

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C.

Avhandlingar och uppsatser.

N:o 522.

ÅRSBOK 45 (1951) N:o 3.

PRE-CAMBRIAN GEOLOGY OF THE PAJALA
DISTRICT, NORTHERN SWEDEN

BY

TRYGGVE ERIKSSON

WITH THREE PLATES

Pris 4 kronor

STOCKHOLM 1954
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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Introduction.

The so-called Pajala district is situated in the Province of Norrbotten, in northern Sweden, and for the purpose of the present description comprises map-sheets No. 16 Pajala and No. 17 Huuki of the ordnance map of Sweden. Thus to the east the district ends at the boundary between Sweden and Finland. To the north, west and south, however, the district is more naturally bounded from a geological point of view. Here are found rocks of a somewhat different character to those within the Pajala district. The rocks here consist mainly of granites and migmatites. To the north-west, however, the rocks of the Pajala district may be said to continue into the so-called Vittangi district.

Administratively the greater part of the district concerned belongs to the parishes of Pajala and Tändö, and smaller parts belong to the parishes of Korpilombolo and Gällivare (to the south and south-west) and the township of Kiruna at Masugnsbyn in the north-west.

In Hummel's paper and on the accompanying map of 1876 (12)¹ no concept "Pajala district" can be found, but as early as 1886, Fredholm (3) separates

¹ Numbers in brackets refer to the list of references page 38.

two sections, called the eastern and the western schist-areas of Pajala ("Pajala östra och västra skifferfält"), which areas as Fredholm points out, are made up of rocks different from the surrounding granites. Not until the end, and immediately after the First World War, did the Pajala area arouse new interest in connection with the discovery of iron ores above all at Kaunisvaara village about 20 km N. of, and in the vicinity of Lake Käymjärvi about 25 km N.W. of Pajala village. Later new ores were also discovered to the north of and in continuation to the streak in which are situated the iron ores of Masugnsbyn known since 1644.

Finally, Geijer, in his extensive monograph on the greater part of the pre-Cambrian rocks of Norrbotten in 1931 (9) deals especially with the supra-crustal rocks of the Pajala district, and he points out that the rocks are of a character somewhat different from those of western Norrbotten.

The field-work, forming the base of this paper was begun by the present writer in the summer of 1945, when detailed geological mapping was carried out within a small area around Lake Käymjärvi. This mapping then was a link in the task undertaken by the Geological Survey of Sweden of making a general geological map of the bedrocks in the Province of Norrbotten. After being absent from the work for two years, the writer, in the summer of 1948, was given an opportunity to continue the field-work on behalf of the Geological Survey. The object was to map the whole of the Pajala district on the basis of the experience gained while mapping at Käymjärvi. This work led, *inter alia*, to the discovery of small deposits of iron ore in porphyries near Peräjävaara hamlet close to the Torne river and in addition the occurrence of extended iron-ore-bearing streaks were indicated through magnetic surveying within Junosuando village.

In the summer of 1949 the geological works proceeded during shorter periods and were then mainly concentrated to the neighbourhood of Junosuando, and to an area made up of porphyries extending to the south of Peräjävaara. At Junosuando extensive geophysical surveying and diamond-drilling were carried out.

Earlier, in the summer of 1943, the Geological Survey carried out magnetic surveying with the Tiberg magnetometre, and also geological mapping and boulder-tracing round Erkheikki to the north-west and Liviöjärvi to the south-west of Pajala, in the continuation of the rockstreak which from the iron ores at Kaunisvaara runs towards the south. In the summer of 1946 too, geophysical surveying (in this case electrical measurings according to the Slingram method¹) was made over a long stretch in the vicinity of Saittarova hamlet, from south of Lake Ruokojärvi to near Masugnsby village in the north. All these geophysical investigations and their results have been placed at the writer's disposal, and have been of invaluable help when making the

¹ See, Ödman, O. H.: Manganese mineralization in the Ultevis district, Jokkmokk, North Sweden. Part I, Appendix by Werner, S.: Geophysical investigations - - - S. G. U. Ser. C N:o 487, 1947.

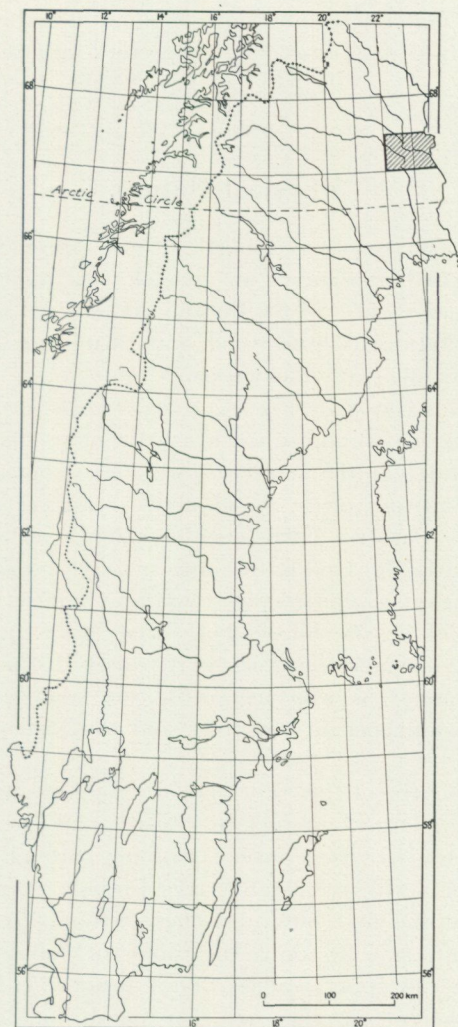


Fig. 1. Map showing location and extension of the mapped area (= Pl. 1).

present map. Not only when drawing the rock-contours, but also when considering the structure as well as the stratigraphy of the field, the geophysical maps have proved most helpful.

During the summer of 1949, the Boliden Mining Company carried out aeromagnetic prospecting within the Pajala district, and the writer received information on part of the preliminary results before the present map was completed.

When preparing the map, rock-samples and rock-slides belonging to the Boliden Company were placed at the writer's disposal and naturally the material previously collected for the Geological Survey was also made use of.

†1—533199. S.G.U. Ser. C, N:o 522. Eriksson.

Among this latter material belonging to the Survey the material collected by Tanner (18) proved most useful as it specifies outcrops within badly exposed areas.

Physical Nature.

The district mapped is situated north of the Arctic Circle, between 67° and $67^{\circ}30'$ N. lat. and it occupies an area of some 3,900 square kilometers (see map, Fig. 1). Large parts of the district are covered with vast bogs often with a sparse vegetation of brushwood and shrubbery. Other parts of the area are covered mainly with pinewoods.

The country is also very flat (Fig. 2). Even though the lowest part is some 100 m and the highest summits reach a little more than 370 m above sea level, it may be said that the surface slowly rises from about 150 m in the east to an average altitude of ca. 250 m above sea-level in the western parts. Above this broken, but still fairly evenly inclined surface, only two parts really rise more markedly. One is the area round Käymäjärvi hamlet, N.W. of Pajala (Fig. 3) the other is an area close to the summit of Mount Suorsapakka some 20 km S.W. of Pajala village; both areas have mountains rising to a height of about 320 m above sea-level. A valley distinctly lower than the immediate surroundings is also met with, viz. along the Kalix river to the south of the confluence of this river and the Tarendö river in Tarendö village.

In a Norrland country of this type the outcrops of rock are mostly very sparse and recurrent larger outcrops are only found on the summits of the mountains. Along the five larger rivers running through the Pajala district viz. the Muonio river, Torne river, Lainio river, Tarendö river and the Kalix river, however, are found the best outcrops. These outcrops sometimes consist of long continuous cliffs as e. g. along the rapids of Pahakurkkio, Rappukoski and Tiankikoski in the upper reaches of the Kalix river, S.W. of Saittarova hamlet. Similar coherent outcrops are also found along glens (the so called "Kursu") of which the largest are "Isokursu" immediately to the east of Masugnsbyn and "Kursujärvin Kursu" and "Kolkojokin Kursu", the latter two situated N.E. of Käymäjärvi.

The area around Käymäjärvi differs, as has already been mentioned, from other parts of the Pajala district. Round Käymäjärvi, for example, there are table-lands with emerging summits on each side of the valley which extends from the north-west of Käymäjärvi with small lakes and tarns, and as a narrow pass at the lake continues to the south-east toward the flat land north of the Torne river. Probably we here find a feature originally caused by tectonical forces. Because of exposures made by running water during and after the Great Ice Age, relatively numerous outcrops are found partly in the valley itself and partly in the hillsides. Between the summits of the table-lands there are also drainage-channels with exposed rocks.



Fig. 2. View towards N. from the summit of Jupukka, N.W. of Pajala village.

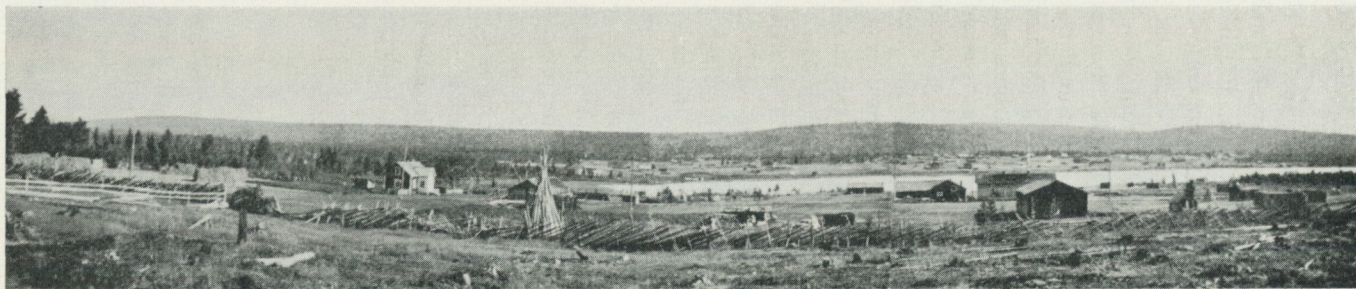


Fig. 3. Käymäjärvi village and lake seen from W. In the background from the left, the mountains Sammelvaara, Käymävaara and Hosiovaara.

Geologic Setting of the District.

The bed-rocks within the Pajala district are made up of pre-Cambrian rocks, partly of supracrustal and partly of igneous origin. As pointed out in the introduction, Fredholm (3) mentions the occurrence of wide-spread supracrustal complexes, which he names the eastern and the western schist-areas of Pajala. According to Fredholm, the larger schist-area, the eastern one, extends from Areavaara—Kaunisvaara—Käymäjärvi towards the south beyond Pajala, Suorsapakka and Sattajärvi, while the western schist-area was situated round the lakes Ruokojärvi and Sattajärvi and extended to Masugnsbyn in the north. As is seen from the map (Pl. 1) this corresponds, in broad outlines with the picture given in the present paper. Fredholm describes the rocks within the schist-areas (skifferfälten) as "hällefintor" (felsites), schists and sediments, such as quartzites, sandstones and conglomerates, and crystalline limestone and gneisses. As regards the age of these rocks, Fredholm considers the rock-complex as belonging to the geological period, preceding the one, during which the schists of the Caledonian mountain range were deposited ("— — — som närmast föregick den då högfjällets skiffer avsattes"). Furthermore he makes the very important observation that the supracrustal rocks of the Pajala district resemble the rocks met with in the Kalix archipelago in southern Norrbotten. Regarding their age, Fredholm also considers the rocks within the two areas contemporary.

As regards the granitic rocks and the gabbros surrounding the schist-areas, Fredholm does not discuss their age except that he points out that the western schist-area and some gabbro-massifs, among others the gabbro round Tarendö village, are enclosed in red granite. The granite which Fredholm regards as more or less undifferentiated, is on the forthcoming map divided into a number of different intrusive rocks of syenitic and granitic composition. Among the latter, migmatite-granite includes besides others the granite described by Geijer as Lina granite. In several of his works (4, 7, 8, 9) Geijer has dealt with Lina granite in detail. Previously, Tanner, in his diary from field-work within the Pajala district in 1918 (18), described the red migmatite-granite as post-Calevian.

The supracrustal rocks which constitute the Pajala district can now be divided into two groups belonging to different geologic series. The older series consists mainly of porphyries and leptites, all obviously of volcanic origin. The younger series on the other hand consists chiefly of sediments of different kinds and these sediments are sometimes later migmatized to gneisses. Apart from the sediments, the younger series also consists of volcanic greenstones, mostly agglomerates and tuffitic sediments. Within the younger series there are also conglomerates, which contain pebbles belonging to the older series. Basal-conglomerates and arkosic sediments which clearly divide the younger series from the older ones are also met with. The older porphyry-porphyrite-series forms a limited area in the central part of the Pajala district

and during a later sinking of the series sedimentary shallow water formations were deposited. This sedimentation was followed by volcanic activity which was characterized by basic volcanics and tuffites. During repeated depressions psammitic sediments were especially deposited. Later on during a folding in which the older volcanics, too, were at least partly involved a whole series of intrusive rocks have penetrated the supracrustal series. These igneous rocks are early, as well as late orogenic, and apart from some diorites and gabbros, which, however, seem to be related to the other intrusives, all clearly cut through or migmatize even the younger sediment-greenstone-series. The latter series and all intrusive rocks found within the district are regarded as belonging to the Karelidian Age.

The different geologic compounds met within the Pajala district can be divided according to the following table beginning with the youngest member.

Karelian	Igneous series: Migmatite-granite (pegmatite, Lina-granite, Kompelussaara-granite, and others). Perthite-granite, syenites, gabbro, diorite. Hornblende-granite.
	Lapponic supracrustal series: Quartzitic sediments and gneisses. Agglomeratic and tuffitic greenstones. Limestone, dolomite and jasper-quartzite. Quartzite with conglomerate. Phyllite and gneisses. Arkose and basal-conglomerates.
Older rocks	Porphyry-porphyrity series: Porphyry with apatite-bearing iron-ore, porphyrite and leptites (felsites).

Geijer (9) considers all supracrustal rocks in the Pajala district as belonging entirely to what he names the porphyry-leptite formation. Geijer, it is true, points out the sometimes great differences between the gneisses and sedimentary rocks of the Pajala district on the one hand and above all the supracrustal rocks dominated by acidic lavas within the Kiruna district on the other. Geijer however states that the relation between different parts of the porphyry-leptite formation is partly dim but that the differences may be due to different development of facies within the formation. Thus he divides the formation at large into a porphyry-part, a greenstone- and a leptite-part, the first of which attains its greatest extent and most typical development within the Kiruna district and round Gällivare. The other two parts, in which the rocks are mostly made up of greenstones, leptites and sediments, are to be found roughly to the east of the porphyry areas proper and thus comprising also the Pajala district. Geijer's view is further supported by the very

important argument that intrusive, deep-seated rocks, especially the perthite-granite at Masugnsbyn (8) are younger than the supracrustal rocks of the Pajala district. All deep-seated rocks, with the exception of the Lina-granite were then, according to experience from the Kiruna district, considered to be older than the discordance below the Vakko formation. This discordance was then the only large one that had been proved to exist within the pre-Cambrian rocks of Norrbotten and thus the deep-seated rocks should belong to the porphyry-leptite formation.

With Ödman's work of 1939 (20), concerning, among other things, the western part of the Pajala district, the question of the rocks within the district came into a new light, especially as a conglomerate with pebbles of intrusive rocks was found interstratified in the supracrustal series. This conglomerate was found at Tiankikoski rapids in the Kalix river south of Lake Saittajärvi. The conglomerate, which lies in conformity with sedimentary gneisses and the character of the conglomerate as intraformational, shows that when the sedimentation took place, the old landsurface must have been deeply denudated with exposed igneous rocks. As a consequence of this and by comparison with other areas, Ödman assigns the rocks around Saittajärvi and at Masugnsbyn to the younger Vakko formation and not to the older porphyry-leptite formation as did Geijer.

By later works, this division of the supracrustal rocks within the Pajala district into two has been further confirmed. Thus in the occurrence within the porphyry-porphyrity series of alkaline porphyries with apatite-iron ore, we find quite equivalent stratas to those regarded as oldest within the Kiruna district. Above the porphyry-porphyrity series conglomerates have been found (of those conglomerates, the one about 5 km N.W. of Liviöjärvi hamlet also contains pebbles of igneous rocks i. e. granite). These conglomerates, which form the bottom of the sediment-greenstone series thus show that a marked hiatus exists between the two supracrustal series.

The younger sediment-greenstone series cannot directly be compared with the rocks belonging to the Vakko series found in the Kiruna district. On the other hand the younger series has a counterpart in the rocks met with in the Finnish Lappland within the parishes of Kolari, Kittilä and Sodankylä. In fact there exists a direct connection between the rock-complexes on the Swedish side and those in Finland across the border-river.

The geology of the pre-Cambrian rocks in Finnish Lappland was described some years ago by E. Mikkola (16) and he calls the counterpart to the sediment-greenstone series in the Pajala district the Lapponian formation. The name Lapponian then, is not used in the same sense as Sederholm used it i. e. he considered Lapponian as belonging to the Bottnian formation-group. According to Mikkola, Lapponium is, on the contrary more closely connected to the Karelian cyclus. Further proofs have recently been put forward by the two Finnish geologists A. Mikkola (15) and M. Härme (13) who from areas round Tornio, Kemi and Rovaniemi in northern Finland have described sediment-greenstone series identical to Lapponium in the sense of E. Mikkola.

These rock-complexes of sediments and greenstones are furthermore closely connected with the Karelian in eastern and central Finland.

In accordance with E. Mikkola Lapponium is suggested in the present paper as a name for the younger strata and relevant rocks of the Pajala district.

Geologic and Petrographic Description.

In the following, the rock-complexes within three in a way different parts of the Pajala district will be dealt with first. These parts, consisting mainly of Lapponian elements are (see map Pl. 1): an area mostly to the west of Masugnsbyn, Saittarova and Junosuando villages, a central part around Käymäjärvi village and to the east one or more streaks extending from the vicinity of Erkheikki hamlet N.W. of Pajala and beyond Kaunisvaara, which streaks are found at and running across the border-river, Muonio River, into Finland. Within these areas it is above all the stratigraphy of the Lapponian supra-crustal-complexes that is of a certain interest, as the results from these parts are of the greatest significance when trying to interpret the structure of the whole Pajala district. In addition the older supracrustal series and the igneous rocks that are met with will be dealt with separately.

Lapponium.

THE KÄYMÄJÄRVI AREA.

At Lake Käymäjärvi within and around the village of the same name outcrops are relatively abundant and they are situated so that it is possible to get a rather good cross-section through the conformation of strata here. The area has also been studied in greater detail than the rest of the district.

The rocks of importance round Käymäjärvi are extensive quartzites with conglomerates, phyllitic sediments, dolomites and limestones, jasper quartzites with iron-ores and agglomeratic greenstones and greenschists.

The quartzitic sediments are seen as rock outcrops and heaps of local boulders called "skravler" (Fig. 4), in the steep hills on both sides of the valley at Käymäjärvi and as exposed rocks close to the brook Käymäjoki and on both sides of the road about 4 km S.E. of Käymäjärvi.

A great many outcrops with quartzite and conglomerate are found on Mount Sammelvaara (see map Pl. 2), about 3 km N. of Käymäjärvi village. The quartzites are grey, mostly of fine grain and well stratified, often with cross-bedding shown by magnetite-rich black-sand beds (Fig. 5). Alternating with these well-bedded quartzites are also others which are light grey, sometimes almost white, more or less glassy and dense, but in which, nevertheless, a diffuse bedding can often be discerned. In the fine-grained quartzites the clastic texture with rounded quartz-grains is visible to the naked eye, some



Fig. 4. Local boulders ("skravler") of quartzite on Lombolovaara, Käymäjärvi area.

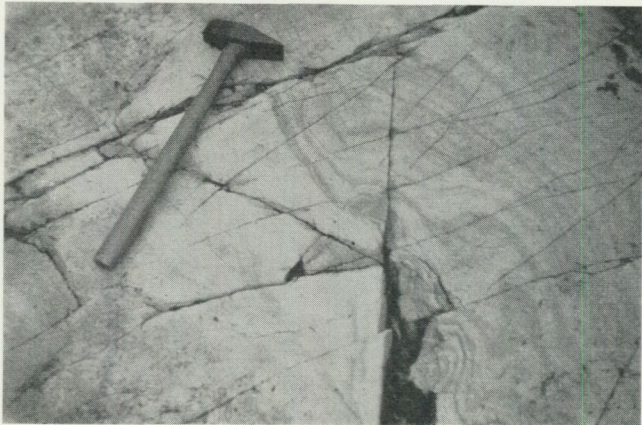


Fig. 5. Black-sand-laminated quartzite, Sammelveaara, Käymäjärvi area.

specimens even show a sandy grit. The dense and glassy types on the contrary, are recrystallized so that not even under the microscope can the clastic structure be distinguished, while the quartz grains, on the contrary, show jagged joints under the microscope. The rocks in question are mainly rather pure quartzites with quartz as the dominating mineral. Furthermore there occur

small laminae, mostly of muscovite, but also of biotite. In addition to the magnetite in the black-sand beds tourmaline sometimes occurs, while feldspar, mainly microcline, is less common.

Several conglomerate-beds occur at short intervals within the quartzites. The conglomerates contain well-rounded pebbles, which consist of grey or bluish-grey quartzite and jasper. Furthermore there occurs, also as pebbles, white, wholly crystalline and rather coarse quartz. The size of the pebbles vary, even within the same bed, and they can attain a diameter of about 2 dm. The thickest conglomerate-bed, which within the now described outcrops on Mount Sammelvaara is found to the extreme S.W., towards the valley at Käymjärvi, is about 30 m thick. Further conglomerates are met with to the N.E., but in that direction with successively lesser thickness and smaller pebbles. About 500 m N.E. of the thickest conglomerate-bed, there is, in the quartzite, a last gravel-grained bed only some cm thick. The thickest bed can be followed about 1 km along the ridge to the N.W., through the local boulders which are very common in that direction. That indicates a rather wide horizontal endurance of the conglomerates within this formation. Farther to N. and N.E. follows, always with concordant bedding, first quartzites, but later also dark grey or black, fine-grained, banded and biotite-rich and also sometimes intimately folded phyllites. The phyllites are partly gneissic and they can be reddish, obviously depending on contact-influence (veins) of granite. N. and N.E. of Mount Sammelvaara no outcrops have been seen until at the grand glen at Kursujärvi, along which lake and its feeder-stream runs a very marked fault (see Fig. 6). On the south side of the fault-line which runs approximately east to west quartzites are again met with. The quartzites however are glassy and recrystallized and partially intruded and veined by granite. The whole complex of sedimentary rocks, on Mount Sammelvaara and at Kursujärvi, seems to be concordantly bedded with a steep dip towards S.W. As far as the rocks on Mount Sammelvaara are concerned, this actually holds true, but as to the quartzites at Kursujärvi it has not been possible to find positive proof of the sequence in bedding due in the first place to the fact that dislocation has caused disturbance and secondly to the effect of the granite. However, here too, a diffuse banding in the quartzite is sometimes seen and this banding strikes N.30°W. and dips vertically.

Towards the S.E. in the direction of strike from the localities on Mount Sammelvaara, the sediments are cut by a massif of red migmatite-granite. Still further to the south, a little to the east of the road, about 5 km S.E. of Käymjärvi village, quartzites and conglomerates again outcrop.

One bed of conglomerate, at least 15 m thick, which can be observed just under 100 m in the direction of strike, is probably equivalent to the thickest bed on Sammelvaara described above. The conglomerate, which lies in conformity with quartzite and dips about 45° towards the west, is, however, in this locality much more metamorphosed, with elliptically elongated quartzite-pebbles up to 1/2 m in size, and sparse partly chloritic groundmass (Fig. 7).

Near the channel of Käymäjoki brook to the west and south-west of the conglomerate and in the hills to the north-east viz. Hosiovaara and Samakko-vaara, there are several large outcrops (see map Pl. 2). The rocks here are in part strongly influenced by the red, microcline-rich migmatite-granite, which to the west has given birth to fine-grained, streaky and unevenly contorted gneisses. These gneisses, which mainly consist of quartz, microcline

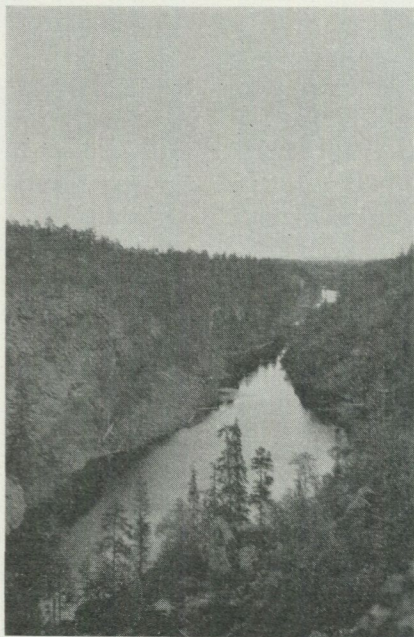


Fig. 6. The valley along lake Kursujärvi, seen from the east.

and muscovite contain, however, relatively well-preserved streaks of quartzite in which the primary bedding can also be recognized. To the north-east better-preserved sediments, obviously of pelitic origin, are met with. They are present as blackish-grey, biotite-rich, banded and thin-lamellar, more or less schistose rocks. Sometimes they contain amphibole and often also altered andalusite in the shape of globules or small knobs in the then silky-lustrous schist. Within more gneissic parts, the schists are cut by veins of microcline-rich granite and the migmatitization does not give the same impression of soaking as is the case with the psammitic sediments more to the west. Apart from more local divergences within the gneissic parts, the dip is relatively flat, throughout directed, broadly speaking, towards the west, and the bedding, which seems to be in conformity, points to a deposition with the lowermost layers in the east.

To the west of the valley that runs past Käymäjärvi, on Mount Lombolovaara about 3 km W.N.W. of the village, rocks, similar to those described

above, are again met with. On the top of the hill there are several small outcrops, which consist of current-bedded, black-sand-bearing quartzites. The quartzites are grey and rather pure but now and then there occur feldspar and often also some mica. In the north-eastern precipice, near the foot of the hill, a conglomerate outcrops. The conglomerate contains, often well-rounded but also angular pebbles of white or lead-grey, very pure, recrystallized quartzite about 15 cm in size. True ground-mass is often lacking, but when it is present it consists of sericite-schistose, fine-grained or dense quartzite. Locally there occurs a weak copper-mineralization in the conglomerate and that mineraliza-



Fig. 7. Conglomerate with quartzite-pebbles. Ca. 4 km. S.E. of lake Käymjärvi. The length of the measure = 1 m.

tion is seen as a sparse impregnation of bornite in the then fine-grained and totally recrystallized quartzite ground-mass. The conglomerate is then also beautifully blue- and green-coloured by azurite and malachite, which both occur as secondary weathering products appearing as a coating mainly on the surfaces of the pebbles and on fissures.

The dip or the sequence of bedding in the conglomerate cannot be ascertained as the outcrops are split and weathered into heaps of debris. In the outcrops with quartzite on the top of the hill the dip is throughout vertical or very steep, but according to the cross-bedding the lowermost beds seem to be found to the south-west and the youngest layers are thus to the north-east or next to the valley at Käymjärvi. There is no reason to suppose that the conglomerate should not appear as concordant beds within the quartzites as the strike is regularly W. to N.W.

Thus in the sediments on Mount Lombolovaara we find the western limb of a syncline and the other limb, the eastern should be made up of the quartzites described above, phyllites and conglomerates N.E. and S.E. of Käymjärvi (see block diagram Pl. 3). The conglomerates on Mount Sammelvaara and on Lombolovaara lie in such a position that they might correspond strati-

graphically to each other and thus serve as a marker-bed within these apparently water-deposited formations.

Lying above the sedimentary formations now dealt with we find the rocks, which outcrop within the "Käymäjärvi depression", the valley that runs to the north and south of Lake Käymäjärvi. On the map (Pl. 2) is shown how a relatively narrow, about 1 km wide streak of greenstone runs through the central part of the depression in the direction N.W. to S.E. On both sides of the greenstone there occur iron-ore-bearing sediments and limestones (dolomites) and the whole streak is strongly folded.



Fig. 8. Agglomeratic greenstone, N.W. of lake Käymäjärvi.

The greenstone makes up the stratigraphically upper-most and thus also the youngest part. The greenstone is found outcropping on several spots in the bogs N.W. of Lake Käymäjärvi and at the northern end of Lake Paturijärvi about 4 km N.W. of Käymäjärvi. The greenstone is partly dense and schistose, and partly made up of fine-grained, small-pebbled agglomerate or, as at Lake Paturijärvi, also showing a marked, no doubt primary banding. Green amphibole ($z \wedge c = 20^\circ$) is throughout the main constituent in all kinds of greenstones. The amphibole occurs as a felted mass or as table-formed specimens and it is always more or less greatly altered. Furthermore there occur basic plagioclases, which are sometimes lath-shaped making a framework filled with amphibole so that the texture becomes ophitic. Secondary formed epidote also constitutes a considerable part of the rock. In the agglomeratic forms (Fig. 8), which are dominant among the greenstones, the pebbles or fragments consist of the same minerals as are found in the ground-mass, but the amount of different minerals varies. Usually the fragments, which are angular or slightly rounded and up to 2 cm in size, are richer in amphibole than the surrounding mass. These greenstones are of effusive origin, or, concerning the banded forms at Paturijärvi, to be regarded as tuffitic sediments, all, however, being supracrustal rocks formed by basic volcanism.

On each side of the greenstone there are, as mentioned above iron-ore-bearing sediments, limestones and dolomites. They occur in several outcrops and apparently with varying thickness probably due to the folding. These sediments are also throughout strongly metamorphosed, with among other things skarn minerals as a common constituent. The iron-ore-bearing layers are found on both sides of Lake Käymjärvi, partly immediately N.E. of the lake and partly on Mount Vinsavaara S.W. of the lake and furthermore at Paturijärvi and within the iron-ore-fields Pellivuoma and Marjarova (see map Pl. 2).

Of the iron-ore-bearing formations those at Pellivuoma and Marjarova, earlier described by Geijer (5), are the only ores proper. The outcrops, now to be seen within these ore-fields, are found at the bottom of two almost demolished shafts. In the outcrops at Marjarova there is a glassy and rusty quartzite in contact with a now strongly weathered, fine-grained magnetite-ore and according to Geijer (5), quartzite and magnetite occur, the latter associated with gangue minerals (pyroxene and amphibole) and fayalite, as alternating bands. At Pellivuoma only a gangue, consisting of pale greenish diopside with lumps and "schlieren" of magnetite, outcrops.

On Mount Vinsavaara and above all at the northern end of Lake Paturijärvi, there are better and larger outcrops, so that the formation can be followed over long stretches. Here can be seen how the iron ore lies as bands or layers in jasper-quartzites. The latter are grey or brownish, very fine-grained ore dense and flint-like and devoid of clastic texture. They often show a very distinct bedding and contain green pyroxene as irregular bands or veins and network of veins (Fig. 9). Connected with the quartzites are also found layers rich in finely diffused graphite and now and then small amounts of pyrites, principally iron pyrites, occur within the quartzites, but chalcopyrites are also met with. The pyrites also occur scattered in the iron-ore layers in which the principal ore is dense or fine-grained magnetite associated with pyroxene, amphibole and also serpentine.

These jasper-quartzites and ores must be considered as sedimentary deposits. Their geological conditions as narrow but longish layers situated in the same horizon within a syncline confirms this view of their origin. Their close association with other sediments, banded limestones (see below) and obviously clastic rocks and above all the presence of graphite-bearing layers make the reasons for a sedimentary origin all the stronger. Geijer (5) also, for these reasons and furthermore owing to the composition and texture of the iron-bearing rocks, considers them primary chemical sediments and not of magmatic or metasomatic origin. Geijer writes (5, p. 11): "As to the origin of these iron-bearing rocks, it seems almost certain that they represent metamorphosed chemical sediments. An igneous origin is entirely excluded, both by characters of the rocks themselves and by their relations to the other members of the leptite formation. For the possibility of an origin by metasomatic alteration no other reasons can be cited than a certain chemical and mineralogical similarity to rocks elsewhere that are so interpreted, and the rather

close association with the skarn ores in limestone that are undoubtedly formed by replacement. However, the geological reasons that have led investigators, among them the present writer, to ascribe such an origin to certain ore-bearing rocks in Central Sweden, do not apply to the siliceous ores here. Also, the analogy in mineral composition is limited: the combination orthosilicate (fayalite) + quartz is not recorded from replacement deposits. As to the association with skarn ores in limestone, it is apparent from the



Fig. 9. Banded jasper-quartzite. Local boulder close to lake Käymäjärvi.

relations at Käymäjärvi that it is with the limestone, and not with the skarn ores, that the siliceous ores are originally associated."

Similar iron ores as those described and also lying in jasper-quartzites have been described by Hackman (11), E. Mikkola (16) and last by Kaitaro (14) from Porkonen—Pahtavaara iron-ore-field within the parish of Kittilä, Finnish Lapland. The present writer has only had the opportunity to examine some rock-specimens and thin-slides from this the largest of all Finnish iron-ore-fields and it can only be stated that the ores and rocks are very much like those found at Käymäjärvi.

In Porkonen—Pahtavaara, too, the quartzites and ores are intimately connected with volcanic greenstones and both Hackman and Mikkola regard ores as well as quartzites as being of sedimentary origin. But while Hackman is of the opinion that the ores are normal sediments and the greenstones are intrusions, Mikkola regards the quartzites and therefore the ores as chemically precipitated and formed in close connection with the basic volcanism. Mikkola writes (p. 175): "As the rocks in question are further decidedly devoid of all clastic textures, they can confidently be explained as chemical precipitations direct from volcanic springs and water conduits or as formed in lakes and pools amidst the ancient volcanic landscape, in analogy with so many jaspilitic 'iron formations' of the world." Kaitaro (14), on the other hand, compares the bedded ores with such formed as submarine deposits from exhalations.

Graphitic layers in connection with the jasper-quartzites have, however, not so far been recorded from Porkonen—Pahtavaara.

Limestones, mostly dolomitic, appear around Käymäjärvi, close to the jasper-quartzites with their magnetite-layers as can be seen from the map (Pl. 2).

The jasper-quartzite and especially the limestones seem to be enriched in the parts most bent by the folding. The limestones are found in one and the

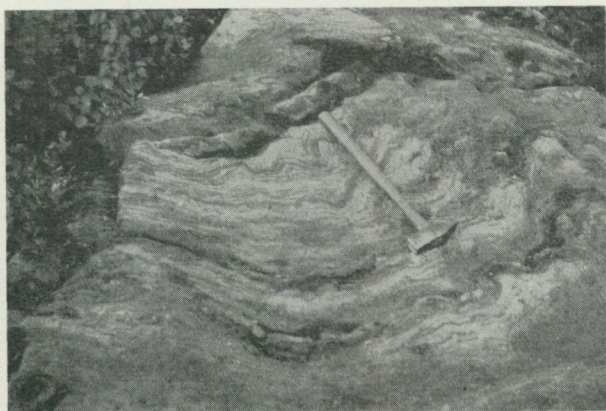


Fig. 10. Bedded and contorted limestone. Close to the road S.E. of Käymäjärvi village.

same horizon on both sides of the central streak of greenstones and that horizon can easily be followed on the north-eastern side of the greenstones, from Lake Paturijärvi through Käymäjärvi village to outcrops nearly 400 m wide, close to the brook Lombolojoki about 5 km S. of the village. On the south-western side of the greenstones, limestone outcrops on Mount Vinsavaara near Lake Lombolojärvi to the N.W. and furthermore limestone is, according to Geijer (5), found at Pellivuoma. The limestones are mostly clearly bedded and sometimes contorted (Fig. 10). Close to Lombolojärvi, in the limestone, are seen sharply defined 1—2 cm thick beds of blackish-grey colour alternating with the white calcite. The dark beds consist of a fine-grained mass of calcite rich in biotite and tremolite, even if the latter two minerals also enter, but to a much lesser extent, in the white beds.

The Lapponic rock-complexes, described above, within the Käymäjärvi area, consisting of sediments and volcanic greenstones, constitute as has been shown, a syncline, the central part of which strikes in an approximately north-westerly direction along the Käymäjärvi valley. The sequence of strata is (recorded from the bottom): phyllitic and quartzitic, partly migmatized and gneissic sediments with intraformational conglomerates, dolomitic limestones and jasper-quartzites with iron ores and at the top agglomeratic and tuffitic greenstones.

THE KAUNISVAARA STREAK.

The same Lapponic rock-elements as those described from the Käymäjärvi area are met with along a stretch more than 30 km long from Erkheikki village, N.W. of Pajala to the border river, the Muonio river, at Areavaara, Huuki and Kolari.

Here volcanic greenstones constitute a continuous narrow belt from Erk-



Fig. 11. Banded tuffitic greenstone. Summit of the mountain Suksivaara W. of the high road between Erkheikki and Kaunisvaara villages.

heikki past Sahavaara and Kaunisvaara to Areavaara. A great deal of these greenstones are made up of distinctly banded actinolite-bearing and chloritic tuffites (Fig. 11). These tuffites may alternate with doleritic sills, obviously intrusive. One form of the greenstones, the geological conditions of which are not precisely known as it is found as pieces of rock blasted from a well, also contains tourmaline. The rock in question is greyish green very fine-grained, almost dense and even to the naked eye thin needles of amphibole are visible. Under the microscope can be seen how the pale green amphibole (actinolite) lies in a felty mass of chlorite, amphibole and biotite and the actinolite cuts through the chlorite. In between "clouds" of that mass there occur small grains of feldspar and it can be seen how even here the actinolite grows into the feldspar. The tourmaline, which seems to be rich in iron occurs as large, relatively abundant idiomorphic grains.

Small-pebbled agglomerates very similar to those at Käymäjärvi also outcrop on Mount Sahavaara and, close to the Muonio river S.E. of Areavaara, are found calcitic spilites. Dolomites and limestones, which sometimes show an indistinct bedding near the greenstones occur in many places. Within Erkheikki village and at the top of a steep hill, Jupukka, N.W. of Pajala village, are found outcrops with layers of iron ore in jasper-quartzites and

associated with these occurs dark green amphibole as thin veins in the quartzite. These iron-ore-bearing sediments exactly resemble those at Käymäjärvi and on Jupukka dolomitic limestone also appears close to the quartzite. The iron ores within the "Kaunisvaara ore-field", the Sahavaara, the Tapulivuoma and the Palotieva ores are considered by the present writer to be of much the same origin, even if the iron ores there are much more strongly metamorphosed and, therefore rich in gangue. Some 30 years ago after exploratory magnetic surveying the ores were investigated in some places by excavating the very thick overburden and by sinking some small pits and shafts (only on Sahavaara). Furthermore diamond drilling has been carried out as no natural outcrops are found along the ore-streaks. The excavations on Sahavaara have fallen in and the writer has not had an opportunity of examining the drill-cores. On the basis of material available, notes in Geijer's diaries (6) and some rock-specimens blasted from the shafts, it is found that the ore, which consists of pyrite-bearing magnetite, lies in contact with limestones and is associated with, among other minerals, pyroxene and amphibole and above all serpentine.

On Mount Areavaara and on the bank of the Muonio river at Areavaara village, rocks of sedimentary origin outcrop and their character shows that they must be regarded as shallow water deposits. There are on the mountain grey, fine-grained, mica-bearing but clearly clastic quartzites with conglomerate-beds. The pebbles, which are well rounded, consist of quartzite and ferroginous jasper. On the bank of the Muonio river, in a long coherent stretch of outcrops, quartzites and phyllites are met with. The quartzites are clastic, grey and fine-grained, the phyllites, which are grey or almost black, fine-grained or dense are very well stratified and rich in biotite. The phyllites show a marked bedding and appear in part interbedded with quartzites so that they might be considered as deposited in a river estuary, but in any case their character of shallow water deposits cannot be doubted. Close to the highway at Kaunisjoki River, S.W. of Areavaara, S.E. of the above described sandy and clayey sediments, a limestone outcrops, a limestone which is situated in the continuation of the ore- and limestone-streaks within the Kaunisvaara ore-field. The limestone here also borders on and lies conformably below a greenstone to the east.

Those rocks, clastic sediments, limestone and greenstone are again met with in Huuki village and here they cross the border-river and continue into Finland, where the limestone especially is well-exposed in the old workings at the so-called Äkäsjoki deposit. At Kolari village and Ristimela farther to the south we again find the greenstones and here they are accompanied by metamorphosed quartzites and graphitic schists and at least on the Finnish side, also by limestone. Obviously in the continuation of this streak into Finland there are the iron ores of the Juvakaisenmaa deposit along the brook Niesajoki. These ores, according to Borgström (1), are situated along a contact zone between what he designates a mica-schist and amphibolite. According to the description these rocks could very well correspond to the known sedi-

ments and greenstones on the Swedish side of the border. Thus it is possible that even the Finnish iron ores at Juvakaisenmaa are situated in one, possibly the same, horizon between sedimentary shallow water deposits and volcanic greenstones as is the case at Käymäjärvi and within the Kaunisvaara orefields.

It seems possible to assume that the long narrow streak with greenstones from Erkheikki, past Kaunisvaara to Areavaara, represents one limb of a syncline, the second limb of which is met with at Kolari, Ristimela and further at Juvakaisenmaa in Finland (see the block diagram Pl. 3). It is, however, not impossible that within these parts faults could have played an important part. Among other things, there are found strongly crushed rocks (mylonites) on Mount Airivaara W. of Ristimela, and within the area occupied by migmatite-granite (see Pl. 1); on the mountains Jalkovaara and Kuusivaara there are fracture-zones running N.E. to S.W., and those features may represent faults or even overthrusts.

As is seen from the map (Pl. 1) the dominating rocks are gneisses and migmatite-granite within the area between the Kaunisvaara streak and the greenstones at Kolari close to the border river. The gneisses concerned are partly strongly migmatized, and all are more or less clearly banded or strongly schistose with the strike throughout running N. to S. or N.E. to S.W. Only close to the border river between Huuki and Ristimela are the rocks less metamorphosed. Here beginning from the N.W., first appears a gneissic and partly granite-veined, muscovite-bearing schist, which towards the S.E. passes into a grey, bedded and glassy quartzite. Further there appear in contact with the quartzite thick folded and overturned layers of graphitic schist, S.E. of which quartzite or quartzite-schist again outcrops. The latter is here relatively rich in mica and also contains red, rounded and partly changed garnets (almandine).

Immediately to the east of Lake Rytijärvi, about 6 km N. of Pajala, there occurs a peculiar form of the gneisses. It is rich in quartz, fine-grained, pale red and contains microcline and mica, above all biotite but also some muscovite. In the fine-grained mass there occur greyish white, ellipsoidal concentrations, up to one dm in size, which consist mainly of quartz and sillimanite and some tourmaline. The gneiss is also cut by red, partly pegmatitic granite rich in microcline. The gneiss is almost massive, but sometimes with a slight schistosity, which is shown by the parallel arrangement of the biotite grains, the direction of which is the same as the longitudinal axis of the quartz-sillimanite-nodules. The quartz-sillimanite-nodules also lie, vaguely it is true, but nevertheless arranged in rows, which gives the impression of a primary bedding, which dips about 35° — 50° towards the N.W.

Geijer (9) considers the origin of the quartz-sillimanite-nodules to be due to metamorphism, even if granite and pegmatite intrusions have contributed to the forming of the gneiss. From the western part of Finnish Lapland, E. Mikkola (16) has described the occurrence of widely spread "sillimanite-gneisses" among which occur forms exactly similar to that at Rytijärvi. Mikkola, who discusses the stratigraphical position of the gneisses, also com-

pares them to the equally richly occurring normal quartzites, and he considers the sillimanite-gneisses as primary sediments, too. He writes (p. 166): "A sedimentary rock of the composition of sillimanite-gneisses — — — would apparently have been an arkosic or micaceous sandstone, partly very rich in quartz. Such a difference in composition from quartzites would have sufficed to account for the quite different behaviour of these two kinds of rock under the influence of powerful metamorphic agencies and of granites."

Like Mikkola, the present writer regards the gneisses at Rytijärvi as representing a later strongly metamorphosed and altered clastic sediment with its primary composition still preserved. A proof of that seems to be present in the rocks found towards S.W. in the direction of strike, and above all N. and N.W. of Liviöjärvi hamlet, about 10 km W. of Pajala. Viz. here outcrop unmistakable sediment-gneisses in which are included quartzites (on the map Pl. 1 drawn as a separate streak), mica-shists and arkoses. The quartzites, which are pale reddish or grey, are sometimes bedded and they are more or less rich in biotite. The arkose, which outcrops in several places W. of the quartzites, is in part strongly schistose and shows even to the naked eye, lighter, grains of feldspar, measuring up to a few mm, in the grey, fine-grained schistose mass. Sometimes a diffuse stratification can also be seen in the rock and now and then there appear bigger, rounded fragments of a phyllitic rock and a dark grey porphyrite with feldspar phenocrysts. Under the microscope can be seen how bigger, partly rounded grains of plagioclase (oligoclase) lie in a fine mass, rich in epidote and with lamellar feldspar often arranged in parallel rows. In addition there are quartz and ore minerals.

Concerning the stratigraphical position of the above described gneisses, it seems to me obvious that all, even the sillimanite gneisses, must be regarded as belonging to the Lapponian supracrustal series. E. Mikkola in his work (16) points out the difficulty in ascertaining the stratigraphical correlation between the sillimanite gneisses and the normal (Lapponian) quartzites. When comparing the sediment complexes in the eastern and the western parts of Finnish Lapland he however arrives at the conclusion that the sillimanite-gneisses must be included in the Lapponian formation, of which they could represent the lowermost horizon. As far as the latter conclusion is concerned, it does not agree with what is known from the Pajala district. As has been shown, the sillimanite-gneiss at Rytijärvi is situated near the middle of a syncline, consisting of Lapponic elements and thus the gneisses concerned must lie rather high up in the supracrustal series. Here, however, must be pointed out the possibility that the streaks of greenstones, in part at least, may be overturned.

THE MASUGNSBY—SAITTAROVA—JUNOSUANDO AREA.

Turning to the western part of the area mapped we find here, too, rocks and also ores coinciding completely with those described above.

Here appear, for example (see map Pl. 1), supracrustal greenstones, which

extend from Masugnsby village towards the S.E. and from here they turn N.E. running to and beyond Junosuando village, apparently constituting a big syncline (see the block diagram, Pl. 3). Close to the greenstones occur bedded magnetite ores and limestones. In the Masugnsby iron-ore-field, known since 1644, and described by Geijer (8), the ores are metamorphic and rich in gangue.

Within the village of Junosuando itself, where in the year 1949 ores were found by means of geophysical surveying and diamond drilling, the ore occurs as thick beds of laminated magnetite alternating with grey, dense glassy and flinty quartzites. The ore also often is epidote-banded containing pyrites and the pyrite grains or veins are mostly situated on the bedding-planes. Layers rich in serpentine are common in the ore, which is separated from the greenstone by a thin but persistent limestone-bed. The greenstone, which seems to overlay the sediments, is schistose but shows nevertheless clearly agglomeratic textures. Immediately east of the ore-streak a drillhole was driven through phyllitic sediments, which are contorted but which show a distinct bedding with alternating fine and dark, and coarser and light material. These phyllites are in part rich in graphite so that locally there exists real graphitic schist, which also contains pyrrhotite.

The ore in Junosuando, which is known only from the drillings, covers an area of some 10,000 to 15,000 sq. metres. Within this "ore-body", however, certain parts hardly constitute an ore proper as the percentage of iron is too low, only about 20 per cent. Within the richer parts an analysis of a drill-core shows the values 45 per cent Fe, 2.56 per cent S, 0.05 per cent P_2O_5 (Analyst: A. Aaremäe).

Judging from the magnetic anomalies there must be some smaller ore-bodies or lenses within the field, but even these can be assumed to consist of only very poor, low-grade ores.

As a comparison it may be mentioned that in the Masugnsby field there are several ore-bodies with a total area of about 56,000 sq. metres. About half of the ore is well concentrated and consists of high-grade magnetite-ore, poor in phosphorus, while the rest forms a dressing or concentration ore (8). The ores in the Kaunisvaara field are estimated to have a total area of about 90,000 sq. metres, half of which contains about 60 per cent and the other half about 40 per cent Fe.

It would lead too far to enter further into the subject of the geology of the iron ores and it will here only be stated that in the Pajala district within the Lapponic supracrustal series there occur regularly iron ores of sedimentary origin and together with limestones they lie practically in the same horizon close to volcanic greenstones.

Within the Masugnsby—Junosuando area clastic sediments are widely spread, in addition to those mentioned above, in Junosuando, we find them chiefly south of Masugnsby village and west of Saittarova hamlet stretching towards the Kalix river. These sediments also comprise quartzite-pebbled conglomerates (Fig. 12) of a similar kind to those at Käymäjärvi. The sediments

found towards the south are transferred into gneisses and schistose rocks (Fig. 13). The latter can be studied in the large outcrops along the Kalix river and they originate by the influence of the migmatite-granite and are also



Fig. 12. Bed of quartzite-conglomerate in quartzite. Kursuvaara, N.W. of Saittarova hamlet. The biggest pebble has a length of ca. 1 dm.



Fig. 13. Flat lying andalusite-bearing schist, close to the rapid Rappukoski in the Kalix river, S.W. of Saittarova hamlet.

certainly due to strong tectonic deformation. In that milieu there occurs a conglomerate close to the rapids of Tiankikoski, which is of great importance in determining the relative age of this supracrustal formation.

The conglomerate, as well as the whole rock-complex in this area has earlier been dealt with by Ödman (20). The conglomerate is strongly metamorphosed

but polygenius, with pebbles of porphyries, felsites and quartzites but in addition intrusive rocks such as syenite or diorite and gabbro and also dyke quartz. The conglomerate cannot be considered a basal-conglomerate as it appears as a conformable intercalation within the other sediments and the existence of such a conglomerate shows that *during the sedimentation the older rocks must have been strongly denudated with exposed deep-seated rocks.*

Tectonics.

As is seen from the description above, the Lapponic supracrustal-complexes form a thick folded series of beds, which within the three separately described areas forms, at least in part, steeply inclined synclines, which are illustrated on the block diagram (Pl. 3).

Within this sediment-greenstone series the fold axes have a steep or moderate dip in a direction roughly N. to S. or N.E. to S.W. Within the area to the south of Masugnsby village the whole rock-complex dips moderately towards N.E., at the Kalix river also superficial or horizontal axes of fold are met with. Round Junosuando village the pitch is steep towards S.W. Within the Käymäjärvi area the pitch is directed south or south-west (see map Pl. 2), as is also the case close to the Muonio river round Huuki village. Along the Kaunisvaara streak the pitch is steep, directed towards the S.W., at least north of and up to Mount Suksivaara. At last within the sediments and gneisses to the south of the Torne river west and south-west of Pajala, there are fold-axes, that are directed towards the N. and N.E. and with moderate dip. There seems, therefore, to be a reason to assume that across the Pajala district, along a line approximately from Masugnsby over Pajala runs a depression of fold-axis with, roughly speaking, a pitch towards the S. or S.W. to the north, but dipping towards the N. or N.E. to the south of the depression.

The basal rocks and the substratum of the Lapponic supracrustal series.

As mentioned above, the rocks underlying the Lapponic supracrustal series are present chiefly in the central parts of the Pajala district, where acid or intermediate eruptive rocks are met with. These rocks have on the forthcoming maps not been divided but have all been coloured yellow.

Within the Käymäjärvi area (see map Pl. 2) porphyric supracrustal rocks flank both sides of the central syncline, which is built up of the Lapponic sediments and greenstones. To the west of Käymäjärvi, however, the contact runs through the bogs around Lombolajoki where there are no outcrops. Only N.E. of Käymäjärvi, in the cliffs round Kursujärvi, are there schistose and chlorite-bearing porphyrites in contact with quartzitic sediments. These porphyrites appear with a marked unconformity against the sediments and as it seems, overlying the latter. However the contact runs along the glen ("kursu") itself, which no doubt is a tectonic feature caused by one or more

violent faultings. Thus there are gliding planes striking E. to W. along the bottom of the glen and these planes also represent the contact between the different rocks (Fig. 14). Thus there is no normal erosional break and it has been impossible, within, in other respects, the easy Käymäjärvi area, to solve the important question of the relations between the Lapponic supracrustal-complexes and what I here call the porphyry-porphyrity series.

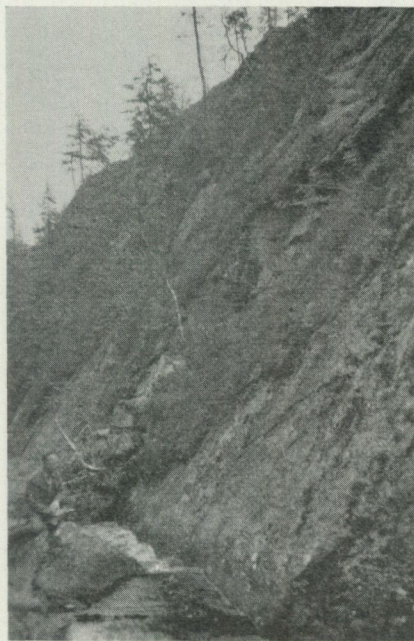


Fig. 14. Sliding-plane along a fault close to lake Kursujärvi. Scale, compare the man in lower left corner of the picture.

In two other parts of the Pajala district there are, however, formations which distinctly show that a marked gap exists between the porphyry-porphyrity series and Lapponium. These formations, in both cases conglomerates and arkoses, appear on both sides of the big porphyry area in the central part of the district and they are overlain by sediments or sediment-gneisses.

The one conglomerate, probably constituting a long practically coherent horizon, is well exposed in the mountain Haukkalaki, between the Kalix and Tarendö rivers, S.E. of Saittarova hamlet, and on the bank of the Tarendö river N.E. of Haukkalaki (see map Pl. 1). In Haukkalaki the conglomerate is strongly metamorphosed and contains elongated but rounded pebbles up to 1 dm in size. The pebbles consist of porphyries and porphyrites with visible phenocrysts of feldspar and even larger grains or aggregates of green amphibole. Pebbles of a dark and dense greenstone also appear. The groundmass, which is rich in epidote, has felsitic texture and contains microcline as well as pyroxene but shows no bedding or even indication of clastic texture. How-

ever, the conglomerate is cut by migmatite-granite rich in microcline, which partly appears cross-cutting, but which, above all, has acted upon the groundmass of the conglomerate so that sometimes only on account of the appearance of the pebbles in a reddish aplitic mass can the character of the rock as a conglomerate be identified.

The conglomerate does not lie in direct contact with any other rock but the cross-cutting granite, but at the northern foot of the mountain there are fairly local boulders of a grey banded biotite-bearing quartzite, which rock recurs outcropping in the northern part of Mount Vinsavaara immediately to the north of Haukkalaki. In the southern part of Vinsavaara again, there outcrops a porphyry with phenocrysts of feldspar and amphibole, and this porphyry completely resembles some of the porphyry pebbles in the conglomerate at Haukkalaki. Therefore it seems as if the conglomerate here constitutes a bed between porphyry-rocks and sediments, the former of which have a wide extension to the east round the Tärendö river. The sediments can be connected with the Lapponic sediments which strike towards the Junosuando village and they make up the eastern limb of the big syncline here (see map Pl. 1 and the block diagram Pl. 3).

A probably equivalent formation to the conglomerate at Haukkalaki is met with in the woodland close to Liviöjoki, about 5 km N.W. of Liviöjärvi hamlet and about 12 km W. of Pajala (see map Pl. 1). Obliquely to the common direction of strike, which runs N.E., there occur in a hill coherent outcrops at a stretch of about 700 m. To the very west in these outcrops (as well as in outcrops that are found further to the west) the rocks consist of red or reddish grey, partly schistose and dense volcanics with phenocrysts. In contact with these (towards the E.) there occurs a fine-grained, strongly schistose, arkosic sediment, which now and then contains dispersed but rounded larger fragments. Farther to the east there occur intermixed with arkoses more than one m thick pebble-rich conglomerate-beds, in which the pebbles are up to 2 dm in size, rounded but flattened. The pebbles consist of porphyries and porphyrites. The groundmass in the almost vertically dipping conglomerate (Fig. 15) consists of pure weathering-debris from volcanic rocks. In some places between the conglomerate-beds, however, can be seen a grey, fine-grained sediment with marked black-sand-lamination. Furthermore there occur green, schistose and lime-bearing sediments, also containing pebbles and more quartzitic layers with fragments of phyllite. The quartzitic layers, which partly contain considerable quantities of feldspar, show a crossbedding through the black-sand laminae. By this it has been possible, in spite of the steep schistosity, which strikes between N.10°E. and N.75°E., to determine that the bottom of the layers is directed towards N.W., with the younger layers found towards the S.E., and "upwards" we find the earlier described arkoses, phyllites and quartzites round Liviöjärvi.

The layers described above have a thickness of more than 300 m and thus an unconformity seems to be present between the extrusive rocks to the west on the one hand and the overlying (Lapponic) sediments to the east on the

other. Concerning the geological significance of this unconformity no conclusion at all can be drawn from the locality described.

Farther to the S.W., in the brook of Liviöjoki itself, N.W. of Mount Kojuvaara, there are a great many boulders of a conglomerate. The boulders lie close to outcrops of almost massive porphyries, and they are up to 2 m in size, flat and square and no doubt quite local. To the west of that conglomerate



Fig. 15. Schistose basal-conglomerate. Ca. 5 km. N.W. of Liviöjärvi hamlet.

extrusive rocks outcrop, both porphyries and porphyrites and to the east there are the conformable strata of varying sediments round Liviöjärvi hamlet. The conglomerate itself is almost massive, and in a dark grey, fine-grained groundmass there appear rounded pebbles of porphyries up to 15 cm in size of different shapes and of pale greyish red, fine- or medium-grained and massive rock of granitic structure. The latter rock, under the microscope, is found to be of quartz-syenitic or granodioritic composition, with as dominating mineral an oligoclase ($An = 25$ per cent, determined with universal-stage, extinction angle \perp MP) in rectangular hypidiomorphic grains. For the rest the rock consists of strongly undulatory quartz, some microcline, often twinned and altered amphibole, biotite in thin lamellar aggregates and furthermore epidote and as accessories ore minerals, titanite, apatite and zircon. This rock, which must be considered as plutonic or hypabyssal, does not completely resemble any known kind of the widely spread syenites or granites within the Pajala district, except perhaps for the so-called hornblende-granite. With the exception of the latter the granites and all the syenites are characterized through the abundance in microcline and above all microcline-perthite (see further below). On the other hand the rock in question has very great resemblance, as well in appearance as in composition, to that syenite which is found as pebbles in the conglomerate at Tiankikoski rapids, in the Kalix river, south of Saittarova, and which has been described by Ödman

(20, p. 76) and above (p. 26). Furthermore there is also a certain resemblance to that diorite which is described by Ödman from Maattavaara, north of the Vittangi river (20, p. 7). According to Ödman the diorite at Maattavaara constitutes the basement to the so-called Vakkoformation within the Soppero—Rautusakara area, between the Vittangi and Lainio rivers N.E. of Kiruna. The diorite here is also found as pebbles in the basal-conglomerate belonging to the sediment-greenstone series of the "Vakkoformation". This fact shows that the diorite at Maattavaara belongs to an older series within the pre-Cambrian rocks of northern Sweden.

Again concerning the conglomerate at Liviöjoki, its dark, fine-grained groundmass consists in part of small porphyry-fragments and in part of square or somewhat rounded mineral grains often cemented together. The porphyry fragments in respect to texture and composition are of different shapes and the rest of the grains consist of undulatory quartz, somewhat weathered plagioclase, occasional microcline, biotite, light mica, epidote, ore and apatite. No bedding or other kind of rearrangement of the grains can be seen in the groundmass and obviously it can be regarded as weathering debris. The occurrence of pebbles of deep-seated rocks in the conglomerate shows that in the very horizon lying between the porphyry-porphyrity series of the Pajala district on the one hand and the Lapponic sediment-greenstone complex on the other, *we have a very great hiatus or an unconformity between two different geological series.*

Those parts of the Pajala district, which consist of rocks belonging to the porphyry-porphyrity series, are as has been stated above, not uniformly built up. The greater part of the rocks here are, however, rather basic of dacitic or andesitic composition. They are often grey or dark grey, fine-grained or dense and, depending on the schistosity, which varies greatly, they contain more or less clear phenocrysts. One kind, which seems to have a wide distribution within an area to the west and south-west of the above described conglomerate at Liviöjärvi, consists of a dark grey, massive or somewhat schistose and dense rock with white, (1—4 mm in size) idiomorphic or hypidiomorphic, plagioclase-phenocrysts. The plagioclase, an albite with 2—10 per cent An, lies in a flow-structured groundmass with small biotite-laminae, plagioclase and ore-minerals. Other kinds again, as for example on Mount Palovaara, about 8 km W. of Liviöjärvi, is fine-grained with phenocrysts of amphibole and feldspar. The feldspar, an oligoclase with ca. 25 per cent An, appears as aggregates or small tables and the amphibole appears as larger irregular prisms. The groundmass consists of oligoclase too, and is poor in microcline and titanite, apatite, ore, amphibole and occasional grains of a greyish-green pyroxene. This most likely andesitic rock, and furthermore albite-bearing uralite-porphyrity series are also the dominating rocks belonging to the porphyry-porphyrity series around Käymäjärvi.

It is really only within a more limited area, close to the Torne river around Peräjävaara hamlet, where more acid, red, quartz- and microcline-

bearing porphyries appear. The porphyries here, often cut by granite or granitized, do not always show clear phenocrysts to the naked eye and they can be wholly recrystallized. Not infrequently, however, can be seen phenocrysts of both plagioclase (albite—oligoclase) and microcline in a fine-grained or dense granoblastic or leptitic groundmass of plagioclase, microcline (sometimes even perthite), quartz and often also amphibole, apart from different accessory constituents.

Close to the Torne river, on its south side, W. of Peräjävaara hamlet and found at the very bank of the river, there occur iron ore segregations in red granitized and leptitic keratophyre outcropping on a stretch of some 25 m in length and with a width of ca. 10 m (exposed by excavations in the autumn of 1948). The ore is an apatite-bearing magnetite and hematite which as narrow veins and "schlieren" cuts the porphyry. (One sample of the ore has given the percentages: 64.5 per cent Fe_2O_3 , 11.7 per cent FeO, 2.16 per cent P_2O_5 . Analyst: A. Aaremäe.) The ore veins, which are accompanied by gangue rich in apatite, appear partly brecciating the porphyry.

The ore at Peräjävaara may be regarded as a miniature of the apatite iron ores of the Kiruna type, which are abundant within the porphyry areas in the western part of the pre-Cambrian of northern Sweden. This fact is one more reason for assuming that the porphyries within the Pajala district correspond to equivalent rocks within the porphyry areas to the west. In these western areas, even in other respects, the same variation of rocks is met with.

Leuko-diabase.

Both close to the Tärendö river, S.W. of Junosuando, and at Kokvuoma N.W. of Kaunisvaara, there occur leuko-diabases or albite-diabases. These rocks at least at the Tärendö River, appear as indisputable intrusive dykes. The dykes are thick and they appear cross-cutting the quartzite, as well as against limestone and the effusive greenstone.

The leuko-diabases are mostly light reddish-brown and they give the impression of not being much altered. They consist of albite and in addition they contain different quantities of amphibole and titanite. They often also contain an abundance of carbonate minerals (ankerite?).

Ödman (20) describes a whole series of such leuko-diabases from the area Övre Soppero—Rautusakara, which there appear connected with long streaks of effusive greenstones and sediments. Even as described by Ödman the leuko-diabases are intrusive rocks, partly appearing as long but rather narrow veins in the greenstones, partly as wide and persistent dykes lying conformably in the bedded quartzites.

This characteristic kind of rock has, apart from Ödman, also been described by Geijer from the Vakko series north of Kiruna. Apparently equivalent rocks are met with in Finnish Lapland from where they have been described by Hackman (11) and E. Mikkola (16). According to the latter, the rocks in question appear, in the parish of Kittilä, closely connected with the Lapponic

greenstones. Along the whole karelidic belt from Lapland to Karelia in southern Finland such albite-diabases (karjalites) are found and they are described by among others, Eskola (2) and Väyrynen (19) and most recently from the Kemi—Tornio district in Finnish Westbothnia by A. Mikkola (15).

Deepseated rocks.

GABBRO, DIORITE.

Gabbroidic greenstones and diorites are found within the mapped area as several larger and smaller massifs and the rocks are more or less uralite-bearing, but also non-metamorphosed, rich in pyroxene and sometimes olivine-bearing kinds occur. They are almost wholly massive and show practically no tectonic influence. Very little can be said concerning their age or their appearance on the whole. The massif around Tärendö village, which is the largest and has the best outcrops, gives, however, few possibilities of solving the problem. The gabbro here appears within an almost flat area as dispersed smaller outcrops and the gabbro is only seen in contact with cross-cutting migmatite-granite. Titano-magnetite- and apatite-bearing kinds of the gabbro occur N.E. of Tärendö, where it has also been possible to trace the rock by means of magnetic surveying. Within the massif along the Lainio river, in the northern part of the mapped area, there are found diffuse remnants of porphyric greenstone in a diorite.

The gabbroidic greenstones may be of different ages, but apart from those found in outcrops along the border-river, the Muonio river, the gabbros and diorites, as may be seen from the map (Pl. 1) occur close to or near massifs made up of syenites.

SYENITES.

Syenites are very widely spread throughout the Pajala district (see Pl. 1). There are, particularly within an area between and north of Käymäjärvi and Junosuando, mostly reddish but also grey syenites or quartz-syenites. Most of the rocks within the massif here, as well as in the smaller massifs which are spread through the mapped area, correspond fairly well to the kind of syenite, which Geijer (9) has characterized as plagioclase-perthite-syenite. It is not always, however, that the feldspars show, as mentioned by Geijer, the characteristic rhombformed habitus with a core of plagioclase surrounded by a border-rim of perthite. Always, however, there occur larger or smaller quantities of perthite together with plagioclase, which latter varies in composition from almost pure albite to oligoclase. Furthermore microcline is not infrequently found as separate grains. Among the femic components, biotite is always present and this may also dominate, as is the case with the syenite outcropping close to Siikajoki to the north of Anttis village by the Torne river. Apart from green to yellow green biotite a green amphibole occurs and

the rock can be relatively rich in quartz. The rock then resembles a granite with the quartz appearing as a granulated mass between larger feldspar grains.

Again in other varieties of syenite, as for example in one found in a drill-core, E. of Salmijärvi (S.E. of the road between Junosuando village and Lauttakoski hamlet, by the Tärendö river) the rock is characterized by a green amphibole and contains only smaller amounts of biotite. This rock is also more basic, poorer in quartz and with microcline and microcline-perthite subordinated in comparison with the plagioclase, which is a basic oligoclase (ca. 25—30 per cent An). The plagioclase, however, shows a zonal build and it sometimes appears with the characteristic rhomb-shape with a thin border-rim of perthite. One more kind of syenite also contains, in addition to biotite, pyroxene. Such a syenite outcrops close to the Lainio river, E. of Junosuando. Apart from biotite in brown tables, diopside occurs as hypidiomorphic, partly uralitized grains. Such a pyroxene-bearing syenite also occurs north of the Torne river, at Junosuando on the hills Viiksvaara and Vinsavaara. A thin-slide from the rock in Viiksvaara shows in the wholly massive rock larger grains of oligoclase veined by microcline, and further also pyroxene, as "rounded idiomorphic" grains, urallite, biotite, ore, titanite and relatively much apatite. The pyroxene consists partly of greyish-green diopside but partly also of hypersthene.

As appears from the above, these "plagioclase-perthite-syenites" vary as to composition between more acid quartz-bearing kinds and syenites proper. But they also vary in respect of the femic constituents so that the syenites can be divided into or classified as biotite-, amphibole-, and pyroxene-syenites respectively.

These different kinds of syenite occur within one and the same large coherent massif. The syenites are intrusive even into the series of Lapponic sediments. N.E. of Junosuando as well as N.W. of Käymäjärvi syenites are found very close to the sediments and the magnetic anomalies (caused by magnetite-layers), which can be followed along the streaks of sediments, are here cut in a way that makes it possible to suppose that intrusive contacts may exist. N.W. of Käymäjärvi there is also in contact with quartzite a porphyric rock, which most probably represents the border-zone of the syenite, which outcrops not more than 50 m away. Finally, in a drill-core from the E. of Salmijärvi, within the Junosuando-field, the above described syenite is found cross-cutting sediments. The drillhole, whose position was decided according to an electric indication, has cut through a thick series of quartzitic and phyllitic, partly graphite-bearing sediments. At a depth of about 100 m the sediments are cut by a 7 m thick syenite-sill, and the syenite is mostly of medium grain and massive but becomes fine-grained towards both contacts. Furthermore the sediment close to the contact is somewhat coarser, rich in biotite, contorted and cut by thin syenite-apophyses.

Thus the syenites within the massif around the Lainio and Torne rivers are younger than all the supracrustal rocks found in the Pajala district. As can be seen from the map (Pl. I) the massif is surrounded, at least in part, by rocks belonging to the porphyry-porphyrite series. Even north of the area mapped close to and north-east of the Torne river, S.W. of Nuoksujärvi hamlet (see

Swedish ordnance map: map-sheet "No. 11, Lainio") porphyries are met with, adjacent to the massif of syenite which terminates here. In the syenite within the large rock outcrops E. of Siikajoki, N. of Anttis, are also found larger portions with remnants of porphyries. These remnants, embedded in the coarse- or medium-grained syenite and with the same brown or reddish-brown colour as the syenite, contain tabular phenocrysts of feldspar, up to $\frac{1}{2}$ cm in size, in a fine-grained, microcline-rich groundmass.

These facts referred to above and the circumstance that the syenite-massif, as to its tectonic situation, appears at the intersection between the depression of folding running approximately in a N.W. to S.E. direction (along the line Masugnsby—Pajala) and a probably larger anticline between Junosuando and Käymäjärvi (see Block diagram Pl. 3), leads to the speculation that the syenites through regeneration may have been formed from porphyric rocks simultaneously with a deep immersion of the older rock-crust.

HORNBLENDE-GRANITE.

Close to Lake Äihämäjärvi and around the highway which runs from Tärendö towards S.E., occurs a smaller massif with hornblende-granite. That granite, which is here entirely enclosed in red migmatite-granite, has a wide distribution south of the mapped area, viz. within the parish of Korpilombolo. The rock in question is grey, massive, mostly of medium grain or coarse and contains an abundance of amphibole and biotite. The feldspar, which is characteristic for the granite, is an oligoclase in tabular grains, but apart from the plagioclase there are often found varying but always small amounts of microcline. Also the amount of quartz varies and in one case in a thin-slide the quartz is found to be almost absent and thus the rock resembles a syenite. The hornblende-granite however differs from the rest of the intrusive rocks partly as it contains darker, fine-grained and rounded basic inclusions and partly in its behaviour to the migmatite-granite. At junctions between the two granites the younger migmatite-granite cuts the hornblende-granite through brecciating veins so that angular fragments of the hornblende-granite are found in the younger granite.

In composition and geological appearance the hornblende-granite resembles very much the granite which is named Haparanda granite (21) and which is very common in the southern and south-eastern parts of northern Sweden (the Province of Norrbotten). It might be that the "hornblende-granite" of the Pajala district and the "Haparanda granite" are to be looked upon as one and the same granite, but so far that cannot be proved.

PERTHITE-GRANITE.

This granite, which is found at Masugnsby village, is brick-red, massive and sometimes, at least close to the large valley ("kursu") running E. to W., east of the village, somewhat crushed. The granite, the feldspar of which is

a perthite of albite and microcline, consists in addition to feldspar of quartz, amphibole and small amounts of biotite, titanite and ore-minerals. The granite shows against the occurring supracrustal rocks a border-zone of light, almost white, partly porphyric albite-granite. The perthite-granite proper as well as the albite-granite and their mutual relationship have been thoroughly dealt with by Geijer (8, 9). Geijer considers that the albite-granite may have been formed from perthite-granite through albitization and that the former is not to be looked upon as a normal differentiation product of the perthite-granite.

From the recent investigations the only further fact that can be established is that the albite-granite cuts through supracrustal rocks, quartzite and phyllitic schists, which underlie the ores at Masugnsby. The contact between the granite and the sedimentary rocks is diffuse and remnants of glassy quartzite and gneiss rich in biotite are found within the granite.

MIGMATITE-GRANITE.

Cutting all other rocks within the district we find migmatite-granite. The conception migmatite-granite includes red, acid and microcline-rich granites, often very poor in femic components. Part of the granites are wholly massive, even-grained and obviously homogeneous as for example the kind of granite called "Linagranite". Other kinds, however, are inhomogeneous, either coarse porphyric or coarse and irregular, sometimes consisting merely of quartz and microcline. Apart from these there are variations with diffuse remnants of older rocks and those granites can develop an almost porphyric structure with large red microclines in a greyish even-grained mass.

This different kinds or forms of the granite are certainly due to an intense migmatitization or granitization of the older rock complexes, but the reasons for the different development of the granite within various parts of the district is a greater problem which will have to be solved on a wider, regional basis.

Conclusions.

The geologic evolution within the Pajala-district shows at least one, relatively young phase of folding. It is this phase that to a great extent characterizes the displayed rocks, and the traits of supposed older foldings or tectonizations have been blurred by the later folding.

As the oldest complex within the displayed rocks we find the porphyry-porphyrite series, on which, contemporary with a sinking, have been deposited mainly shallow water sediments. Before the sinking the older rocks have represented a land-surface, exposed to weathering and denudation as is shown by the occurrence of arkoses and conglomerates which must be considered as weathering-debris. The Lapponic supracrustal series lying above that discordance, consists of sediments and volcanic greenstones, all obviously deposited in shallow water or on land. To a great extent these sediments

may be looked upon as denudation products from the older rocks and the occurrence of widely spread sedimentary iron ores as true horizons may be interpreted so that the iron content in these ores has been supplied from iron concentrations within porphyries belonging to the porphyry-porphyrone series. Such a small iron ore segregation in porphyry is known from Peräjävaara close to the Torne river.

Thus the Lapponic complexes within the Pajala district do not contain any geosyncline sediments proper. Only within the south-eastern part of the mapped area occur highly migmatized rocks. That migmatite-landscape continues towards the south, within the parishes of Korpilombolo and Överkalix, along a stretch of more than 100 km till better preserved rocks are found in the Kalix area. The so-called Kalix series runs along the northern gulf of the Gulf of Bothnia in an approximately east to westerly direction and consists mainly of sediments and schists.

It therefore seems as if, within the Pajala district no bigger depression occurred but the real geosyncline is to be found south of the mapped area. Towards the east from the Pajala district, as has already been mentioned, we find the direct continuation of the younger supracrustal series extending far into the Finnish Lappland. Towards the west or north-west the geological surveying still going on has revealed data that makes it possible to assume that within the Vittangi area we again meet the Lapponic supracrustal series. As in the south too, viz. in the Kalix area, the rock-forming complexes continue directly towards the east in the Kemi area within Finnish Westbothnia, it seems probable that the geosyncline depression, if any, extends in about an east to westerly direction and is to be found in the areas between the Kalix and Kemi areas and the Pajala district.

The late folding which occurred, and which is closely connected with the Karelidic orogenesis, has within the Pajala district developed the synclines, which roughly run in a north-easterly to south-westerly direction. In connection with the folding the intrusive rocks have penetrated the now accessible part of the mountain chain and the last link in the evolution has been formed through the development of the migmatite-granite.

Concerning the relation of the age of the rocks of the Pajala district on the one hand and those of the surrounding areas on the other, there is little doubt that the younger supracrustal series must be considered as belonging to the Karelian formation group because of the direct connection which it is possible to make eastwards. E. Mikkola, too, pointed to the mutual connexion that existed between the Lapponic series and the Karelian formation groups proper. He writes, comparing his results with those put forward by Ödman in 1939 (16, p. 178): "But as the author in any case considers the Lapponic formations, which have clearly a basement of gneissose granites etc. in E. Lappland, as joining more closely the Karelides in respect to the age of deposition and time of folding than the other, more ancient orogenic cycle of the Svecofennides which occurred in Finland, we agree completely in assuming that the main phases of the petrogenetic development in the N.

boundary region between Sweden and Finland are connected with the Karelidic orogeny."

In E. Mikkola's Lapponic series, a conception which has also been adopted by the present writer to the younger supracrustal complexes within the Pajala district, there is present a widely dispersed series of sediments and greenstones. In the eastern part of Finnish Lappland they have as basement, the so-called Tuntsa—Savukoski series, consisting of gneisses which are cut by gneissose granites. A still younger sediment series, not cut by any granite, by E. Mikkola called the Kumpu—Oraniemi series, consists of quartzites and conglomerates and rests on a basement of Lapponic rocks. Any counterpart to the Kumpu—Oraniemi series as it has been described, is not known from the area now dealt with.

Concerning the Kumpu—Oraniemi series Mikkola compares it with the Vakko series. To parallelize the two series is, however, as Geijer has already pointed out (9), not possible, as the Vakko series is cut by granite. On the other hand it seems as if the discordance found below the Lapponium in the Pajala district may correspond to the discordance below the Vakko series within the Kiruna area and the area Rautusakara—Soppero. However, certain parts of the intervening pre-Cambrian rocks of northern Sweden have not yet been studied enough to solve this problem with certainty. Thus it is not yet possible to decide whether the basal parts of the Lapponium in the Pajala district stratigraphically corresponds to the basal parts of the younger series on Mount Maattavaara and within the Kiruna area.

Acknowledgments.

As assistant geologist to Professor, then State geologist, Olof H. Ödman the author had his first opportunity to carry out real geological mapping within the Pajala district. After that, which was carried out in the Käymäjärvi area, Ödman suggested the extended mapping that led to the present paper. At an early date Ödman also gave me an opportunity to work within other parts of northern Sweden, where I could study rocks and geological problems that have been of greatest value for the present map and description. It is under the leadership of Ödman that this work has been made and it is thanks to his keen interest and willingness to discuss problems connected with the work that it has been possible to carry it out.

To Mr. A. Theolin, who was my assistant during all the field-work, I will here take the opportunity to express my gratitude. In addition to his help in the field, Theolin has also been of the greatest assistance in the laboratory in arranging and preparing the material collected.

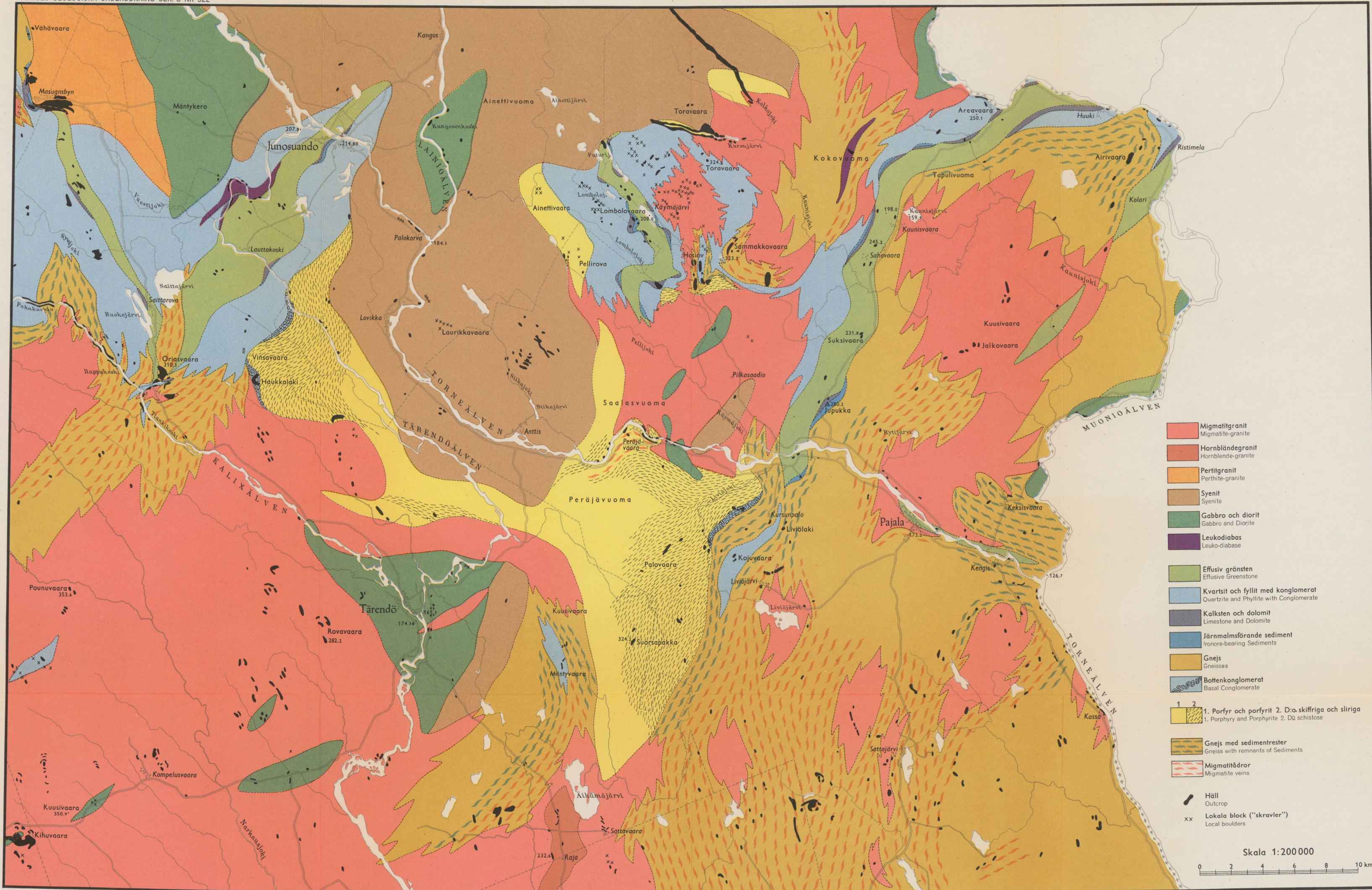
Further I have had the advantage both in the field and in the laboratory to discuss many questions and problems of greatest importance with the former head of the Geological Survey, Professor P. Geijer and Dr. E. Grip, Chief geologist to the Boliden Mining Co.

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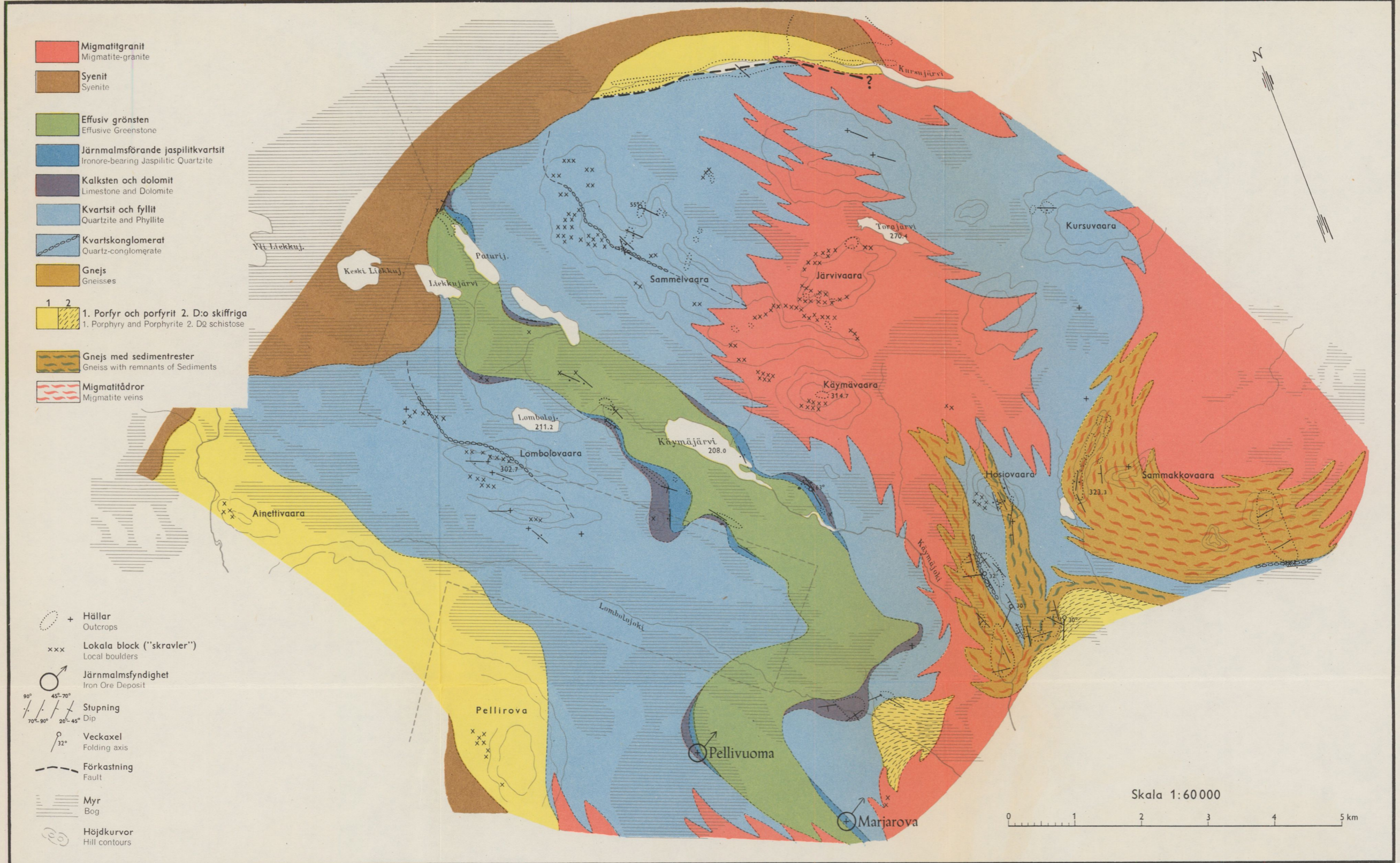
- Migmatitgranit
Migmatite-granite
- Hornbländgranit
Hornblende-granite
- Perlitgranit
Perthite-granite
- Syenit
Syenite
- Gabbro och diorit
Gabbro and Diorite
- Leukodiabas
Leuko-diabase
- Effusiv grönsten
Effusive Greenstone
- Kvartsit och fyllit med konglomerat
Quartzite and Phyllite with Conglomerate
- Kalksten och dolomit
Limestone and Dolomite
- Järnmalmförande sediment
Ironore-bearing Sediments
- Gnejs
Gneisses
- Bottenkonglomerat
Basal Conglomerate
- 1. Porfyr och porfyrit 2. D:o skiffriga och sliriga
1. Porphyry and Porphyrite 2. D: schistose
- Gnejs med sedimentrester
Gneiss with remnants of Sediments
- Migmatitådror
Migmatite veins
- Häll
Outcrop
- xx Lokala block ("skravler")
Local boulders

Skala 1:200 000
 0 2 4 6 8 10 km

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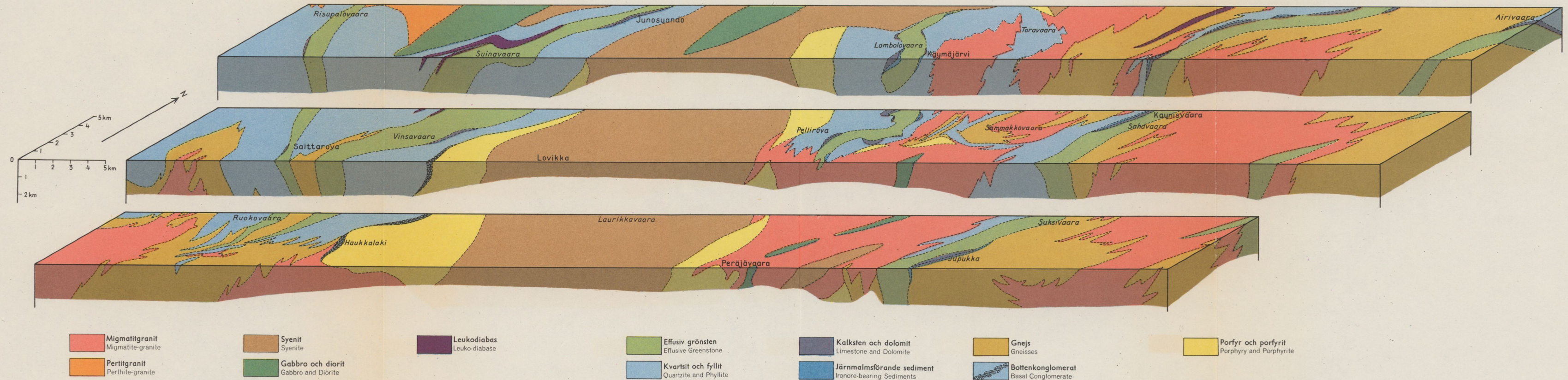
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