, pointing to comparatively short transportation of the debris. In some of the examined occurrences of the Sito Formation the tillite-like rocks are separated from their Archean substratum by an arkosic sandstone bed.

FOURTH STOP: The boundary between the Vakkejokk breccia and its superposed formation of red and greenish grey shale is covered by debris. This Middle shale Formation, *D* on the section of fig. 14, is in most respects comparable with the shale formation *D* of the Luopakte section on fig. 11. The two shale formations have the same stratigraphical position. The lowermost part of the above-named shale at Vakkejokk lies on a level 0.8 m higher than the top of the uppermost part of the Vakkejokk breccia and 15 m to the north of it. No fossils have been collected from the shale at the stream. However, in more easterly situated exposures of the shale fossils, representing the Lower Cambrian Zone two, Zone with *Volbortella* and *Platysolenites,* have been obtained. Among other fossils the *Platysolenites lontowa* Öpik may be mentioned. The shale formation is about 17 m thick. The upper part of the formation is silty, with a thin dolomite bed in its uppermost part, visible at the stream only at low water. We ascend further along the eastern branch of the stream across the *E-Unit* on fig. 14. The lower part of Unit E is mainly siltstone, the upper part of it is a grey sandstone with some silty beds. E is 10—11 m thick.

FIFTH STOP: Superposed on the grey sandstone lies a formation of light-grey, coarse-bedded sandstone about 6 m thick, F on fig. 14. In its lowermost part the sandstone holds small cakes and fragments of shale and pebbles of grey to dark-grey sandstone. Beds of current-bedded calcareous sandstone occur. Ripple marks and other markings are common on the beds of the sandstone formation.

SIXTH STOP: Ascending to the top of the sandstone formation, we notice that the following formation, G on fig. 14, starts with a thin phosphorite conglomerate, well exposed at the base of a little, cube-shaped rock in the course of the stream, see fig. 14. Above the phosphorite conglomerate lies black siltstone, black shale and dark coloured sandstone in alternating beds. Upwards this sediment grades into grey and blueish grey sandstone, partly coarse-bedded. However, available good exposures are wanting in the steep slope along the stream. The difference of altitude between the base and the top of unit G is 40 m. As the sediments are folded, well demonstrated in the walls of the stream course, the real thickness of the unit is considerably less than 40 m.

SEVENTH STOP: Available good exposures of the following sedimentary unit are sparse along the stream. So we do not stop on the steep slope but ascend to the base of the little scarp, where the thrusted Archean rocks are superposed on a sedimentary substratum of alum shale. During our way up to the scarp local debris and scattered outcrops exemplify the composition of the bedrock. The lowest m of Unit H is composed of fine-grained sandstone with thin intercalations of dolomitic limestone. In some local boulders the present author has collected carbonate rocks with stromatolite structure. On the mentioned basal beds rests a thin bed of calcareous conglomerate with small pebbles and fragments mainly composed of sandstone. The upper and major part of Unit H is formed of dark-grey to blackish silstone with beds of sandstone and shale. The whole sequence of H is about 20 m thick. The alum shale, the Unit J, superposed on Unit H, is schistose and about 15 m thick.

From the bottom bed of the sedimentary sequence up to the top of the schistose alum shale the difference in altitude is 128 m. However, during our walk along the stream section we have noticed that the sequence of strata is folded and that the real thickness of every formation is hard to fix. However, the figures of the description give us an idea of the magnitude of thickness of the various units of the Vakkejokk section.

EIGHTH STOP: The little platform above the alum shale is composed of cataclastic igneous rocks of Archean age. We climb to the crest of the platform. According to the present author the thrust rocks belong to the lower part of the Abisko Nappe. To the east, quartzite and slate of the Rautas Complex type occur below the Archean of the Abisko Nappe. At Vakkejokk, however, the rocks of the Rautas Nappe-Complex have dwindled out. In the stream course to the west of the plateau, above the head of the two-step waterfall we notice that the thrust-rocks are composed of cataclastic, salic igneous rock, as well as metamorphic and strongly deformed dark-grey dolomitic limestone, greenstone and quartzite. There is a possibility that the whole of this rock assemblage is of Archean age.

From the flat of the plateau there is a fine view of the mountain landscape to the south of Torneträsk. With the geological map of the Torneträsk area to hand it is easy to get a general view on the main features of the geology and the topography of the various mountain areas south of the lake.

From the outlook plateau we descend to the mouth of Vakkejokk and go back to Abisko T by the tourist boat.

Some guiding words may be added for those who would like to ascend further along the stream. During the first 300—400 m up the stream ravine the bedrock is formed by dolomitic limestone, carbonaceous schist, quartzitic schist and greenstone. The next 600 m to the north — up to a bend of the stream — banded quartzite and schist with some lenses of greenstone crop out along the stream course. From the named bend it is advisable to follow a tributary to the north about 500 m, passing across quartzitic schist, greenstone, gneisose rocks of varying composition, graywacke conglomerate-like rock, porphyritic rock etc, up to some outcrops of cataclastic, salic igneous rock. This salic rock represents the uppemost exposure of the metamorphic sequence of thrust-rocks of the tributary area, referred by the author to his Abisko Nappe. The next outcrop lies about 300 m up the tributary and its calcite marble, mica-schist and amphibolite represent the lowest part of the Seve-köli Nappe. Compare the geological map, fig. 5.

Our main purpose this day is to examine the Giant-boulder deposit of Kärkevagge U-valley. Our second purpose is to examine the bedrock of this part of the Western Abisko high mountains.

From Abisko T by train to L å k t a t j å k k a h a l t. The railway-journey lasts one hour. The train runs at first to the northwest along the steep but debris-covered slope of Mt Nuolja. To the north of Björkliden station blue-black fine-grained marble of the lower part of the Seve-köli Nappe is exposed in railway-cuttings. We soon turn to the west and run across banded quartzite, schist and dolomite. Similar rocks around Abisko T are referred by the present author to his Abisko Nappe. To the west of Tornehamn halt whitish dolomite is exposed along the railway. During our continued trip we can watch the flat vaulted Archean of the Kuokel window. We may also notice the east-west running chain of lakes, situated along the boundary zone between the Archean substratum and the bedrock of the Caledonian Chain. In the upper part of the steep slope to the south of Kopparåsen station the marble formation of the area crops out as a scarp. Further to the west the railway crosses the Archean basement rock, which is composed of "Vassijaure granite", gneissose rock, volcanics, and mica-schist.

We arrive at Låktatjåkka halt and walk towards the SSW and south along the eastern side of Kärkevagge, see the sketch-map, fig. 20, up to Lake Rissajaure at the southern corner of the valley. This lake lies about 350 m higher than the railway at Låktatjåkka halt.

During our first km the rock of the outcrops is Archean gneiss with their structure dipping steeply WNW.

FIRST STOP: After passing the unexposed boundary between the Archean basement and the Lower sandstone of the Hyolithus Series, we arrive at an exposure of the sandstone, the base of which lies about 133 m higher than Låktatjåkka halt. The lower part of the sandstone is arkosic, with a conglomeratic bottom bed. Above the sandstone formation lie thrusted schists. One hundred m to the south of the sandstone ledge we come across an outcrop of banded schist, exceptionally with small lense-formed inclusions of Archean granite. The banded schist formation is about one hundred m thick and by the present author referred to his Abisko Nappe. However, we have no time to visit the upper part of the banded schist formation or the sequence of marble, black schist, garnet-mica-schist and other representatives of the Seve-köli Nappe unit that compose the uppermost part of the steep slope and the scarp of Mt. Kärketjårro in the southeast.

SECOND STOP: After walking another km to the south along the mountain slope we may stop and look out over the deposits of Kärkevagge. To the northwest we can see the boulder ridges of the mouth of the valley and to the west and southwest the giant-boulder deposit of the valley. One of the largest boulders, inspected by the present author, is demonstrated in fig. 21.

During our further walk along the valley slope we may study the structure of the deposit and the composition of the boulder material.

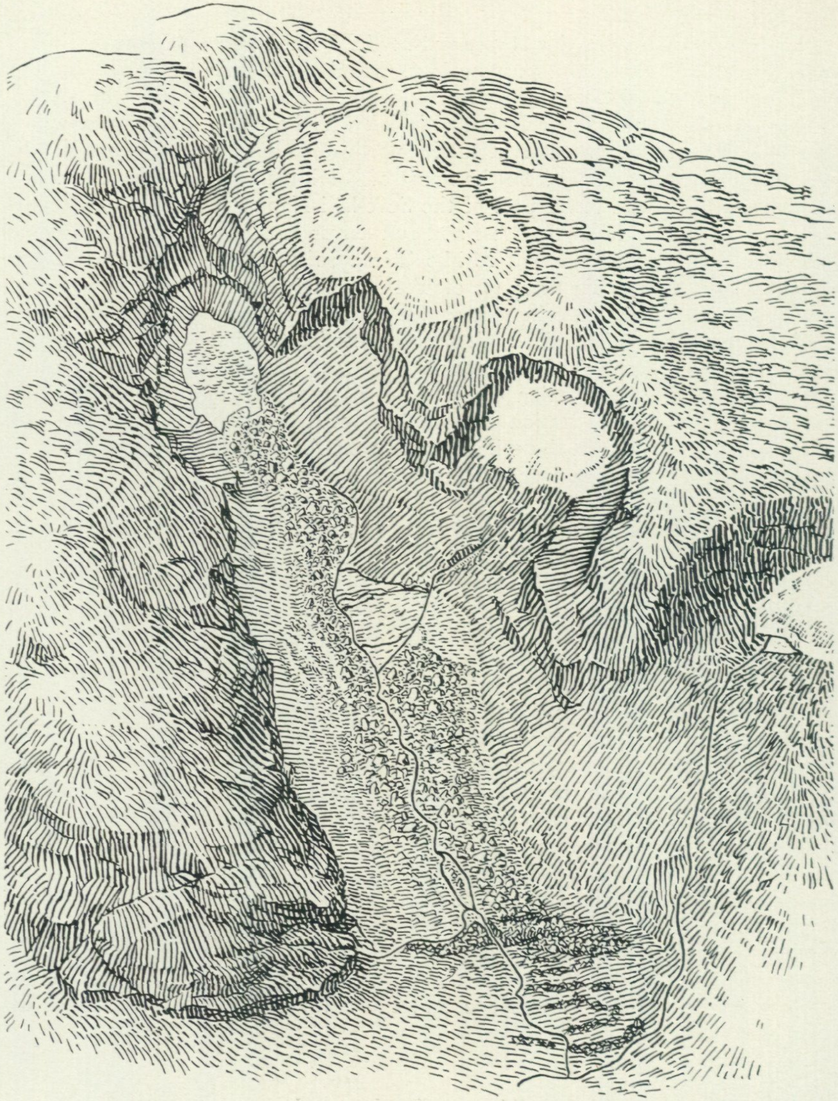

Fig. 20. Kärkevagge seen from the north. The mouth of the U-valley is crossed by a series of moraine- and boulder-ridges. To the north of these ridges and down to the railway there are glacifluvial deposits. From the southernmost ridge the giant-boulder deposit of the valley extends up to Lake Rissajaure, situated at the southern corner of Kärkevagge. Two small cirques with retreating glaciers are seen at the eastern scarp of Mt Vassitjåkko, the mountains to the west of the valley. A snowfield lies above the scarp of southeastern Vassitjåkko. Below the snowfield and to the west of Rissajaure a big scar in the mountain wall is seen. The present author's view is, that a great deal of the material of the giant-boulder deposit of the valley is derived from the scar-part of the mountain-scarp by means of a series of mountain-slips probably during Late-Glacial time, during the time of melting of the ice. The picture from Holdar 1957.

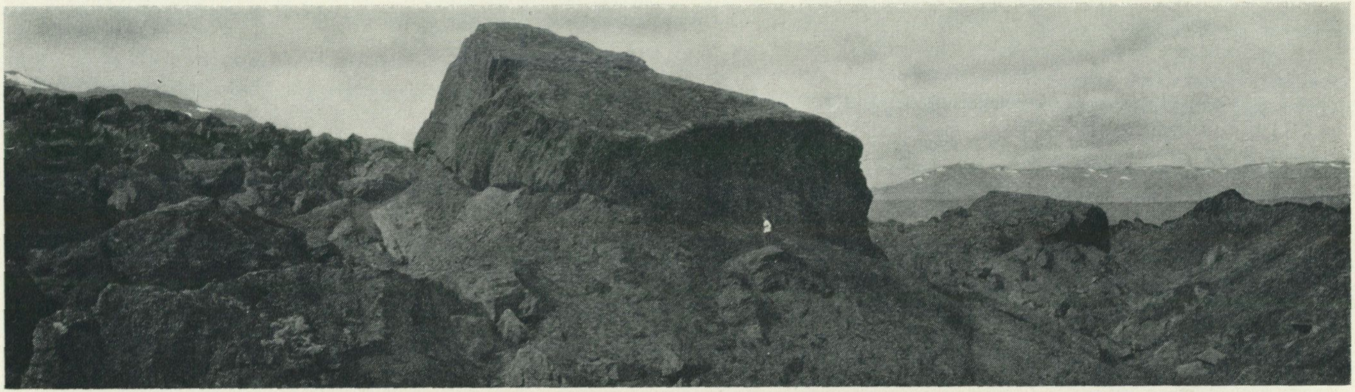

Fig. 21. Picture from the northwestern part of the Kärkevagge giant-boulder deposit. Looking to the north from about 4 1/2 km to the NNW of Rissajaure and a few hundred m to the west of Rissajokk. The giant-boulder behind the man is composed of garne-mica-schist and belongs to one of the largest inspected by the author.

Fig. 22. Picture from the southeastern part of the Kärkevagge giant-boulder deposit about one km to the NNW of Lake Rissajaure. Looking NNW. All the boulders are composed of garnet-mica-schist.

THIRD STOP: After about one km we stop again and look at the deposit of the valley and at the mountain sides of the U-valley. To the southwest we see a little glacier cirque at the western side of the valley. A melting glacier occupies the inner part of the cirque.

FOURTH STOP: We continue southward and arrive after 1 1/2 km at L a k e R i s s a j a u r e passing the part of the boulder deposit from which the picture, fig. 22, is taken. On the northern shore of Lake Rissajaure lies a giant-boulder accumulation. A view of the boulder ridge from the ESE is reproduced in fig. 23. The upper part of the scarps around the lake is composed of the Seve-köli Nappe unit. The lower part of these and the bottom of the valley are formed of rocks belonging to the Abisko Nappe. In the mountain-scarp of the western side of the lake we see the big scar, from which repeated mountain-slips are supposed to have been generated on a large scale contributing to the giant-boulder deposit of the valley.

From another part of the Torneträsk area the author has pictured a Post-Glacial mountain-slip, fig. 24, in magnitude probably comparable with one of the slips in Kärkevagge. Compare latter part of introductory notes.

Lake Rissajaure is 34 m deep. Its water is extremely clear. The fauna and the flora of the lake are very poor. After the visit to Lake Rissajaure we walk back to Låktatjåkka halt and go by train to Abisko T.

S i x t h d a y (Aug. 12th and Sept. 1st).

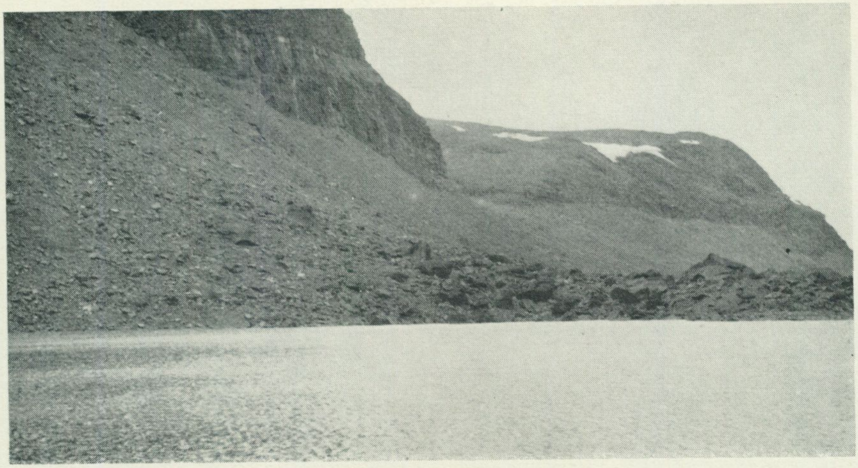

Fig. 23. The boulder-accumulation on the northern shore of Lake Rissajaure. According to Holdar the accumulation is about 15 m thick and lies on the bedrock-threshold of the lake. Holdar's opinion is that the scar area to the west of the lake has furnished material to the moraine-ridge on the northern shore of Rissajaure.

The Narvik—Ofoten excursion

Our main purpose this day is to get a general view on the western part of the North Scandinavian Caledonides along the southern shore of Ofot fiord. Compare fig. 25. By an early train from Abisko T to Narvik at the Ofot fiord. The train-journey lasts about two hours and runs at first the same way as before to Låktatjåkka halt. From immediately west of the halt to Vassijaure railway-station the train crosses a north-south trending, downfolded part of Caledonian rocks in the Archean substratum. Thus the Lower sandstone of the Hyolithus Series with its coarse basal beds is exposed in the vicinity of the railway-station. Further west, the train runs across the Archean Vassijaure granite (its Norwegian name is Rombak granite), crosses the national boundary in a pass and after some km to the west runs along the eastern slope of a narrow valley to the southwest and south for about six km. The bedrock of the area is mainly an Archean syenite, the Hundalen syenite. However, during its journey the train has crossed a string of sandstone and conglomerate, a western, somewhat metamorphic facies of the lowest part of the Hyolithus Series, downfolded into the syenite. Southeast of Katterat station the railway line turns west and runs along the southern slope of the valley of the west flowing river Rombakselven. It then proceeds along the southern slope of Rombaksbotn-Rombakken fiord down to Narvik. The boundary between the Archean basement rocks, the western part of which is composed of schist and biotite-quartzite of Bottnian Age, and the Caledonides runs immediately to the west of the mouth of Rombaksbotn in Rombakken, where a thin formation of "Basement conglomerate" occurs between the Archean and the thrust-rocks of the Caledonides.

Our journey continues across the thrusted rock units of the Caledonides to Narvik. See introductory notes to this excursion.

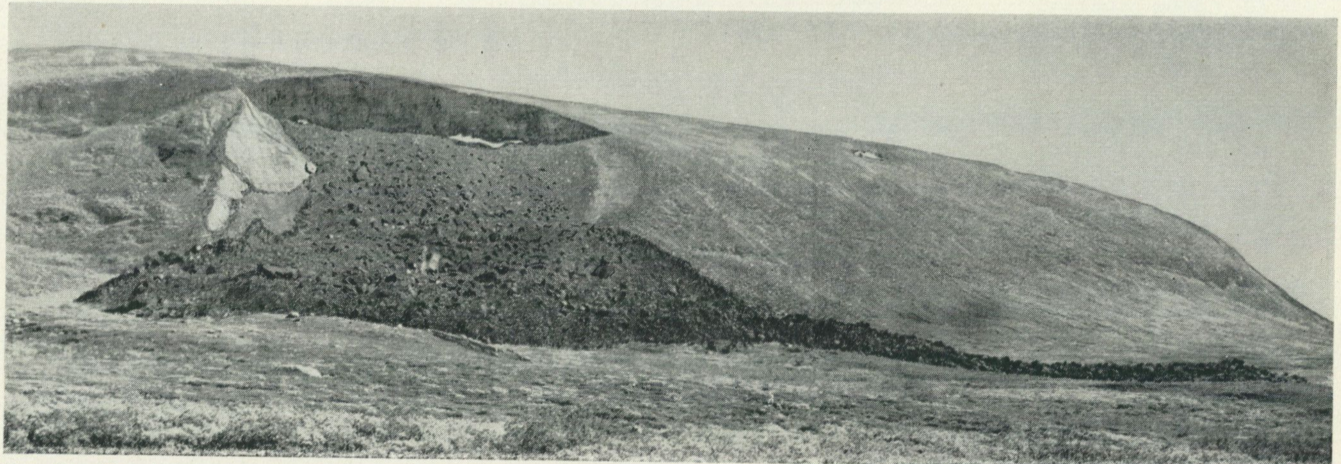

Fig. 24. The lightly retouched picture shows a Post-Glacial mountain-slip from the southeastern part of the Torneträsk area, and situated about four km to the north of the northwestern corner of Lake Rautasjaure and on the western slope of Mt Vidjavare. The scar in the mountain slope is about 1/2 km in lenght. The slip has advanced to about one km from the scarp. The biggest boulders of the slip exceed 50 m:s in length and are thus comparable in magnitude with the bigger ones of the Kärkevagge giant-boulder deposit.

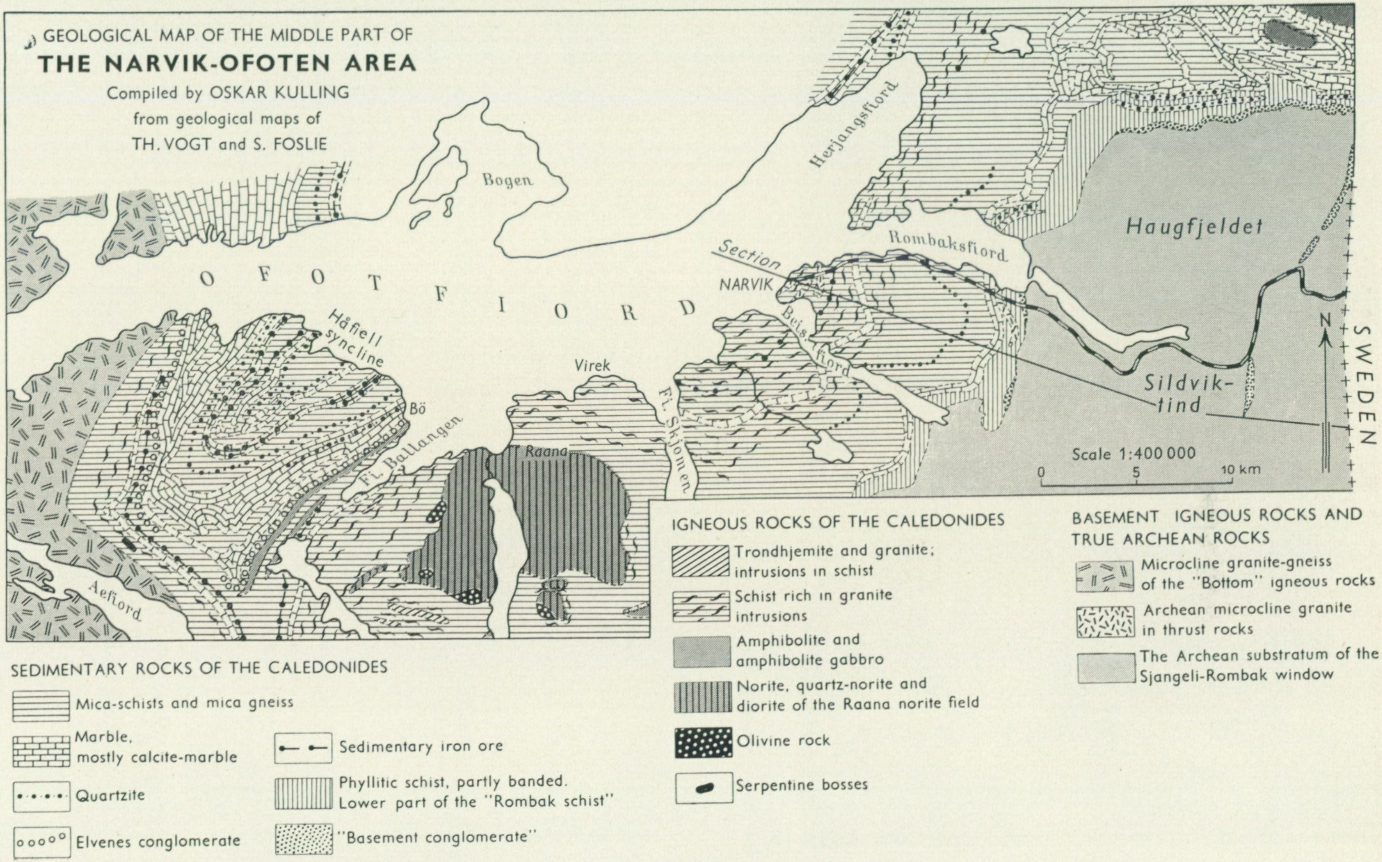

Fig. 25. Section, see Fig. 6

Fig. 26. A picture from the injection gneiss-development of "the Narvik schist". Part of the exposure opposite the Narvik railway-station.
White trondhjemite pegmatite in garnet-amphibole-mica-schist with the pegmatite irregularly folded and pulled apart, demonstrating the state of tectonisation of the rocks.

The town of Narvik lies on the eastern shore of Ofot fiord at the western corner of the peninsula between Rombakken fiord and Beis fiord. The bedrock on which the town stands belongs to the upper part of the so-called Narvik schist and is composed of injection gneiss.

FIRST STOP: After our arrival at Narvik we immediately inspect the schist in an exposure opposite the railway-station, where garnet-amphibole-mica-schist interwoven by white trondhjemite, irregularely folded, is demonstrated. Compare fig. 26.

SECOND STOP. We enter a bus and start for the "LKAB" iron-ore loading-wharf. — Immediately to the west of the railway-station we pause a moment and look at a cutting where a broad sill of microcline-holding granite in garnet-mica-schist milieu is well-exposed.

THIRD STOP. We then go to the loading-wharf, to be conducted round by a member of the resident staff.

Via the wharf ten millions tons (metric) of iron ore are exported to foreign countries each year. The iron ore comes from the Kiruna ore field in N. Sweden. The ore is first emptied into a big central container with ore-crusher. After crushing, the ore is distributed by means of a system of conveyers to stock-

Fig. 27. A picture from the injection gneiss part of "the Narvik schist". Road-cutting to the north of the custom-house on the highway through the sourthern part of Narvik. Dykes and lenses of greyish white microcline-bearing granite which cut across the garnetiferous mica-gneiss of the area.

piles. From the stock the ore is taken by automatic grabs which deposit it on conveyors that carry it to the New wharf and down into the ships' holds. At the New loading-wharf, or more exactly the loading-mole that protrudes into the fiord, two ships can be loaded at the same time. One of the ships can be up to 25 000 metric ton. The loading capacity is 4 000 metric tons an hour. Weighing and proof sticking are automatic.

After breakfast we enter our bus and follow the coastal highway along the southern shore of Ofot fiord towards the southwest and west, passing Ankenes, crossing the entrance of Skjomen fiord by ferry, then passing Raana, Ballangen, Bö, Kjeldbotn and arrive at Porsöen, where the highway ends about 90 km from Narvik. Back to Narvik the same way.

On leaving Narvik we notice good cuttings in injection gneiss and schist with dykes and lense-formed bodies of trondhjemite and granite, e. g. north of the custom-house in the southern part of Narvik, compare fig. 27.

Fig. 28. Road-cutting, showing the injection-gneiss of the Ankenes area. At the highway immediately to the southwest of the bridge across Beis fiord.

FOURTH STOP. Immediately to the southwest of the bridge across Beis fiord we stop and look at the injection-gneiss type of Ankenes area, compare fig. 28.

During our way to Ballangen we pass a great many fine cuttings of the various types of rocks of the injection gneiss.

FIFTH STOP. We stop about half a km to the west of Emmenes and examine the behaviour of the trondhjemitic pegmatite bodies in the injection gneiss complex.

A ferry takes us across the entrance of Skjomen fiord.

SIXTH STOP. We then stop in the Raana norite field, to the west of Raana and half a km to the west of the minor road to Råndal. We here examine the norite of the northernmost part of the Raana norite field. According to the description by Foslie to sheet "Tysfiord" the ultrabasic association beside norite is quartz-norite, diorite and peridotite. The norite seems to be intruded into the lowest part of the schists, now in the state of injection gneiss.

SEVENTH STOP: We pass Ballangen and stop southeast of Lake Saltvand, about three km northeast of the community, where "the Elvenes conglomerate", Unit 5 of Foslie's stratigraphical table, is exposed to the northeast of the farm Brenna. The conglomerate is bounded below by amphibolite and above by calcite marble. The conglomerate is an important guide formation being the only coarse sedimentary formation of the whole Håfjell area. The pebbles of the conglomerate are composed of quartz diorite, trondhjemite and quartzite. Foslie followed up the conglomerate for some 25 km, and stated that the pebble material is always the same. At Elvenes, about 25 km to the soutwest of the Brenna locality, the conglomerate is about 75 m thick. Foslie often characterizes the conglomerate as a conglomeratic calciferous mica-schist. — In this connection the present author may mention a conglomerate formation with wide distribution in the middle part of the low metamorphic facies of the Seveköli Nappe. This last-named conglomerate, the polymict Gilliks conglomerate of the Gilliks Series, is rich in pebbles of albite granite, Na-keratophyre and sedimentary rocks but has no material with K-felspar. The fossiliferous Gilliks conglomerate on the national boundary zone of the Southern Norrbotten Mountains, in the Ikisjaure-Mavasjaure area, is a calciferous schist with scattered pebbles with the above-mentioned characters and with fossiliferous lenses with tabulate corals such as *Halysites*, *Columnaria*-like fossils, fragments of pelmatozoa etc. The age of the conglomerate is almost certainly Uppermost Caradoc or Lowermost Ashgill. Compare the preceding paragraph on the Caledonides of Swedish Lapland. If this supposition holds good, then the Bö quartzite (of stop 9) is to be correlated with the Vojtja quartzite and quartzite conglomerate, lying as the basal formation of the Slätdal-Vojtja Series, and superposed on the Gilliks Series. Further conclusions will not be advanced in this paper.

EIGHTH STOP. The next stop is a quarry in white to pinkish dolomite a good km to the north of the conglomerate locality. The dolomite is a member of the 1 200 m thick Ballang limestone sequence, Unit 6 of Fosile.

NINTH STOP. This stop is made in order to show the above-named Bö quartzite, exposed to the northwest of a little brook. The locality shows greyish white quartzite and grey mica-schist with intercalations of carbonate. Foslie states, that the Bö quartzite amounts to 60 m in thickness.

TENTH STOP. After another km we stop some hundred m to the east of a brook, where the highway crosses the Fuglevann limestone Series, Foslie's Unit 10. In this Series the two Håfjell iron ore formations are of special interest. The ore is located in a formation of black mica-schist.

Proceeding by bus, we cross the following upper units of the Håfjell syncline; Mica-schist, the Hekkelstrand dolomite and limestone, the Djupvik quartzite, and the mica-schist of the synclinal core. The core lies to the east of the bay Djupviken.

The bus trip continues downwards through the synclinal sequence of strata to its base, that is, to the zone where the injection gneiss is superposed on the "Bottom" microcline granite-gneiss.

ELEVENTH STOP. We stop at this point and examine the granite-gneiss, that is even-grained and of reddish colour. It lacks all signs of pre-gneissic structure. The boundary between the granite-gneiss and its overlying injection gneiss is covered. The geological map of Foslie, however, shows a marked unconformity between the two named rock units.

Outside the map-area, for instance on sheet "Tysfiord" to the south, the southern continuation of the "Bottom" granite-gneiss lies on the so-called Tysfiord granite, that is rather massive, coarse-grained and of light grey to pinkish colour. However, nearly always the Tysfiord granite shows a faint lenticular parallel structure, in some regions quite prominent. Foslie's opinion is that the granite is rather re-crystallised. In several districts there is a thin formation of mica-schist, quartzose rock, and quartzitic gneiss as a boundary zone between the "Bottom" granite-gneiss and the Tysfiord granite. Accarding to Foslie the Tysfiord granite is Archean, the mica-schist and quartzose rock remnants of a metamorphic western equivalent to the Hyolithus Series of the eastern Caledonian Mountain border zone, and the "Bottom" granite gneiss of Caledonian age, intruded, gneissified and folded together with the overlying mountain schists. To the south of the Tysfiord map-area the Tysfiord granite crosses the international boundary and in the Swedish Akkajaure area runs to the southeast right on to the eastern border zone of the Caledonian Mountains and as reported in a preceding paragraph of this paper by the present author, referred to the Archean part of his Middle Caledonian thrust-rocks. Much attenuated parts of the "Bottom" granite-gneiss reach the international boundary but seem to have dwindled out not far from the boundary zone.

The bus takes us back to Narvik.

A 25: Late train from Narvik to Stockholm.

C 20: Overnight stay in Narvik. Train to Stockholm in the following morning.

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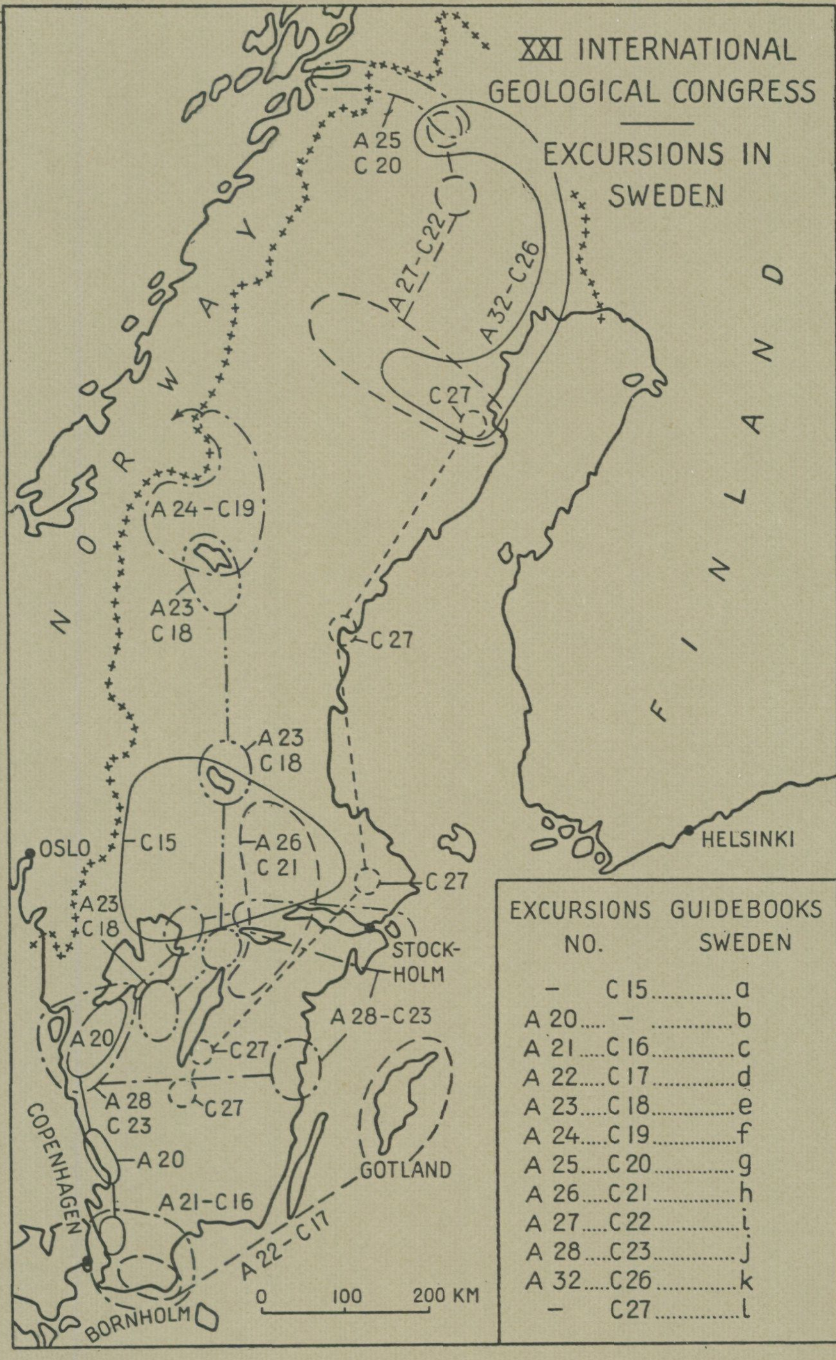
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