SVERIGES GEOLOGISKA UNDERSÖKNING

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RUDYARD FRIETSCH

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ABSTRACT

Rudyard Frietsch: Petrology of the Kurravaara area, northeast of Kiruna, northern Sweden.

The present work is a petrological study of the Precambrian rocks in the Kurravaara area situated northeast of Kiruna in Northern Sweden. The rocks occur in a monoclinal sequence which, from the oldest to the youngest, comprises Kiruna greenstone–Kurravaara conglomerate–syenite-porphyry – quartz-bearing porphyry – Lower Hauki Formation with acid and intermediate volcanic rocks – conglomerate – phyllite – quartzitic sandstone. The Kiruna greenstone, about 1 900–2 200 Ma old, is a spilite in which abundant pillow-structures indicate sub-aquatic eruptions. The greenstone contains intercalations of tuffites and ultrabasic intrusions. The Kurravaara conglomerate is a clastic deposit formed soon after the basic volcanism; only very few of the fragments are derived from the greenstone and associated sediments. The porphyries were formed about 1 600 Ma ago. In the Lower Hauki Formation, the eruptions were largely explosive giving agglomerates and tuffs. Textural features in the so-called ''Rektor porphyry'' indicate that it is a pyroclastic flow. The last phase in the volcanism comprised hydrothermal activity with sericitization and silicification of the Lower Hauki Formation. The formation of small siliceous hematite ores is connected with this process. Later, narrow quartz veins with hematite, calcite and ankerite were formed. The clastic sediments overlying the porphyries were deposited in a basin bounded by dislocations, these being due to epeirogenic movements. The fragments of the basal conglomerate and the conglomeratic intercalations in the quartzitic sandstone consist mainly of porphyries and rocks of the Lower Hauki Formation.

INTRODUCTION

The present work is a petrological study of the Precambrian rocks in the area between the town of Kiruna and Kurravaara village, about 10 km to the northeast of the towncentre (Fig. 1). Extensive geological investigations have previously been carried out in the Kiruna district, but only a relatively restricted part of the area northeast of the town has been studied in detail.

The well-known iron ores at Kiruna and their surroundings were mapped for the first time by various geologists between 1905 and 1909 under the supervision of Hjalmar Lundbohm. The area northeast of Kiruna was mainly surveyed by Per Geijer and Nils Zenzén. Geijer mapped the southern part of the area and the results were presented in Geijer (1910). Attention was focussed on the iron ores and their host rocks. In the same publication, a rather detailed map of the area northeast of Kiruna as far as Lake

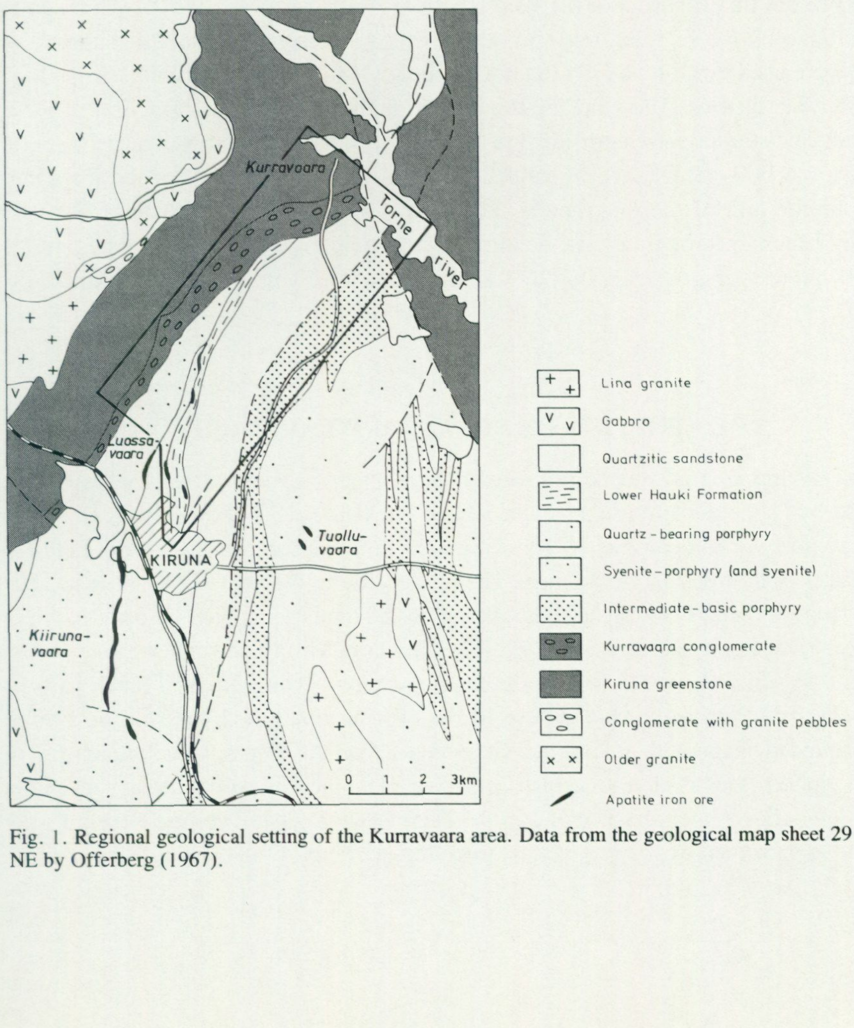

Fig. 1. Regional geological setting of the Kurravaara area. Data from the geological map sheet 29 J Kiruna NE by Offerberg (1967).

Syväjärvi was given. Zenzén who mapped the northern continuation of the area, far to the north of the Torne river, did not publish his results, but they were presented on the maps by Lundbohm (1910) and Sundius (1915). In connection with a prospecting campaign in the 1960's by the Luossavaara-Kiirunavaara Aktiebolag (LKAB), the area northeast of Kiruna was geologically and geophysically investigated. The geological results were presented by Parák (1969, 1975).

Previous geological investigations of the Kiruna district have mainly dealt with the iron ores, the Kiruna greenstone, the Kurravaara conglomerate and the ore-bearing porphyries. The present study concentrates mainly on the rocks of the Lower Hauki Formation (Series) and the Quartzite group (Upper Hauki Series). Descriptions of these rocks in earlier accounts are rather cursory. The Lower Hauki Formation is the host rock of some smaller apatite-rich iron ores. It is of dominantly volcanic origin and characterized by an intense schistosity and extensive metasomatic alteration. Geijer (1910) gives a detailed account of these rocks in the area between the Rektor iron ore and Lake Syväjärvi. The northern continuation of the formation has, however, never been described.

The present investigation of the Kurravaara area started more than 20 years ago in connection with the regional mapping of the Precambrian of Norrbotten county. The results were used by Ödman (1957) and Offerberg (1967) when describing the geology of the Kiruna district. The work by the present author was mainly done in 1955–57; some detailed studies were performed in 1959 and 1962. Field reconnaissance maps on the scale 1:8 000, established by LKAB in 1901–1902, were used for the mapping. The configuration of the outcrops is, in many cases, taken from the field maps by Zenzén. Much information was obtained when the present author mapped (scale 1:2 000) prospecting trenches dug by LKAB in the 1960's in the southern part of the area.

DESCRIPTION OF AREA AND TOPOGRAPHY

The Kurravaara area is situated northeast of the town of Kiruna. The area mapped is bounded by the settlement to the southeast and the Torne river to the northeast.

The terrain is characterized by low, rounded hillocks surrounded by flat land, in many cases with rather large swamps. The hillocks lie in the central part of map. The terrain slopes gradually from the south, at about 550 m a.s.l., towards the north where the Torne river lies at 322 m a.s.l. The highest point is Kurravaara at 606 m a.s.l. The hillocks do not rise above the tree-line and are covered by dwarf birches. Small parts of Kurravaara and Palsivaara have almost 100 % exposure. All the hillocks have a more or less rounded shape with at least one side steeper than the others, sometimes forming high precipices. This is obvious on Iso Gruuvivaara where the steep northerly face falls 100 m over a horizontal distance of 250 m. The morphological features of the hillocks are partly determined by the geological structures, particularly in the cases of Nukutusvaara, Kurravaara, Palsivaara, Kuusivaara, Iso Gruuvivaara and Pikku Gruuvivaara, where the orientation of the hill and the strike of the rocks coincides.

The topography has been affected by pre-glacial weathering and glacial denudation. The quartzitic sandstone of the Quartzite group and the rocks of the Porphyry group occur at the highest altitudes. The Kiruna greenstone usually occurs in the low-lying terrain, except in the north of the area, where it on the northern slopes of Kojuvaara and Pikku Mäntyvaara, lies about 50 m above lowland. The Kurravaara conglomerate occurs on low terrain in the south and on the hillocks in the north. The rocks of the Lower Hauki Formation and the stratigraphically lower members of the Quartzite group, namely conglomerate-greywacke and phyllite, were less resistent to erosion and comprise the low terrain.

GEOLOGICAL SETTING

The rocks of the Kurravaara area are of Precambrian age and belong to four supracrustal units, the Greenstone group (oldest), the Schist–conglomerate group, the Porphyry group, and the Quartzite group (youngest). The stratigraphy is shown in Table 1. The rocks occur in a monoclinal sequence which strikes roughly NNE except in the northern part where the direction is ENE–WSW (Plate 1). The dip is about 60–70° E and S. From west to east, the following units can be discerned in decreasing age: 1, the Kiruna greenstone of the Greenstone group, 2, the Kurravaara conglomerate of the Schist–conglomerate group, 3, syenite-porphyry, quartz-bearing porphyry and the Lower Hauki Formation with highly altered lavas of intermediate and acid composition, all belonging to the Porphyry group, and 4, conglomerate and greywacke, phyllite and quartzitic sandstone of the Quartzite group. The rocks form a concordant succession. Local, small angular unconformities occur, however, between the Kiruna greenstone and the Kurravaara conglomerate (Parák 1971), and between the Lower Hauki Formation and the Quartzite group. East of the Quartzite group, occurs an amphibolite which is a metamorphosed basic lava. The boundary between these rocks is a fault. The stratigraphic position of the amphibolite is unsettled. According to Offerberg (1967), it mainly belongs to the Porphyry group; the northernmost part, however, is attributed to the Greenstone group. Parák (1975) considered the amphibolite to be a Kiruna greenstone.

The age of the different rock units is not known for certain. Radiometric age determinations are very few. The age of the oldest unit, the Kiruna greenstone, can only be estimated by comparison with similar rocks in other areas. North of the Kurravaara area, the greenstone lies on a basement of a gneissose granite which has a U/Pb radiometric age of about 2 750–2 800 Ma (Welin *et al.* 1971). Between the granite and the greenstone, there is a conglomerate containing pebbles of the granite, indicating erosion and an unconformity in the sequence. Similar greenstones are widespread in Northern Sweden and are correlated with those in Kiruna; for example,

Table 1. Stratigraphic scheme for the Kurravaara area

Ma			
>1 565	Quartzite group	quartzitic sandstone with conglomerates phyllite conglomerate and greywacke	
1 605	Porphyry group	Lower Hauki Formation	siliceous hematite ore apatite-rich hematite-magnetite ore (Rektor, Henry, Nukutus, Lappmalmen, Hauki)
		quartz-bearing porphyry	
			apatite-bearing magnetite ore (Kiirunavaara, Luossavaara)
		syenite-porphyry	
	Schist–conglomerate group	Kurravaara conglomerate	
1 900–2 200?	Greenstone group	Kiruna greenstone	
(2 750–2 800)		(Basement granite north of Kiruna)	

the Veikkavaara greenstone group at Tärendö (Padget 1970) and Lainio (Witschard 1970), and the Vittangi greenstone group at Vittangi (Eriksson and Hallgren 1975). The greenstones in these areas have been intruded by granitoids (mostly granodiorites and gabbros). Radiometric Rb/Sr age determinations made on similar granitoids in the coastal area around Haparanda give an age of about 1 880 Ma (Welin 1970, Welin *et al*. 1970). Whether the granitoids in the above mentioned areas have the same age is an open question. If this is the case, the Kiruna greenstone should have an age of between 2 750–2 800 and 1 880 Ma. Welin *et al*. (1971) presumed an age of deposition between 1 900 and 2 100 Ma. It should be pointed out that similar greenstones in northern Finland have yielded radiometric ages in 2 000–2 200 Ma range.

The Kurravaara conglomerate, which is superimposed on the Kiruna greenstone, is a clastic deposit possibly closely related in time to the basic volcanism producing the greenstone. The Kurravaara conglomerate is attributed to the Schist–conglomerate group which is of limited extent in Northern Sweden but forms a distinct marker horizon. Stratigraphic equivalents outside the Kiruna district are the metasediments of the Pahakurkkio group at Tärendö (Padget 1970) and Lainio (Witschard 1970).

Rb/Sr age determinations on the next unit in the Kiruna sequence, the Porphyry group, are available from the syenite-porphyry and quartz-bearing porphyry in Kiirunavaara and Luossavaara and have given an age of about 1 605 Ma (Welin *et al*. 1971). Similar rocks from Kaska Tjåurek, 30 km WSW of Kiruna, have yielded an age of about 1 635 Ma.

The youngest unit, the Quartzite group, is of uncertain age. In the conglomeratic parts, there are pebbles from the Porphyry group, indicating that the latter was eroded prior to the deposition of the Quartzite group. In the Vittangi area, east of Kiruna, there are similar metasediments (Mattavaara Quartzite Group, Eriksson and Hallgren 1975). According to Geijer (1931a), these sedimentary rocks were metamorphosed by the Lina granite. Pegmatites of the latter intrude the Vittangi metasediments (Ödman 1939). The age of the Lina granite is about 1 565 Ma (Rb/Sr age determination, Welin *et al.* 1971); for some granitoids, however, an age of about 1 820 Ma has been recorded. The distribution between the younger and older Lina granites is not known.

The formation of the Quartzite group in the Kiruna district is therefore presumed to have taken place between 1 605 and 1 565 Ma ago.

The late-magmatic, apatite-bearing iron ores of the Kiruna district occur in the Porphyry group, but at somewhat different stratigraphic positions (Table 1). The main magnetite ores (Kiirunavaara and Luossavaara, both to the south of the Kurravaara area) lie at the contact between the syenite-porphyry and the quartz-bearing porphyry. In the Kurravaara area, there are several smaller magnetite-hematite ores with a high content of apatite (Rektor, Henry, Nukutus and Lappmalmen) which occur at the contact between the quartz-bearing porphyry and the Lower Hauki Formation. The Lappmalmen ore does not outcrop as it is overlain by 400–500 m of the Quartzite group. The Hauki ore, which is similar to the other apatite-rich ores, lies in a different stratigraphic position, partly within the Lower Hauki Formation, partly between it and the Quartzite group. In the Lower Hauki Formation, there are also small occurrences of siliceous hematite ore of hydrothermal origin. All these deposits, with the exception of the siliceous hematite ores, will not be dealt with in the following description. The apatite-bearing ores are described by Geijer (1910, 1931b, 1950), Parák (1975) and Frietsch (1977).

The rocks of the Kurravaara area are folded and faulted. The flat-lying sequence must have been uplifted before the deposition of the Quartzite group, but the present steep dip is later than this deposition. The monoclinal folding has been affected by later faulting. The eastern boundary between the Quartzite group and the amphibolite is a NNE- to NE-striking fault, possibly with a steep dip to the east. A NE-striking fault delimits the western side of Porfyrberget and forms the contact between the quartz-bearing porphyry and the Lower Hauki Formation. The fault, which is topographically clearly visible, continues northeast into the quartzitic sandstone of the Quartzite group. A NE-striking fault is found between the Rektor ore deposit and Doktorns kulle; it has dislocated the Rektor ore and the rocks of the Porphyry and Quartzite groups. West of Kirkasjärvi, an E–W-striking fault forms part of the contact between the Lower Hauki Formation and the Kurravaara conglomerate. An important tectonic zone probably follows the rocks of the Lower Hauki Formation. The strong schistosity, however, prevents tracing of distinct faults, and none are therefore marked on the map. Most of the faults have probably been formed by upthrusting with movements from the southeast and east.

All the rocks of the Kurravaara area are more less schistose. The most strongly deformed rocks are those of the Lower Hauki Formation. The direction of the schistosity is roughly N20°E with a deviation of 10° towards east or west. The dip is mostly vertical, in some cases steeply to the east or southeast, and occasionally to the west. In the southernmost part of the Kurravaara area, between Haukivaara and Haukijärvi, the schistosity has a moderate dip (35–50°) to the east.

In the northern part of the Kurravaara area, between Kurravaara and Pikku Mäntyvaara, the schistosity lies at right angles to the E–W strike of the rocks. This has caused peculiar phenomena in the rocks. The fragments in the Kurravaara conglomerate, the agglomeratic syenite-porphyry of the Lower Hauki Formation and the conglomeratic layers in the quartzitic sandstone are orientated N–S due to deformation, whereas the bedding still strikes E–W. This phenomenon is most obvious on the northern slope of Kurravaara in the quartzitic sandstone, this feature already described by Hummel (1877). On the northern slope of Palsivaara, step-like precipices, 1–5 m high, occur in the Kurravaara conglomerate which result from the schistosity lying at right angles to the bedding.

DESCRIPTION OF ROCKS

GREENSTONE GROUP

GREENSTONE

The Kiruna greenstone forms part of a greenstone belt which extends about 60 km from Lake Torneträsk in the north to the Kalix river in the south. Within the Kurravaara area, the greenstone shows only minor variations. Intercalations of tuffites and intrusives, such as uralite diabase and peridotite, are relatively abundant in the stratigraphically higher parts (adjacent to the Kurravaara conglomerate).

The greenstone is mostly a grey-green to grey, fine-grained, weakly schistose rock rich in chlorite and amphibole. At Valkeasiipivaara the greenstone is markedly schistose and has a high content of epidote occurring as small irregular aggregates or as narrow veins. The greenstone sometimes contains small amounts of magnetite and, rarely, some grains of pyrite and chalcopyrite. Occasionally, there are rounded amygdules (1 cm in size) which are filled with calcite, and in the marginal parts small amounts of epidote and chalcopyrite. Pillow structures are rather common in the greenstone; e.g. between Pikku Gruuvivaara and Kojuvaara, at Kojuvaara and at Pikku Mäntyvaara. The best preserved pillow structures are encountered south of Valkeasiipivaara (Fig.2). The pillows are about 2–3 dm in size but occasionally reach 8 dm. The pillow structures between Pikku Gruuvivaara and Kojuvaara show that the top of the volcanic flow lies to the southeast.

The mineralogical composition of the greenstone is rather similar over the whole area. The main minerals are tremolite-actinolite and albite. The albite, which often predominates, forms 0.2–0.5 mm long subhedral laths, sometimes in a more or less intersertal arrangement (Fig.3). The albite also occurs as small anhedral grains. The

Fig. 2. Pillows in Kiruna greenstone. South of Valkeasiipivaara.

Fig. 3. Greenstone with actinolite-tremolite, epidote and albite. Black grains are magnetite. Pikku Mäntyvaara. Crossed nicols, x 100.

Fig. 4. Greenstone with fragments of albitophyre (grey and rounded) and magnetite (black, to the right of the match-box). Valkeasiipivaara.

tremolite-actinolite, which is characterized by c: γ about 16–17°, Z=grass-green and X=pale olive-green or pale brown-green, forms needle-like grains up to 0.5 mm long, which sometimes grow into the plagioclase laths. Epidote is a common mineral, mostly occurring in small amounts, but in the greenstone at Valkeasiipivaara and between Kojuvaara and Pikku Gruuvivaara it is one of the dominant constituents. Biotite, penninite, quartz and calcite occur in small amounts, magnetite and sphene as accessories.

Chemical analyses show that the greenstone has a spilitic composition with a dominance of sodium over potassium (49.10–55.04 % SiO_2, 13.83–15.70 % Al_2O_3, 1.87–4.11 % Fe_2O_3, 7.39–10.59 % FeO, 2.86–6.91 % MgO, 7.08–10.88 % CaO, 2.39–5.90 % Na_2O, 0.36–1.44 % K_2O; analyses Nos 3, 4 and 6 in Sundius 1915).

The greenstone is overlain by the Kurravaara conglomerate to the east. The contact between the rocks is only exposed at a few localities. The best exposure is at Valkeasiipivaara, about 700 m to the north of Korpsjön. The contact strikes N10–20°E and the dip is vertical or occasionally steep to the east. The following details can be observed from east to west. The Kurravaara conglomerate passes sharply over into a deformed and schistose greenstone with abundant veins of calcite and some chalcopyrite. Quite near the contact, the greenstone contains a 4 dm thick intercalation of a banded jaspilite ore with layers (one cm thick) of hematite and dense, tile-red chert; in addition it contains narrow veins of magnetite. The schistose greenstone passes westwards into a denser and less schistose greenstone. Locally there are zones (up to

Fig. 5. Agglomerate in greenstone. Kojuvaara.

one metre thick) which contain rounded, or less commonly, sub-rounded fragments about 2–6 cm in size. The fragments, which are more resistent to weathering and clearly visible on the weathered surfaces (Fig.4), are made up of a grey, dense, non-schistose albitophyre with albite-oligoclase and small amounts of epidote and hornblende. In addition, magnetite-fragments are found in small amounts. This fragment-bearing intercalation is, in many respects, similar to the Kurravaara conglomerate. At Valkeasiipivaara, there are intercalations of the conglomerate (p. 16) in the greenstone.

The contact between the Kurravaara conglomerate and the Kiruna greenstone is also exposed at Pikku Gruuvivaara and Kojuvaara. It strikes N60°E and the dip is vertical. At the contact, the greenstone is mostly well-preserved with clearly visible pillow structures. Locally, the greenstone is epidote-altered and veined by narrow quartz-schlieren. Near the contact at Kojuvaara, the greenstone is strongly deformed and agglomeratic in appearance (Fig. 5). 1–10 cm long, irregular and sub-angular fragments of a light-green, dense, crushed greenstone occur in a carbonate-rich, schistose matrix. The agglomerate is cut by abundant, 1–5 mm wide veins of carbonate. Coarse breccias and agglomerates in the greenstone have been described by Sundius (1915) from Pahtosvaara and north of Luossajärvi, both south of the Kurravaara area. Sundius considered them to be explosive products related to the volcanism producing the greenstone. Formation by tectonic processes cannot be ruled out for the agglomerate at Kojuvaara.

According to Parák (1971), there is an angular unconformity between the Kiruna greenstone and the Kurravaara conglomerate at Pahtosvaara, south of Kiruna. The contact between these rocks strikes approximately N–S. The layering of the conglomerate lies, according to Parák (1971), about 30 degrees (no direction is given) to the contact. This angular unconformity must, however, be of quite local extent. The layering in the Kurravaara conglomerate at Pahtosvaara generally has a N–S strike, i.e. parallel with the contact (cf. Sundius 1915, Plate VII).

ULTRABASIC–BASIC INTRUSIVES

Intercalations of chlorite-amphibole-rich rocks, up to 100 m thick, occur in the greenstone at Piinotieva, northeast of Syväjärvi, and at Valkeasiipivaara. They represent ultrabasic intrusions. The difference in age between the greenstone and the ultrabasites is probably small. Similar chlorite-amphibole-rich rocks are met with at Ädnamvare (Matjäksa) and Ailitisvaara in the southern part of the Kiruna greenstone belt (cf. Sundius 1915 and Offerberg 1967). The pre-metamorphic composition of these rocks was probably that of a pyroxenite or peridotite.

At Piinotieva, the rock is a green-grey, fine-grained, markedly schistose amphibolite almost entirely composed of 0.2 mm long needles of pale-green tremolite-actinolite. Leucoxene is a common mineral. Pale-green chlorite, epidote and quartz occur in small amounts. The ultrabasite northwest of Syväjärvi is also markedly schistose and impregnated with uniformly distributed, 1 mm large aggregates of calcite. The rock is dominated by a pale-green chlorite, presumably a chlinochlore, and small anhedral grains of quartz. The other main minerals are tremolite-actinolite and epidote. Sphene, partly leucoxene, magnetite and apatite are found in small amounts. The ultrabasite at Valkeasiipivaara, which appears immediately to the east of the eastern tuffite intercalation, is a coarser rock consisting mainly of amphibole. Sundius (1915) considered this rock to be a peridotite and suggested that the original minerals were probably olivine, pyroxene and biotite.

A 400 m long and 100 m thick intrusion of a coarse uralite diabase occurs in the greenstone at Valkeasiipivaara, at the contact with the Kurravaara conglomerate. According to Sundius (1915), the rock is composed of hornblende, albite, leucoxene, and apatite. Epidote, sericite, biotite, and chlorite occur as secondary minerals. The intrusion occurred before the deposition of the Kurravaara conglomerate, as shown by the fact that the lower part of the conglomerate contains pebbles of a similar coarse uralite diabase.

TUFFITIC SEDIMENTS

In the Kurravaara area, tuffitic sediments occur at a high stratigraphic level in the greenstone at Valkeasiipivaara, northwest of Syväjärvi, and at the contact between the greenstone and the Kurravaara conglomerate at Iso Gruuvivaara. These intercalations are generally less than 10 m thick. Due to the lack of outcrops their length is not known.

The tuffite consists of fine-grained, anhedral feldspar. The grain size varies between 0.003 and 0.006 mm, which prevents a correct determination of the feldspar, but most probably it is an albite. Grains of olive-green biotite, grass-green tremolite-actinolite and pale-green penninite, up to 0.5 mm in size, occur in the fine-grained feldspar aggregate. The tremolite-actinolite and chlorite are associated and mostly parallel with the layering. Small amounts of calcite and zircon and accessory amounts of epidote and tourmaline also belong to the association.

The tuffite is grey or green-grey in colour, dense and shows a very distinct layering. The layers, generally some millimetres but occasionally some centimetres thick, vary in colour between light-grey, grey and grey-green, depending on the mineralogical composition. The darker layers are rich in amphibole. Locally, pink, dense felsite-like layers occur. A small amount of calcite is always present in the tuffite, partly as an impregnation, partly as millimetre-thick layers. Secondary calcite occurs as brecciating veins. At Valkeasiipivaara, the tuffite gradually passes into a schistose and skarn-rich, calcitic limestone. The skarn occurs partly as layers of decimetre to metre thickness and consists of tremolite-actinolite.

The strike of the layering in the tuffite is N25°E in the southern part of the area. The dip is vertical at Valkeasiipivaara and 60°SE in the area northwest of Syväjärvi. At Iso Gruuvivaara, the tuffite strikes E–W and dips steeply south. Cross-bedding at Valkeasiipivaara indicates way-up to the east.

SCHIST–CONGLOMERATE GROUP

KURRAVAARA CONGLOMERATE

In the mapped area, the Kurravaara conglomerate extends from Valkeasiipivaara in the southwest to the Torne river in the northeast. The conglomerate apparently does not extend further east than the Torne river. According to the map by Sundius (1915), the conglomerate extends north from the Kurravaara village. 3 km to the north of the village, on the western shore of Ala Vuolusjärvi, an outcrop of the conglomerate is marked. However, this rock is without doubt a conglomerate of the quartzitic sandstone of the Quartzite group. In addition, outcrops of the Kurravaara conglomerate are marked on the map by Sundius east of the Kurravaara village on the eastern shore of the Torne river. A thorough search by the present author has not revealed any conglomerate, all the outcrops consisting of greenstone and amphibolite. A continuation of the Kurravaara conglomerate southwest from Valkeasiipivaara is found at Pahtosvaara, about 9 km southwest of Kiruna towncentre. The conglomerate at Pahtosvaara is somewhat different from that at Valkeasiipivaara, but is probably an equivalent formation.

The thickness of the conglomerate at Valkeasiipivaara is 300–400 m, and increases towards the northeast to about 900 m at the Torne river. At Valkeasiipivaara, the conglomerate strikes about N40°E and dips vertically. Further north the strike is roughly E–W and the dip is partly vertical, partly 80–60°S. Between Pikku Gruuvivaara and Pikku Mäntyvaara, and between Pikku Gruuvivaara and Kojuvaara, graded bedding can be observed in arenaceous layers within the conglomerate; these indicate way-up to the south.

At Valkeasiipivaara, a 4 m thick and 80 m long intercalation of the Kurravaara conglomerate occurs within the Kiruna greenstone. In composition it is similar to the main part of the conglomerate (Sundius 1915). This conglomeratic intercalation lies about 100 m northwest of the main greenstone-conglomerate contact, and thus occurs at a somewhat lower stratigraphic level than the narrow fragment-bearing intercalation in the greenstone described on p. 13. In addition, Parák (1969) has been able to demonstrate the occurrence of a rather thick intercalation of the conglomerate in the greenstone by drilling west of Syväjärvi. This intercalation is situated some hundred metres west of the main boundary between the two rock types.

Pebble-rich layers

The Kurravaara conglomerate bears mostly pebbles in considerable quantities, but locally it is poor in pebbles; fine-grained, layered, arenaceous sediments occurring instead. The pebbles of the conglomeratic parts are usually 2–10 cm in size, but layers with 10–20 cm large fragments are rather common (Figs. 6 and 7). Occasionally fragments up to 40 cm in size are found. The size of the pebbles tends to be rather constant within one layer. The pebbles are rounded to sub-rounded and sometimes deformed.

The matrix of the conglomerate and the layers poor in pebbles is a grey to green-grey, fine-grained, schistose, greenstone-like rock. The schistosity is locally marked, for example west of Kirkasjärvi, north of Palsivaara and west of Iso Mäntyvaara, and the matrix has been transformed to a greenschist. On the other hand, a weakly deformed matrix is found at the eastern part of Kuusivaara and at the northern parts of Pikku Gruuvivaara and Kojuvaara.

The matrix contains secondary calcite as impregnations or veins; the latter are usually a few centimetres wide and a few decimetres long. Sometimes, as at Kojuvaara, the veins brecciate the conglomerate, which occurs as fragments in the calcite. Calcite veins, bearing quartz in the centre, are found at Palsivaara, Iso and Pikku Gruuvivaara, Kojuvaara and Iso Mäntyvaara. Small amounts of bornite, chalcopyrite and native copper occur in these veins. The bornite is partly altered to malachite. Gruuvivaara (Mining Hill) derives its name from former exploration works done on these copper-bearing veins (Svenonius 1877) which, however, are quite uninteresting economically.

The matrix of the pebble-rich and pebble-poor layers has a rather homogeneous

Fig. 6. Kurravaara conglomerate. Valkeasiipivaara.

Fig. 7. Kurravaara conglomerate with layer rich in small fragments. North of Palsivaara.

TABLE 2. Composition of matrix in the Kurravaara conglomerate (volume per cent)

		Valkea-siipi-vaara	Koju-vaara	Pikku Gruuvi-vaara
Biotite, chlorite, epidote, calcite, etc. groundmass		83.8	83.8	84.3
Fragments (0.1–1 mm in size)	albite	16.0	10.0	10.2
	syenite-porphyry	0.1	2.6	0.5
	quartzite	0.1	3.5	0.1
	magnetite-syenite-porphyry		0.1	3.6
	iron ore			1.0
	quartz			0.3
		100.0	100.0	100.0

composition. The main components are biotite, chlorite, epidote and calcite. Magnetite and tremolite-actinolite are subordinate; accessories are quartz, sericite, sphene, zircon, apatite, and allanite. Small fragments, less than 1 mm in size, of albite and different rock types make up less than one–fifth of the matrix (Table 2).

The biotite in the matrix is olive-green and forms 0.2 mm long laths mostly arranged in a parallel network. The chlorite is pale-green and somewhat subordinate to biotite. Epidote is an essential component at Valkeasiipivaara and Kojuvaara and locally dominates. Calcite occurs in the central and northern parts of the conglomerate but seems to be present only in small amounts in the south at Valkeasiipivaara. A pale-green tremolite-actinolite is found at Valkeasiipivaara. Magnetite is generally relatively abundant. Small amounts of sericite are found at Palsivaara and Pikku Gruuvivaara. Sphene occurs at Valkeasiipivaara in greater quantities and at other localities as an accessory mineral. In part it is altered to leucoxene. At Valkeasiipivaara there are skeleton crystals of sphene with parallel lamellae of magnetite.

The matrix of the conglomerate at Valkeasiipivaara shows the following chemical composition: 54.99 % SiO_2, 16.43 % Al_2O_3, 7.09 % Fe_2O_3, 4.89 % FeO, 3.31 % MgO, 2.82 % CaO, 8.24 % Na_2O and 0.50 % K_2O (analysis No. 7, Sundius 1915).

The different types of rock which are found as pebbles and fragments seem to be rather uniformly distributed throughout the Kurravaara conglomerate. The coarser pebbles and fragments are made up of (in decreasing amounts) 1, grey or red-grey syenite-porphyry, in part dark and epidote-altered; 2, magnetite-syenite-porphyry; 3, grey, pink or dark quartzite, in part jaspilitic and with bands of iron oxides; 4, magnetite ore; 5, green-white phyllite and grey shale; 6, brown limestone; 7, dark-green greenstone and greenschist; and 8, green, dense tuffite. Among the smaller fragments, albite ($Ab_{95}An_5$) dominates and represents about 10–15 per cent of the matrix between the coarser fragments (Table 2). The albite forms 0.1–0.5 mm long laths which are commonly bent, crushed and altered to varying amounts of biotite, epidote, calcite, and sericite (Fig. 8). Occasional quartz occurs in the matrix at Palsivaara and Pikku Gruuvivaara, and forms irregular, angular and crushed fragments about 0.2 mm in size.

Among the coarser fragments syenite-porphyries dominate. In most cases they make

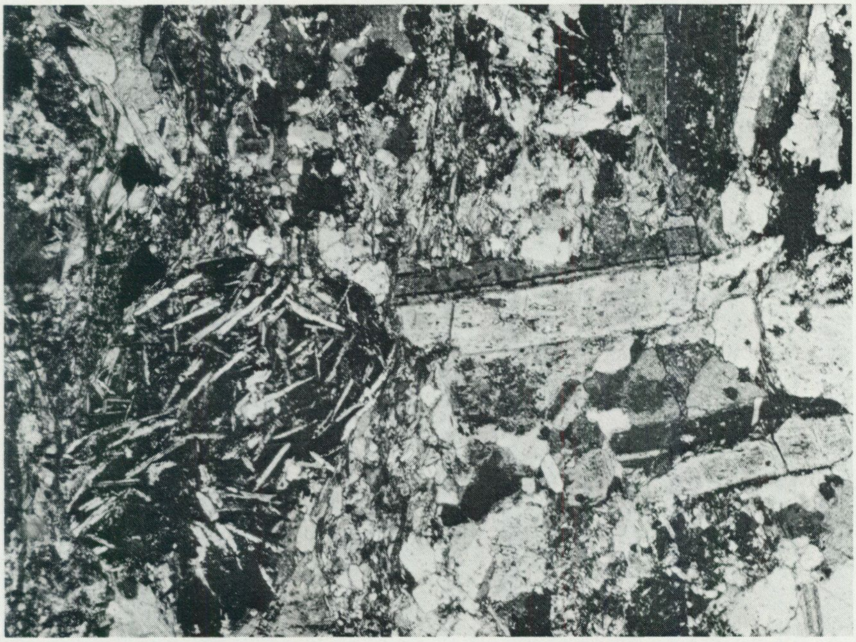

Fig. 8. Kurravaara conglomerate. Fragments of albite and magnetite-syenite-porphyry (left, lower part) in a matrix of calcite, biotite and some epidote and quartz. Black grains are magnetite. Pikku Gruvivaara. Crossed nicols, x 38.

up 70 per cent or more of the pebble-material. The syenite-porphyry pebbles are well rounded and generally 1–10 cm in size. The syenite-porphyry is grey to dark-grey, but also red or green varieties are encountered. The colour depends on the mineralogical composition, especially the content of dark minerals, mainly magnetite. 1–3 mm large vesicles filled with epidote and calcite occur in the dense, non-schistose matrix. The phenocrysts are 0.1–1 mm in size, occasionally 20 mm and are made up of albite ($Ab_{95}An_5$), which has usually been altered to varying amounts of sericite, epidote, biotite, calcite, and iron oxides (Fig. 9). Some varieties almost totally lack phenocrysts and are felsitic. The matrix consists of anhedral grains of albite (0.02 mm in size) which lie at random or, more rarely, are arranged in a trachytoidal or sub-parallel texture. Some of the syenite-porphyries are rather rich in magnetite and there are gradations to magnetite-syenite-porphyries. The magnetite has in part been altered to hematite. Secondary minerals such as epidote, calcite, biotite, and sericite occur in the phenocrysts and in the matrix. In places the matrix is totally altered. At Valkeasiipi-vaara, epidote, tremolite-actinolite, biotite, and some calcite, leucoxene, magnetite, and apatite occur. At Kirkasjärvi there are felsite-pebbles the matrix of which is rich in sericite and quartz.

Pebbles of a grey or red, fine-grained, non-schistose albitophyre are common, but these pebbles are mostly small, 1 cm or less. The albitophyre is composed of 0.4–1 mm long, narrow laths of a calcite-epidote-altered albite. The laths intersect each

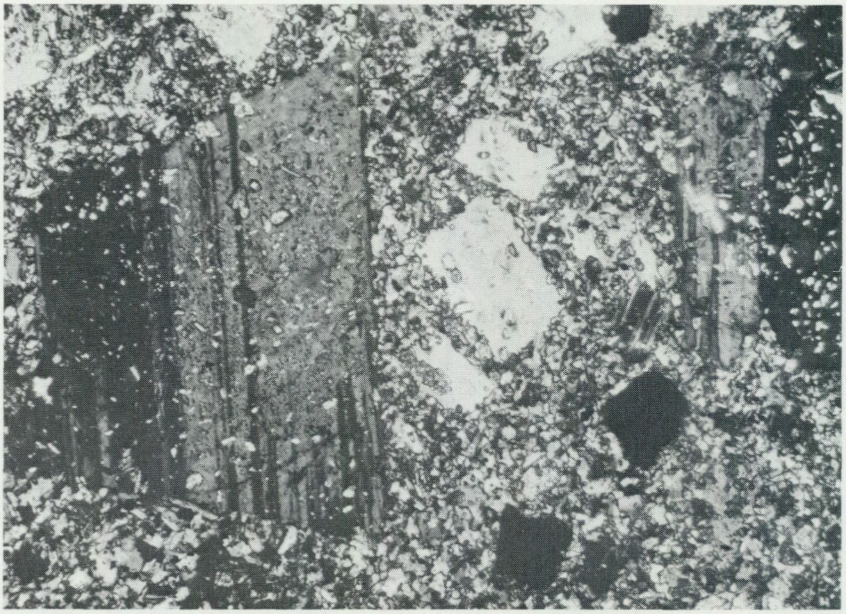

Fig. 9. Pebble of syenite-porphyry in Kurravaara conglomerate. Matrix and phenocrysts of albite, to some extent altered to epidote. Black grains are magnetite. Kojuvaara. Crossed nicols, x 100.

other, or, in some cases, they are almost radially arranged. The albitophyre pebbles from Palsivaara are texturally different, the albite laths are arranged at random and have a broader habit.

Sub-rounded to sub-angular pebbles of dark-grey, dense, non-schistose and felsitic magnetite-syenite-porphyry have been observed at Valkeasiipivaara, Palsivaara, Pikku Gruuvivaara and Kojuvaara. The high content of magnetite, roughly about 20–30 per cent of the volume, is conspicuous. The rock is dominated by 0.2 mm long, needle-shaped laths of albite, occurring at oblique angles to each other (Fig. 8). The albite which is sometimes ''striped'', contains secondary biotite, epidote, tremolite–actinolite, calcite, and magnetite. The matrix between the albite needles is made up of magnetite and small amounts of biotite, epidote and leucoxene. Apatite is an accessory mineral. Occasionally, as in the area north of Kirkasjärvi, the magnetite-syenite-porphyry contains lath-shaped phenocrysts of albite, about 0.5 mm, which are strongly altered to chlorite, sericite, calcite, and biotite.

Pebbles of quartzite have been observed mainly at Kojuvaara but occur also in other parts of the Kurravaara conglomerate. The quartzite is grey to grey-white, dense and non-schistose, occasionally with an indistinct layering. Millimetre-thick layers of hematite are fairly common. The quartzite consists of quartz as anhedral grains, 0.02–0.08 mm in size, with small amounts of albite, sericite, biotite, calcite, and accessory amounts of magnetite and zircon. At Kojuvaara, occasional pebbles of a hematite-bearing quartzite with small amounts of garnet occur.

Pebbles of jaspilite quartzite have been observed in the whole Kurravaara conglomerate except for the southern part at Valkeasiipivaara. The pebbles are 2 to 20 cm in size, rounded or less commonly sub-angular. Often they are somewhat broken and crushed, being veined by calcite-chlorite-filled fissures up to some centimetres wide. A red or violet jaspilite quartzite is common; a greyish type is less common. The quartzite is dense, non-schistose and generally comprises layers with different amounts of iron oxide pigmentation. In addition there is an alternation of quartz with iron oxides (hematite, in part magnetite). The thickness of the layers is a few millimetres, but in some cases up to a few centimetres. The different types of jaspilite quartzite are rather similar in composition; the variation in colour is due to different amounts of iron oxides. The rock is dominated by quartz occurring as irregular grains about 0.02–0.2 mm in size. The hematite occurs as irregular grains 0.001 and 0.01 mm in size or as pigmentation. The magnetite is mostly somewhat coarser and forms euhedral grains 0.2 mm in size. Calcite and sericite occur in small amounts.

Angular pebbles, some centimetres in size, of a dark-grey phyllite rich in hematite and a green-grey, sericite-rich phyllite occur infrequently in the Kurravaara conglomerate.

Pebbles of a dense magnetite ore with some quartz and calcite are rather common. They are angular to sub-angular and mostly small, a few centimetres in size, but attain occasionally a diameter of about 1 dm. Magnetite also occurs abundantly as angular, or less commonly, rounded fragments (0.1–0.5 mm in size) often orientated parallel to the schistosity.

North of Kirkasjärvi there are pebbles of a dense hematite ore which contain some calcite and albite. The ore is in part martitic: the larger hematite grains contain irregular remnants of magnetite at their centres.

Layers poor in pebbles

The conglomeratic parts of the Kurravaara conglomerate grade into layers poor in pebbles. In these, there is an alternation between somewhat coarse-grained beds, with fragments 1–2 mm in size, and more fine-grained beds, with fragments 0.1–0.2 mm in size (Fig 10). In the more coarse-grained beds, 1–5 cm large fragments occasionally occur. Locally, magnetite-rich layered parts resembling ''black sands'' have been met with. At Kojuvaara, there is a 1–2 dm thick pebble-free layer with cross-bedding indicating way-up to the south.

The distribution between the pebble-bearing and pebble-poor layers is not known in detail. There seems, however, to be a tendency for the pebble-poor layers to occur in the stratigraphically lower part of the conglomerate, near the contact with the Kiruna greenstone. Pebble-poor parts are more common at Valkeasiipivaara, where the thickness is about 100 m. At Kuusivaara arenaceous layers are intercalated with pebble-bearing layers. Around Iso and Pikku Gruuvivaara, there are rather large parts which are poor in pebbles. The large, continuous outcrop at Iso Gruuvivaara and the southern part of Pikku Gruuvivaara is almost free from pebbles.

At Iso Gruuvivaara, between the Kiruna greenstone and the Kurravaara conglomerate, there is a fine-grained tuffite which may well be a pebble-free part of the latter .The tuffite which strikes E–W or N80°W and dips steeply south or vertically, contains 1–10 mm thick, dark-grey layers in a light-grey matrix. Locally layers rich in iron oxides are met with. In addition coarser-grained layers with a grain size of some millimetres occur. Cross-bedding in these indicates way-up to the south. Occasionally the tuffite is pebble-bearing. The tuffite has a parallel texture and is composed of albite, biotite and chlorite, small quantities of quartz and accessory amounts of epidote, magnetite and tourmaline. Angular fragments, up to 0.5 mm in size, of magnetite-syenite-porphyry and sericite-altered felsite occur in small amounts. The tuffite lies in contact with a brown-grey, fine-grained, schistose arkose. About 5 metres to the south of the latter, the Kurravaara conglomerate appears. The arkose is composed mainly of crushed grains 0.3 mm in size of a sericite-epidote-altered albite. The matrix between the albite is made up of chlorite, biotite and minor amounts of quartz and calcite. Accessory minerals are sphene, epidote and apatite.

INTRUSIONS IN THE KURRAVAARA CONGLOMERATE

In the northern part of the Kurravaara conglomerate, there are some long and narrow intrusions of rocks of different composition, which in the main follow the strike of the conglomerate. At Palsivaara, near the contact with the Lower Hauki Formation, the intercalations are made up of a sericite quartzite which is probably an altered acid volcanic rock. Between Pikku Gruuvivaara and the Torne river, a porphyrite, a syenite-porphyry and an ultrabasite are found at about the same stratigraphic level in the conglomerate.

Sericite quartzite

On the northern slope of Palsivaara, in the Kurravaara conglomerate, two parallel intercalations of sericite quartzite occur, which are 10–20 m thick and have a considerable length; the northern intercalation attains a minimum length of about 1 500 m. The contact between the sericite quartzite and the Kurravaara conglomerate is sharp and straight. Both the strike (roughly E–W) and the dip (about 60–70°S) of the sericite quartzite are conformable with the layering of the Kurravaara conglomerate. The northern intercalation, between Kuusivaara and Kurravaara, is oriented N–S and cut to the south by an E–W trending fault here forming the boundary between the Kurravaara conglomerate and the rocks of the Lower Hauki Formation.

The sericite quartzite is a grey to green-grey, dense, often almost glassy rock with a concoidal fracture. A characteristic feature is the small content of grains, 0.1–0.5 mm in size, of quartz and feldspar. 1–3 mm large, rusty and limonite-filled vesicles are

Fig. 10. Kurravaara conglomerate. Pebble-free layer. To the left fine-grained layer with quartz and magnetite. To the right fragments of albite and magnetite (black) in a matrix of biotite, epidote and some magnetite. Kojuvaara. Crossed nicols, x 38.

common. The western part of the northern intercalation contains 5 mm large, light-grey spots rich in sericite. Locally, as in the southern intercalation, the sericite quartzite at the southern contact with the Kurravaara conglomerate contains light-coloured layers, which have thicknesses of some centimetres but only very restricted extensions along the strike. The layering is sometimes obliterated as it is cut at right angles by the schistosity.

The sericite quartzite has a grain size of about 0.02 mm and consists of quartz, some sericite and albite, and small amounts of magnetite. In this aggregate with a parallel texture, there are sparse phenocrysts, about 0.2 mm in size, of quartz, and a somewhat sericite-altered albite (Fig. 11). The vesicles, up to 3 mm in size, are filled with calcite, ankerite, pale-green chlorite, and quartz.

A sample of a dark, layered, tuffite-like quartzite shows that the fine-grained layers, with a grain size of about 0.02 mm, are built up of quartz, sericite, magnetite, and subordinate amounts of albite. Coarser layers with a grain size between 0.1 and 0.5 mm have the same composition, but in addition these contain some green biotite and pale-green chlorite and accessory amounts of tourmaline.

The sericite quartzite in the Kurravaara conglomerate is identical to that of the Lower Hauki Formation (p. 54). Probably the sericite quartzite in both formations is of magmatic origin, being an altered acid lava. The sericite quartzite in the Kurravaara conglomerate thus represents an intrusion related to the lavas in the Lower Hauki

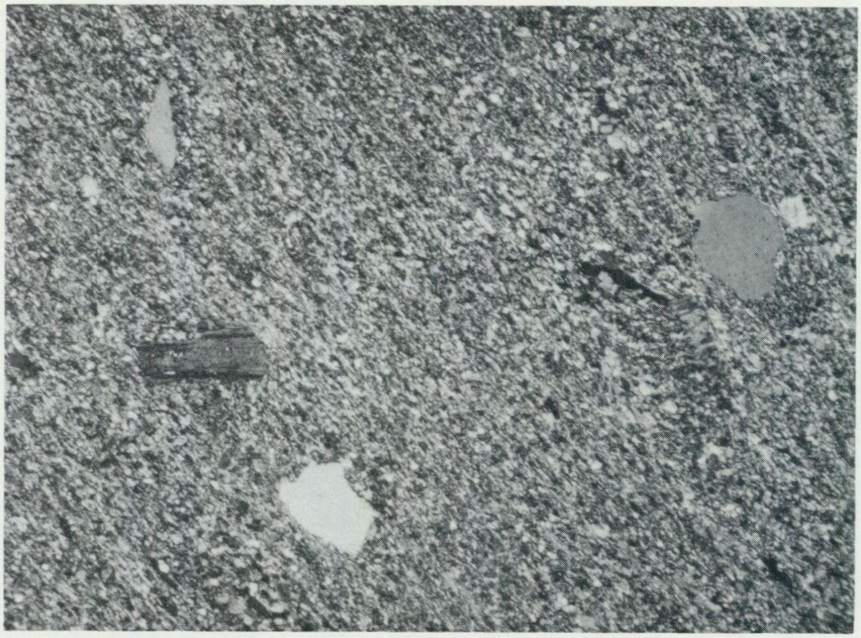

Fig. 11. Sericite quartzite in Kurravaara conglomerate. Phenocrysts of quartz and albite in a matrix of quartz, sericite and some albite. Northwest of Kirkasjärvi. Crossed nicols, x 38.

Formation. This rises the question as to why the sericitization-silicification that altered the lava rock did not affect the surrounding Kurravaara conglomerate.

Porphyrite

Some hundred metres south of the highest point of Pikku Gruuvivaara, a porphyrite appears in the Kurravaara conglomerate. The extent of the porphyrite is not known with certainty, but the thickness is at least 10 m. The strike is probably parallel to the layering in the Kurravaara conglomerate, i.e., about N80°E. A 3 dm large fragment of a greenstone-like rock is enclosed within the porphyrite. The former is almost certainly a pebble-free layer in the Kurravaara conglomerate. The porphyrite is cut by decimetre-wide veins of quartz with some amphibole and epidote.

The porphyrite is rich in lath-shaped phenocrysts, up to 4 cm in length, of light-grey feldspar. The matrix is dark-grey, fine-grained and at places rich in small accumulations of biotite. Amygdules, filled with quartz, calcite and some epidote are rather common. These are a few centimetres in size. The feldspar phenocrysts consist of albite ($Ab_{92}An_8$), which has frequently been altered to sericite and to a lesser extent biotite, epidote, and calcite. The matrix is composed of biotite, albite, epidote, calcite, magnetite, and apatite. There are irregular spots almost exclusively built up of 0.005–0.05 mm long laths of albite which in part intersect each other.

A dike of a similar porphyrite in the Kurravaara conglomerate at Pahtosvaara has been described by Sundius (1915).

Ultrabasite

About 450 m southeast of the summit of Pikku Mäntyvaara, in the Kurravaara conglomerate, a green-grey, fine-grained, markedly schistose chlorite-amphibole rock occurs, which is similar to the ultrabasic intrusions in the Kiruna greenstone (cf. p. 14). The rock is composed of up to 5 mm long needles of tremolite-actinolite in a matrix of a pale-green penninite. The extent of this rock is not known, but it is supposed to have intruded conformably with the layering in the conglomerate. Neither the age nor the relationship to the other ultrabasites in known, possibly they all belong to the same igneous activity.

Syenite-porphyry

About 240 m to the south of the highest point of Pikku Mäntyvaara, in the Kurravaara conglomerate, a grey-black syenite-porphyry rich in narrow calcite-filled veins is met with. The rock is dominated by 0.05–0.1 mm long laths of albite in a sub-parallel texture; biotite and chlorite are subordinate and hematite appears in small amounts. Apatite and epidote are accessories. Phenocrysts (1 mm in size) of a weakly sericite-altered albite occur in this rock type.

The syenite-porphyry probably displays an intrusion into the Kurravaara conglomerate. In the Kiruna greenstone, northwest of Kiirunavaara, there are dikes of a keratophyre (Sundius 1915) which are similar to the syenite-porphyry. It is not possible to state whether these porphyries are genetically and temporally related to the formation of the rocks of the Porphyry group.

PORPHYRY GROUP

The rocks of the Porphyry group, which take up the central part of the Kurravaara area, are, from west to east, 1, syenite-porphyry, 2, quartz-bearing porphyry, and 3, the rocks of the Lower Hauki Formation. The latter continue farthest to the north, here forming an intermediate member between the Kurravaara conglomerate and the Quartzite group. The thickness of the Porphyry group is somewhat more than 1 500 m in the south.

The contacts of the Porphyry group with the surrounding rock units are not exposed. The contact between the syenite-porphyry and the Kurravaara conglomerate was accessible for observation, however, in an artificial exposure (made by excavation) at Valkeasiipivaara (Fig. 12). About 10 m to the west of the contact, the Kurravaara conglomerate is crushed and deformed. Eastwards, the conglomerate passes successively, over a distance of some metres, into a schistose, soft rock rich in amphibole. In

Fig. 12. Contact between syenite-porphyry (under the axe) and Kurravaara conglomerate (to the right). Valkeasiipivaara.

this rock, which has a thickness of 0.5–2 m, there are rounded pebbles (1–5 cm in size) of a grey felsite and small, irregular remnants of the Kurravaara conglomerate. East of the amphibole-rich rock, there is a crushed and deformed felsite cut by centimetre-wide chlorite-filled veins. The contact surface, which strikes N60°E and dips 75–80°NW, is partly irregular as the felsite has been ''intruded'' and split up by decimetre-thick wedges of the conglomerate. The felsite contains angular spots up to 2 cm in size, where the rock is bleached and weathered. The contact between the Kurravaara conglomerate and the syenite-porphyry at Valkeasiipivaara has therefore been affected by deformation. The syenite-porphyry adjacent to the conglomerate is locally somewhat crushed and deformed. There is, however, insufficient evidence to believe in any great unconformity between these two rock units.

SYENITE-PORPHYRY

The syenite-porphyry in the Kurravaara area is the direct continuation of the footwall rock of the iron ores at Kiirunavaara and Luossavaara. The thickness of the syenite-porphyry is greatest in the southwestern part, at Valkeasiipivaara, reaching about 1 000 m. To the northeast it pinches out at Välivaara. The syenite-porphyry shows rather great variations in texture and mineralogical composition. In the southwestern part there are mainly varieties with a clear porphyritic texture; to a minor extent felsitic varieties occur. In the northeastern part amygdaloidal, magnetite-rich syenite-porphyries and magnetite-syenite–porphyries dominate. These are, in part, potassium-rich and thus differ from the main part of the porphyry which is sodium-rich or alkali intermediate (Table 3).

The porphyritic variety at Valkeasiipivaara, west of Nukutusjärvi and locally at Hopukka and Välivaara, is a brown-grey, dense rock with 1–5 mm long, lath-shaped phenocrysts of a grey or pale-red, somewhat biotite-sericite-altered albite ($Ab_{95}An_5$) which are crushed and broken (Fig. 13). The matrix between the phenocrysts has a grain size of about 0.02 mm and consists mainly of anhedral grains of albite; biotite, sphene and magnetite occur in subordinate or small amounts. Accessory minerals are apatite, chlorite and epidote. The porphyry near the contact with the Kurravaara conglomerate is often somewhat crushed and has a reddish colour. The porphyry west

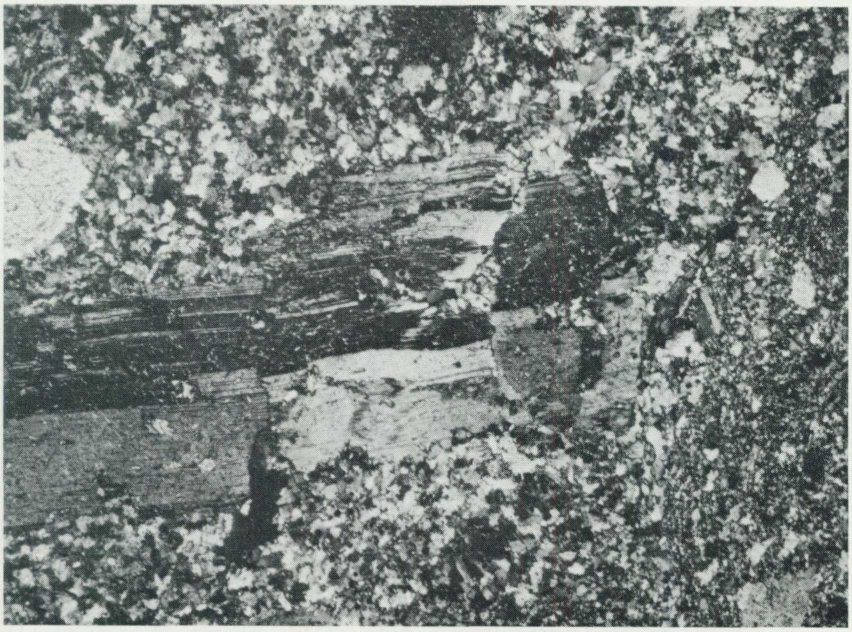

Fig. 13. Syenite-porphyry. Phenocrysts of albite in a matrix of albite and subordinate magnetite, biotite and epidote. Valkeasiipivaara, 650 m northeast of Korpsjön. Crossed nicols, x 38.

of Nukutusjärvi is darker than usual due to a relatively high content of amphibole, hornblende, biotite, magnetite, and sphene. Amygdaloids are relatively common. They contain 1–3 mm large vesicles, sometimes elongated in the direction of the schistosity, and filled with calcite, biotite, albite, and small amounts of sphene.

The felsitic variety is mainly found at Valkeasiipivaara along the contact with the Kurravaara conglomerate. It also occurs locally west of Nukutusjärvi. It is a grey or pale-red, dense rock often crushed and cut by narrow veins with calcite and small amounts of chalcopyrite. The felsite consists of anhedral, or sometimes lath-shaped, grains of albite, about 0.02 mm in length, which are arranged in a diffuse trachytic texture. Magnetite, epidote, tremolite-actinolite, and biotite occur in small amounts. Accessories are apatite, allanite and sphene. The matrix contains occasional phenocrysts, 0.5–1 mm in size, of a ''striped'' albite which is somewhat epidote-calcite-altered.

Magnetite-rich syenite-porphyries and magnetite-syenite-porphyries occur at Hopukka and Välivaara. They are often rich in amygdules, 1–2 mm in size (occasionally up to 1 cm), which are filled with calcite, quartz and small amounts of apatite, magnetite and sericite. The magnetite-rich syenite-porphyry is a black, dense rock which consists of albite and subordinate amounts of magnetite. The albite is often ''striped'' and forms 0.1 mm long laths, which are arranged intersertally or sometimes more or less parallel in a texture similar to a fluidal one. The albite laths are surrounded by magnetite and small amounts biotite and leucoxene. In this matrix euhedral laths, 0.4–1 mm long, or tables of a somewhat brown-coloured and turbid, ''striped'' albite occur. The magnetite-syenite-porphyry differs from the magnetite-rich syenite-porphyry by a higher content of magnetite, making up almost half of the matrix.

On the southeastern part of Hopukka, a dark-grey or black-grey, dense, somewhat schistose rock occurs which is rich in ellipsoidal vesicles (0.5–2 cm in size) filled with quartz and calcite. This amygdaloidal rock is potassium-rich and thus differs from the other syenite-porphyries. Biotite and potash-feldspar dominate and occur as grains (0.04 mm in size) mostly arranged at random. The biotite, however, shows a parallel arrangement around the vesicles. Magnetite is subordinate and apatite and zircon are found in accessory amounts. In this biotite-feldspar-rich matrix occur rounded spots, 1 mm in size, which are composed of 0.1 mm long, narrow laths of potash-feldspar and small amounts of magnetite and biotite. On the southern part of Hopukka, there is a dark, dense rock consisting of biotite and magnetite, some calcite and apatite and accessory amounts of tourmaline.

The magnetite-rich syenite-porphyry near the contact with the Lower Hauki Formation is locally secondarily altered. At Välivaara, the porphyry is crushed and cut by small veins with sericite (Fig. 14). In addition calcite, quartz and small amounts of albite, microcline, apatite, and allanite are present. The feldspar in the porphyry is totally sericitized. On the southeastern part of Hopukka, the porphyry is cut by 2–3 mm wide veins with calcite.

Fig. 14. Magnetite-rich syenite-porphyry veined by sericite (light). Summit of Välivaara. Crossed nicols, x 100.

The magnetite-rich syenite-porphyry west-northwest of the summit of Hopukka is cut by irregular veins, up to 10 cm wide, of a grey, dense sericite quartzite (Fig. 15). The contact between the quartzite and the syenite-porphyry is sharp. The quartzite contains small, irregular fragments of the porphyry. The quartzite is composed of fine-grained (grain size about 0.02 mm) quartz and sericite, further small amounts of albite and accessory amounts of zircon and apatite. The quartzite is in turn cut by narrow veins of albite and tourmaline.

This alteration in the magnetite-rich syenite-porphyries, with the formation of sericite, quartz and calcite as main secondary minerals, is apparently connected with the alteration that affected the rocks of the Lower Hauki Formation.

Locally, tuffs, mostly of rather restricted extent, occur in the different varieties of the syenite-porphyry.

The porphyritic variety near the contact with the Kurravaara conglomerate is rather rich in fragments which are up to 1–2 cm in size, rounded or sub-rounded, narrow and oriented parallel to the schistosity. The fragments consist of syenite-porphyries, albitophyres and, rarely, magnetite-bearing albitophyres. The syenite-porphyry of the fragments contains 0.1–2 mm long, lath-shaped phenocrysts of albite which are altered to sericite with some biotite and zoisite. The matrix consists of anhedral grains of albite (0.05 mm in size); biotite, epidote, zircon, and apatite are subordinate. The albitophyre fragments are dominated by 0.5 mm long laths of a sericite-altered albite and contain small amounts of epidote, sericite, sphene, biotite, and apatite. In the

Fig. 15. Veins of sericite quartzite in amygdaloidal magnetite-rich syenite-porphyry. Hopukka.

syenite-porphyry at Välivaara 1–2 cm large, irregular fragments of a magnetite-rich syenite-porphyry occur.

Tuffs are also found in the felsitic variety. In the northernmost outcrop of the syenite-porphyry at Valkeasiipivaara there is a tuff, previously described by Fredholm (1894) and Geijer (1910), which contains angular fragments, up to 1–2 cm in size, extended parallel to the schistosity. Most fragments consist of an albitophyre composed of 0.1 mm long laths of albite, and small amouts of actinolite, magnetite and sphene (Fig. 16). Sparse fragments of a magnetite-syenite-porphyry occur both here and in the felsite west of Nukutusjärvi.

The magnetite-rich syenite-porphyry at Hopukka contains irregular, almost schlieren-like fragments (2–3 mm in size) of a magnetite-rich albitophyre. In addition there are irregular fragments (1–2 cm in size) of a pale-red, dense quartzite which consists of quartz accompanied by subordinate amounts of calcite, biotite, potash-feldspar, and tourmaline.

QUARTZ-BEARING PORPHYRY

The quartz-bearing porphyry, which occurs between the syenite-porphyry and the rocks of the Lower Hauki Formation, has a thickness of about 300 m in the southwestern part. The northernmost locality is found at Hopukka, where the quartz-bearing porphyry pinches out. South of Haukivaara, the quartz-bearing porphyry appears east

Fig. 16. Felsite tuff. Matrix of albite and some biotite, magnetite, epidote and zircon. To the left a fragment of albitophyre. Valkeasiipivaara, 650 m northeast of Korpsjön. Crossed nicols, x 38.

of the Lower Hauki Formation and forms a wedge in the rocks of the Quartzite group. This irregularity is due to tectonic disturbances: the NE–SW trending fault from Porfyrberget to Haukijärvi forms the contact between the quartz-bearing porphyry and the rocks of Lower Hauki Formation and the Quartzite group.

The quartz-bearing porphyry is rather homogeneous: a grey-red to brown-red, non-schistose rock with lath-shaped phenocrysts of feldspar, 1–5 mm, occasionally 1–2 cm, in size. Concentrations of magnetite measuring a few mm in diameter are rather common in the matrix. North of Matojärvi, the porphyry contains 1–2 mm large cavities filled with limonite and some quartz. In the outcrops north of Olofs kulle, the porphyry is cut by veins up to 10 cm wide and filled with hematite and quartz. In the same area, there are veins of apatite which brecciate the porphyry (Geijer 1910).

The phenocrysts consist of a micro-perthitic feldspar in which albite-oligoclase dominates and potash-feldspar is subordinate. The groundmass consists of alkali feldspar and quartz in micropoikilitic intergrowths. In addition, there are small amounts of magnetite and zircon and accessory amounts of sphene, hornblende, apatite, and calcite.

Adjacent to the rocks of the Lower Hauki Formation, the quartz-bearing porphyry is tectonically and metasomatically affected. North of Olofs kulle and north of Matojärvi, the porphyry is markedly schistose, sericite-altered and intersected by narrow quartz veins. The porphyritic texture is obliterated in places. The feldspar of the

Fig. 17. Quartz-bearing porphyry with schistosity gently dipping to the east. Porfyrberget.

phenocrysts and in the groundmass is sericitized. Other secondary minerals are quartz, zircon, tourmaline, and albite. In an outcrop 400 m north of Olofs kulle, there is a network of small veins with quartz and some sericite, barite and tourmaline. In the Rektor iron ore, the porphyry contains ankerite and sometimes also biotite.

At Porfyrberget, the porphyry shows a pronounded schistosity which strikes N–S and dips 35–45°E (Fig. 17). Here an agglomerate occurs with fragments of the quartz-bearing porphyry which are 2–20 cm in size and elongated in the direction of the schistosity. The porphyry around the fragments is strongly deformed, sericitized and rich in parallel quartz veins. Agglomeratic varieties have been described by Geijer (1910, p. 137) from the area about 650 m north of Olofs kulle; 5 cm large fragments of a pale-red, dense felsite and a magnetite-syenite-porphyry occur in a rock which is made up of a dark-grey, fine-grained, schistose, biotite-rich matrix with grains, 1–10 mm in size, of a white or pale-red feldspar.

At the Nukutus iron ore deposit, the quartz-bearing porphyry is texturally different and contains more quartz than the great mass of the porphyry. It is a pale-red to tile-red, dense, non-schistose rock which usually contains narrow veins of hematite and calcite. Phenocrysts of albite with some potash-feldspar and irregular phenocrysts of quartz occur in a fine-grained matrix of feldspar and quartz. The rock contains some sericite and calcite in schlieren or as small spots. In the outcrops farthest to the south, the porphyry is strongly altered and rich in quartz, calcite and apatite. Albite, biotite and magnetite are subordinate, and allanite, zircon and tourmaline occur in small amounts.

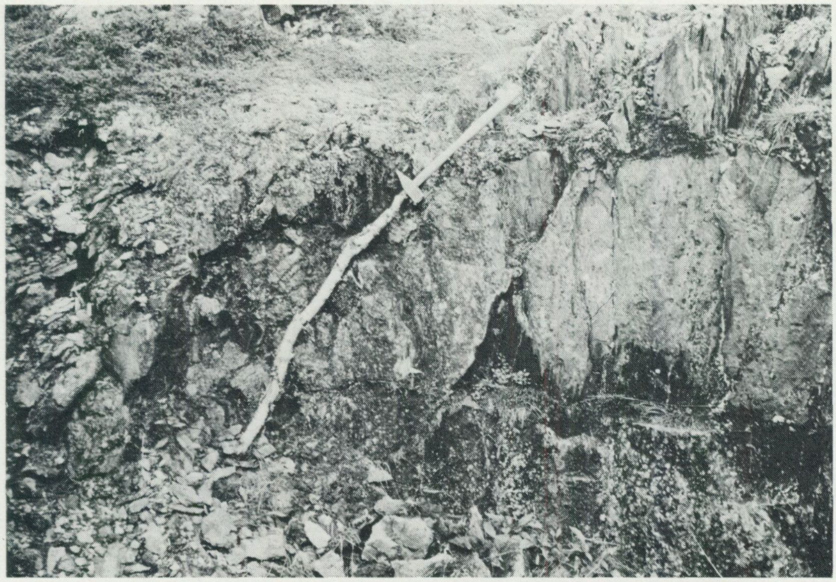

Fig. 18. Contact between basal conglomerate of the Quartzite group with moderatly dipping schistosity (to the left) and syenite-porphyry of the Lower Hauki formation with vertical schistosity. North of Olofs kulle.

LOWER HAUKI FORMATION

The Lower Hauki Formation is the stratigraphically highest part of the Porphyry group. The formation is 100–400 m thick and bounded to the west by the quartz-bearing porphyry, the syenite-porphyry and the Kurravaara conglomerate. To the east the Lower Hauki Formation is bounded by the sediments of the Quartzite group, except for the southernmost part where the quartz-bearing porphyry occurs.

The rocks of the Lower Hauki Formation are conformable with the surrounding rock units. North of Olofs kulle, however, there is a small angular unconformity against the rocks of the Quartzite group: the schistosity in the rocks of the Lower Hauki Formation dips vertically whereas that of the basal conglomerate of the Quartzite group dips 60°E (Fig. 18). This is a result of upthrust movements from the east (p. 9).

The Lower Hauki Formation contains intermediate and acid volcanic rocks in a rather irregular distribution. All the rocks are characterized by marked schistosity and monotonous mineralogical composition. Major components are quartz and sericite, locally accompanied by subordinate to small amounts of chlorite and calcite. Hematite is an ubiquitous mineral occurring in minor quantities. The present mineral composition of the rocks is related to a late hydrothermal alteration in the volcanism which produced the Porphyry group. The original nature of the rocks of the Lower Hauki Formation cannot always be established with certainty due to the secondary mineralogical composition and the marked schistosity.

The following rock members can be discerned: 1, syenite-porphyry, which is largely agglomeratic, including minor parts which are tuffitic; 2, sericite-rich breccia; 3, light sericite quartzite with narrow intercalations of siliceuos hematite ore, and 4, ''Rektor porphyry''. Of these, the syenite-porphyry is without doubt of volcanic origin. The sericite-rich breccia possibly represents a completely altered agglomerate similar to that in the syenite-porphyry. The light sericite quartzite and the ''Rektor porphyry'' are presumably highly silicified acid lava flows. The ''Rektor porphyry'' has textures preserved locally which indicate that the rock originally was an ignimbrite. The siliceuos hematite ores in the sericite quartzite represent parts where the addition of iron has been considerable.

In the south, the syenite-porphyry forms the central part of the Lower Hauki Formation; the porphyry is surrounded by light sericite quartzite and sericite-rich breccia. To the north, the light sericite quartzite and the syenite-porphyry alternate. Farthest to the north only the latter is found.

The Lower Hauki Formation, from Lake Syväjärvi northwards to Palsivaara, has been given different designations on previous geological maps. On the map by Lundbohm (1910), the rocks in this northerly part are marked as a continuation of the syenite-porphyry (foot wall) of Kiirunavaara and Luossavaara, whereas on the map by Sundius (1915), these rocks are considered to belong to the Lower Hauki Formation. According to Sundius, however, there are restricted occurrences of the same quartz-bearing porphyry at Hopukka and Palsijärvi as in the hanging wall of Kiirunavaara and Luossavaara. On the map by Parák (1975), the Lower Hauki Formation covers the area between the Kurravaara and Kuusivaara hillocks. The part farther north, at Palsivaara, has been designated as the Kurravaara conglomerate.

The present map is in accordance with that of Sundius, the only difference being that Sundius' quartz-bearing porphyry at Hopukka and Palsivaara is attributed to the Lower Hauki Formation in the present work, forming a special (red) type of the agglomeratic syenite-porphyry. The rocks at Palsivaara are built up of a sericite-altered, fragment-bearing syenite-porphyry and belong, without doubt, to the Lower Hauki Formation. They show no resemblance to the Kurravaara conglomerate.

Syenite-porphyry

The main rock in the Lower Hauki Formation is a syenite-porphyry, which is agglomeratic over large areas, mainly north of Syväjärvi. The syenite-porphyry is generally so markedly schistose and altered that the porphyritic texture is obliterated. Porphyritic parts are only preserved at the Nukutus iron ore and in the area between Entiejärvi and the Rektor iron, as well as around Palisvaara.

At the northern end of the Nukutus iron ore, the syenite-porphyry contains subhedral phenocrysts (2–8 mm in size) of a sericite-altered albite ($Ab_{95}An_5$). The matrix between the phenocrysts is composed of small albite laths oriented at random together with minor amounts of magnetite, apatite, leucoxene, and biotite (Fig. 19). The rock is cut by narrow veins with chlorite, biotite and quartz.

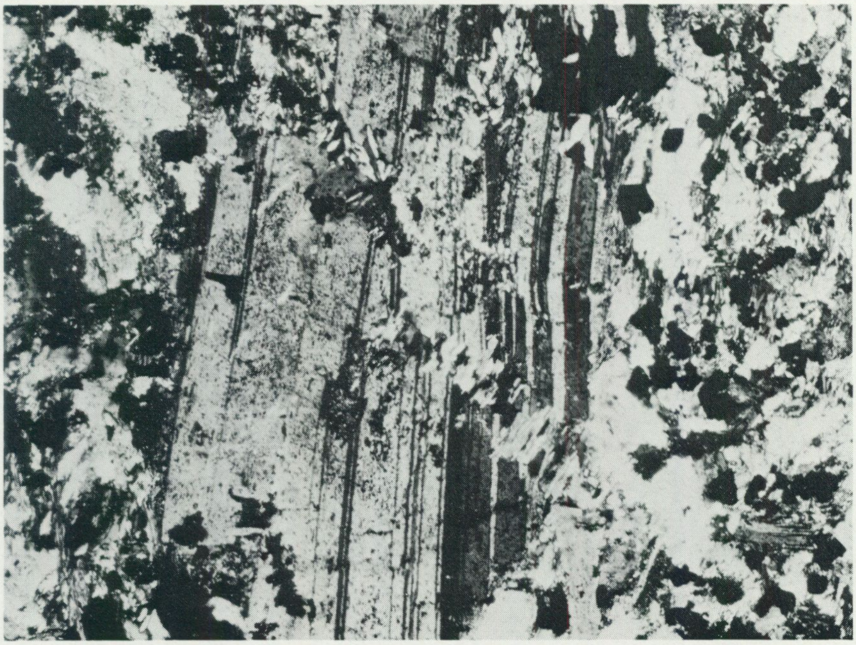

Fig. 19. Syenite-porphyry. Phenocrysts of albite in a matrix of albite, some magnetite (black), leucoxene and biotite. Southwest of Syväjärvi. Crossed nicols, x 38.

About 500 m south of the previous observation, a green-grey, markedly schistose syenite-porphyry occurs which is veined by narrow schlieren of calcite and chlorite. The porphyry contains some anhedral albite phenocrysts about 1 mm in size. Occasionally they are lath- or table-shaped but mostly resorbed by the matrix, strongly crushed and chlorite-calcite-altered. The groundmass consists of a fine-grained aggregate of quartz with small amounts of albite. In addition tourmaline, epidote, zircon, allanite, apatite, and iron oxide occur as accessories.

The better preserved part of the syenite-porphyry south of the Rektor iron ore is made up of a grey, locally brown-grey or dark-grey, schistose rock which contains pseudomorphs (2–20 mm in size) of albite phenocrysts, in the present state strongly affected by pressure and totally altered to sericite (Fig. 20). In places there are irregular, diffuse remnants of albite in the central parts of the sericite pseudomorphs. In the area farthest to the south, southwest of Entiejärvi, laths- or square-shaped albite phenocrysts are still preserved (Fig. 21).

West of Entiejärvi and between Entiejärvi and the Rektor ore, the syenite-porphyry is rich in amygdules which vary in size from a few millimetres to some centimetres. They are rounded or at times to some extent elongated in the direction of the schistosity. The amygdules are filled with quartz and calcite, some hematite (as a fine impregnation or small needles), sericite, apatite, biotite, and occasionally bornite. In the area west of Entiejärvi, the amygdules have an outer rim, 0.1–1 mm wide, of

Fig. 20. Syenite-porphyry. West of Entiejärvi.

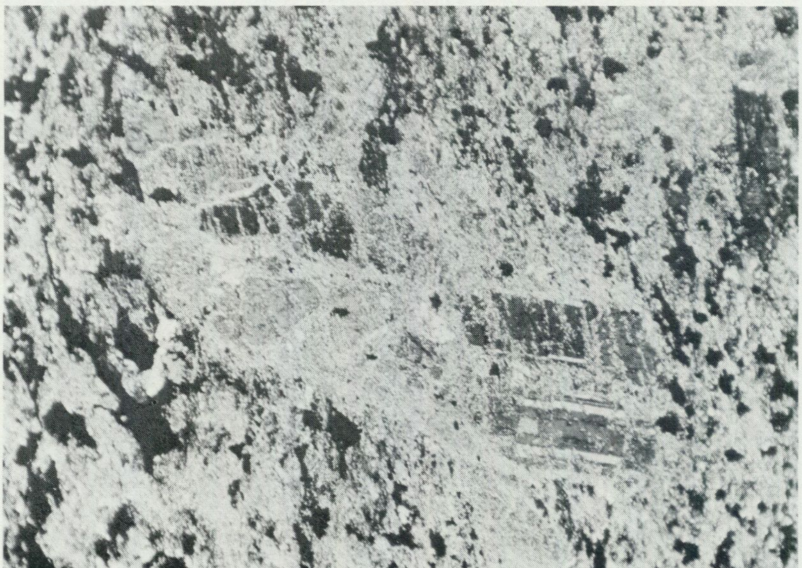

Fig. 21. Syenite-porphyry. Sericite-altered phenocrysts of albite in a matrix of sericite, hematite (black) and some albite. Southwest of Entiejärvi. Crossed nicols, x 25.

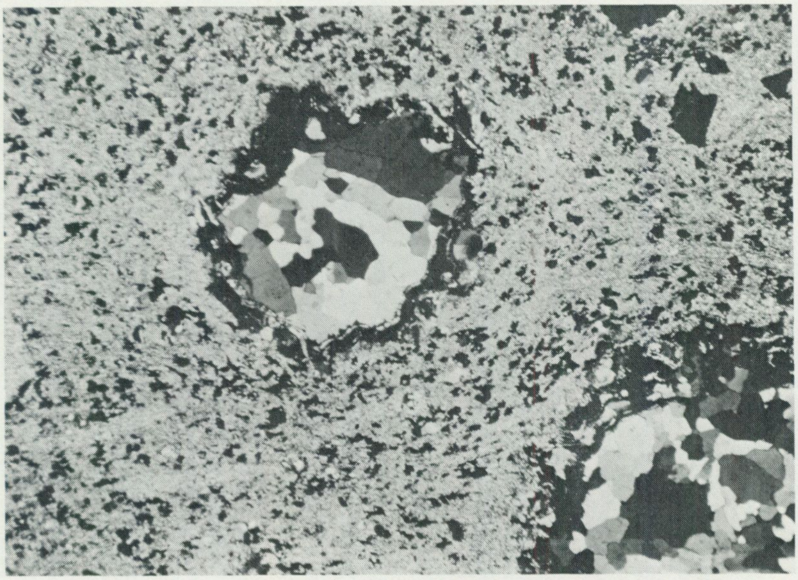

Fig. 22. Amygdaloidal syenite-porphyry. Vesicles with quartz and hematite (black outer rim) in a matrix of sericite and some hematite and quartz. West of Entiejärvi. Crossed nicols, x 17.

hematite (Fig. 22). Sometimes the amygdules are weathered and empty (Fig. 23) or filled with goethite. Often, the amygdules grow into the feldspar phenocrysts, which indicates that the amygdules are later than these.

The amygdaloidal syenite-porphyry consists of a fine-grained aggregate of a turbid, ''striped'' albite which occurs as small anhedral grains or sometimes as 0.1 mm long laths oriented at random. Sericite, calcite and hematite are present in subordinate amounts and chlorite in small quantities.

Around Palsivaara, the syenite-porphyry is usually strongly altered, but west of Kirkasjärvi there are parts where the primary textures are preserved. The porphyry contains slightly crushed phenocrysts, about 0.5 mm in size, of a sericite-altered albite. The matrix is composed of subhedral albite grains, about 0.01 mm in size, in a trachytoidal arrangement, and some sericite and magnetite (Fig. 24).

The syenite-porphyry is otherwise a grey, markedly schistose sericite quartzite rock with little of the original mineralogical composition preserved. The rock is fine-grained and foliated with sericite, quartz and hematite as main components (Fig. 25). The hematite occurs as a pigmentation or as small irregular grains. Sometimes hematite is found only in minor amounts or is almost lacking. A pale-green chlorite is occasionally present in small amounts, but can locally be a major mineral, such as east of Syväjärvi. Accessories are tourmaline, apatite, sphene, and zircon.

In the sericite-quartz-hematite-rich matrix, 1–2 mm large, irregular spots are sometimes found. These consist of small laths of a brownish, turbid feldspar (not identified) (Figs. 26 and 27). In addition, there are sparse irregular and corroded laths of a

Fig. 23. Amygdaloidal syenite-porphyry. North of Entiejärvi.

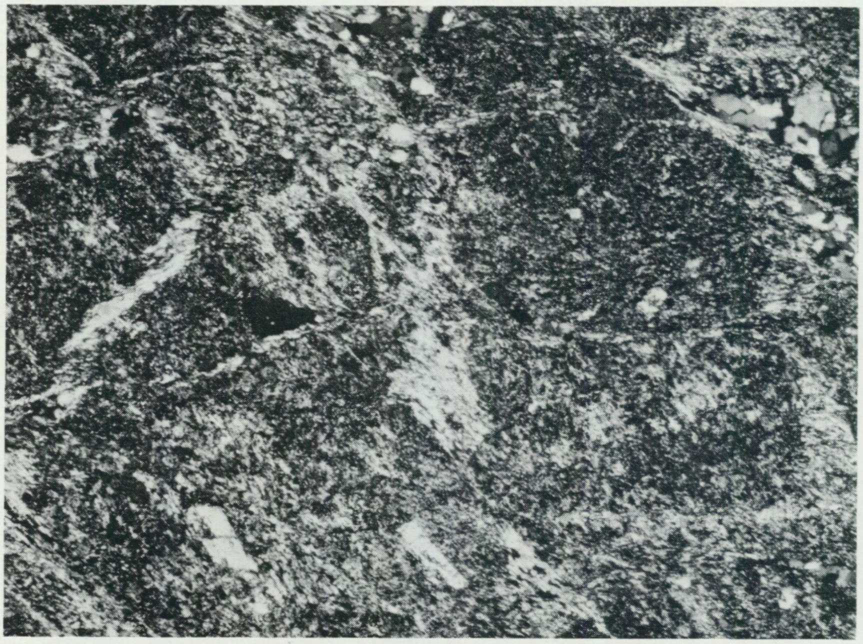

Fig. 24. Syenite-porphyry. Phenocrysts of albite in a matrix of albite, some sericite and magnetite (black). Light veins=sericite and some quartz. West–southwest of Kirkasjärvi. Crossed nicols, x 38.

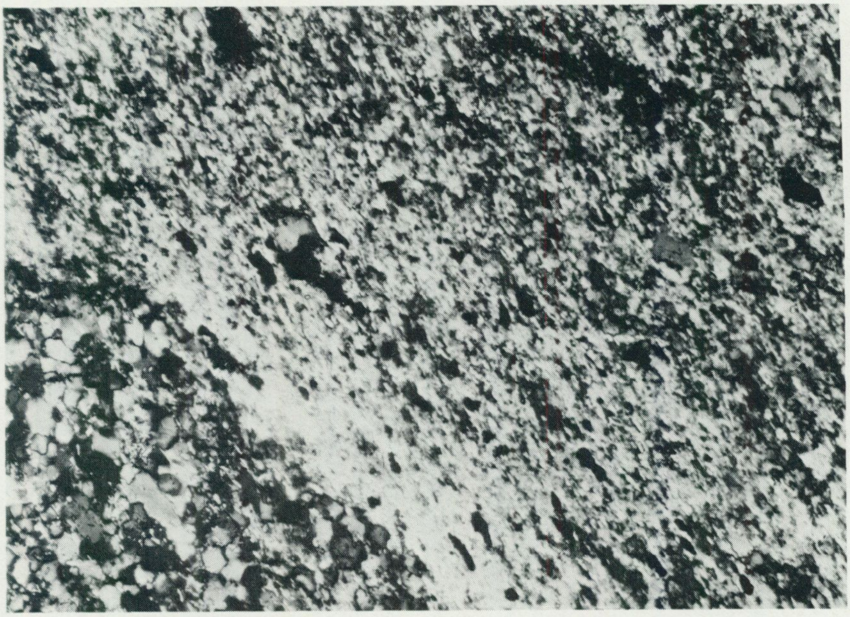

Fig. 25. Sericite-quartzitic syenite-porphyry. Schistose aggregate of sericite, quartz and hematite (black). North of Olofs kulle. Crossed nicols, x 100.

feldspar (0.1–0.2 mm in size), probably albite, which are more or less totally sericitized. The spots probably represent remnants of the original feldspar-rich matrix in the syenite-porphyry.

On the top of the hillock Olofs kulle and west of Entiejärvi, there are inclusions, some metres long and some decimetres thick, of a reddish, dense, hematite-rich quartzite in the sericite-quartzitic syenite-porphyry. At Entiejärvi, the quartzite contains small angular fragments of the syenite-porphyry and a fine-grained hematite ore.

Secondary schlieren veining the syenite-porphyry are rather common, especially in the amygdaloidal porphyry between Entiejärvi and the Rektor iron ore (Fig. 28). The veins which are up to 5 cm wide and oriented in the direction of the schistosity contain quartz, sericite and calcite. Occasionally chlorite, hematite and red feldspar are present.

The chemical compositions of a syenite-porphyry with preserved albite, and of a sericite-quartzitic syenite-porphyry are shown in Table 3.

A comparison of the syenite-porphyry in the foot wall unit and the syenite-porphyry of the Lower Hauki Formation shows that the latter has higher contents of potassium, crystal water, phosphorus, and carbonate, but lower contents of magnesium, calcium and sodium. Calcium in the foot wall unit is almost entirely bound to the femic minerals whereas in the Lower Hauki Formation it is present as calcite. Knowledge of the original composition of the porphyry in the Lower Hauki Formation is restricted, but it might have been similar to that of the foot wall unit. The differences in chemical

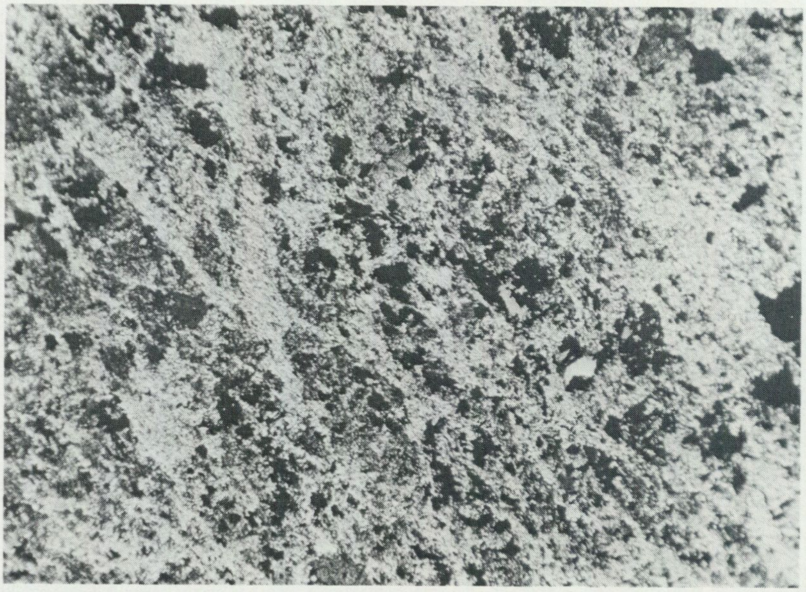

Fig. 26. Sericite-quartzitic syenite-porphyry. Feldspar (grey) and hematite (black) veined by sericite (light). South of Doktorns kulle. Crossed nicols, x 38.

Fig. 27. Sericite-quartzitic syenite-porphyry. Sericite and quartz accompained by some albite and hematite (black). Olofs kulle. Crossed nicols, x 100.

Fig. 28. Amygdaloidal syenite-porphyry veined by sericite and quartz. Southeast of Rektor iron ore.

composition between the two types of porphyry are without doubt the result of metasomatic alterations of the Lower Hauki Formation. As pointed out by Frietsch (1966), the wall rock in the iron ores of the Kiruna type was altered at a late stage of ore-formation by metasomatic changes which involved an increase in Fe^{3+}, K and H_2O and a decrease in Na, Ca, Mg, and Fe^{2+}. All these changes are found in the syenite-porphyry of the Lower Hauki Formation.

Agglomeratic syenite-porphyry

The syenite-porphyry of the Lower Hauki Formation is agglomeratic over large areas, and in addition tuffs occur locally. There are no sharp boundaries between the pyroclastic and the porphyritic parts, these grading into each other by successive transitions.

The agglomeratic syenite-porphyry is found between Entiejärvi and the Rektor iron ore, north of Olofs kulle and between Syväjärvi and Palsivaara. The greatest thickness of the agglomerate, more than 250 m, occurs at Palsivaara and Välivaara. The fragments are angular to sub-angular, sometimes sub-rounded and mostly elongated in the direction of the schistosity. The contacts between the fragments and the matrix are sharp. The matrix follows smoothly the shape of the fragments. There seems to be a difference concerning the size and composition of the fragments between the southern–central part and the northern part of the syenite-porphyry.

In the agglomerate north of Entiejärvi, at Olofs kulle and Syväjärvi, fragments

TABLE 3. Chemical analyses of syenite-porphyry in the Lower Hauki Formation and the foot wall unit at Luossavaara and Kiirunavaara.

Lower Hauki formation

	1	2	3	4	5	6	7
	Weight per cent						
SiO_2	47.35	47.42	66.85	58.74	56.88	64.24	62.00
TiO_2	1.50	1.44	0.52	0.85	0.84	0.60	0.58
Al_2O_3	16.97	17.83	13.81	17.76	19.36	16.12	16.49
Fe_2O_3	17.53	10.73	3.22	7.61	5.99	5.42	4.27
FeO	2.58	0.71	1.14	0.72	0.80	0.93	0.88
MnO	0.07	0.12	0.16	0.21	0.05	0.12	0.06
MgO	3.09	1.61	0.57	1.06	3.17	0.52	0.92
CaO	0.80	5.43	2.78	1.79	0.84	1.10	1.96
BaO	0.03	0.02					
Na_2O	0.69	1.20	5.05	3.30	3.53	3.35	0.28
K_2O	5.12	6.27	3.03	4.45	5.77	5.14	8.76
$H_2O<110°$	0.14	0.12	0.06	0.14	0.04	0.08	0.06
$H_2O>110°$	3.43	2.71	0.92	1.88	2.18	1.41	1.93
P_2O_5	0.56	0.45	0.19	0.41	0.35	0.21	0.09
CO_2	0.09	3.98	1.90	1.10	0.37	0.83	1.25
F	0.42	0.39					
S	0.01	<0.01	0.06	0.02	0.01	0.03	0.02
	100.18	100.43	100.26	100.04	100.18	100.10	100.15
	Cation per cent						
SiO_2	48.5	48.8	63.8	57.2	53.8	61.8	61.5
TiO_2	1.2	1.1	0.4	0.6	0.6	0.4	0.4
Al_2O_3	20.5	21.6	15.5	20.4	21.6	18.3	19.1
Fe_2O_3	13.5	8.3	2.3	5.6	4.3	3.9	3.2
FeO	2.0	0.6	0.9	0.6	0.6	0.8	0.7
MnO	0.1	0.1	0.1	0.2	–	0.2	0.1
MgO	4.7	2.5	0.8	1.5	4.5	0.8	1.3
CaO	0.9	6.0	2.9	1.9	0.9	1.1	2.1
Na_2O	1.4	2.4	9.4	6.2	6.5	6.2	0.5
K_2O	6.7	8.2	3.7	5.5	7.0	6.3	11.0
P_2O_5	0.5	0.4	0.2	0.3	0.2	0.2	0.1
	100.0	100.0	100.0	100.0	100.0	100.0	100.0
K/(K+Na)	0.83	0.78	0.28	0.47	0.52	0.50	0.95
$Fe^{3+}/(Fe^{2+}+Fe^{3+})$	0.87	0.93	0.72	0.90	0.88	0.83	0.95

1. Syenite-porphyry, sericite-altered. SW of Entiejärvi. Frietsch (1966, p. 252, analysis No. 33).
2. Syenite-porphyry, sericite-quartzitic. Olofs kulle. Frietsch (1966, p. 252, analysis No. 34).
3. Tuff. 60 m SW of summit of Palsivaara.
4. Agglomeratic syenite-porphyry. 20 m N of Kirkasjärvi.
5. Layered tuff. 160 m NNE of summit of Palsivaara.

Foot wall unit

	8	9	10	11	12
			Weight per cent		
SiO_2	61.24	60.78	59.71	60.97	61.12
TiO_2	0.82	2.14	0.66	1.65	1.35
Al_2O_3	13.95	14.95	16.18	15.39	17.06
Fe_2O_3	3.81	4.04	4.89	3.29	3.20
FeO	1.45	2.27	2.64	1.19	2.96
MnO	0.14	0.07	0.09	0.36	0.23
MgO	4.23	2.39	1.54	3.39	1.17
CaO	3.69	3.22	3.77	5.04	2.91
BaO	0.05				
Na_2O	5.13	5.81	5.93	5.65	7.25
K_2O	4.53	3.53	3.69	2.88	2.04
$H_2O<110°$	0.09	0.18	0.07		
$H_2O>110°$	0.38	0.53	0.22	0.60	0.74
P_2O_5	0.01	0.01	0.44	0.11	0.02
CO_2	0.51				
F					
S	0.02		tr.		
	100.05	99.92	99.83	100.52	100.05
			Cation per cent		
SiO_2	56.3	56.1	55.9	55.6	56.0
TiO_2	0.5	1.5	0.4	1.2	0.9
Al_2O_3	15.2	16.4	17.6	16.6	18.5
Fe_2O_3	2.7	2.8	3.5	2.3	2.2
FeO	1.1	1.8	2.1	0.9	2.3
MnO	0.1	0.1	0.1	0.3	0.2
MgO	5.9	3.4	2.1	4.7	1.6
CaO	3.7	3.2	3.7	5.0	2.9
Na_2O	9.2	10.5	10.6	10.0	13.0
K_2O	5.3	4.2	4.4	3.4	2.4
P_2O_5			0.3		
	100.0	100.0	100.0	100.0	100.0
K/(K+Na)	0.37	0.29	0.29	0.25	0.16
$Fe^{3+}/(Fe^{2+}+Fe^{3+})$	0.70	0.61	0.62	0.72	0.49

6. Agglomeratic syenite-porphyry, red type. 140 m SW of Kirkasjärvi.
7. Agglomeratic syenite-porphyry, red type. 200 m NE summit of Välivaara.
8. Syenite-porphyry. Luossavaara. Geijer (1910, p. 54, analysis No. 11).
9–12. Syenite-porphyry. Kiirunavaara. Geijer (1910, p. 33, analyses Nos 3–6).
Analyst for Nos 3–7: A. Aaremäe.

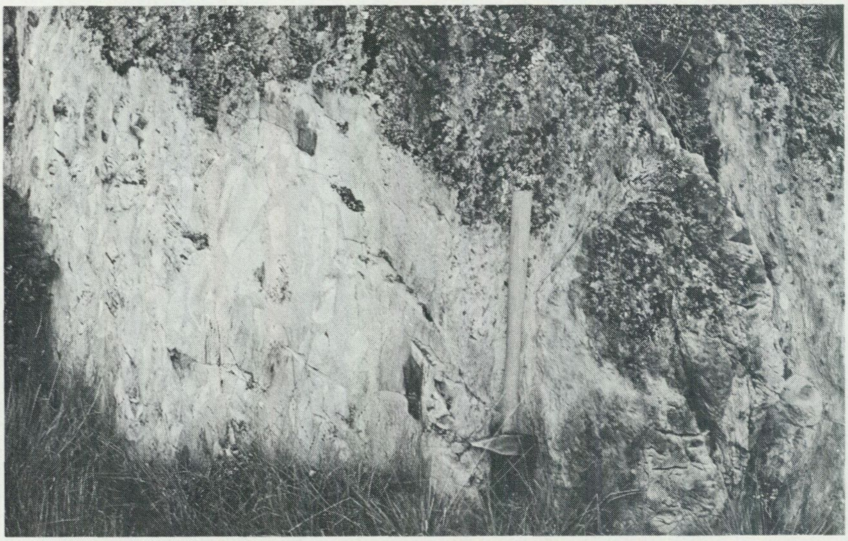

Fig. 29. Agglomeratic syenite-porphyry. Note the large fragment to the right of the hammer. Palsivaara.

measuring 1–5 cm dominate. They consist mainly of a light-grey, light-brown or pale-red sericite quartzite and a pale-green or grey-green sericite-rich schist. To a lesser extent, there are fragments of a light-grey, violet-grey or red, hematite-rich quartzite and a dark-grey or black-grey, quartz-sericite-bearing hematite ore. All these fragments are rich in quartz and contain varying amounts of sericite, calcite, hematite, and sometimes also chlorite. Fragments of a grey, weakly schistose syenite-porphyry similar to the syenite-porphyry of the Lower Hauki Formation are less common. The porphyry is quartz-sericite-altered, but in some fragments, 0.1–0.2 mm long laths of a ''striped'' albite are preserved. Occasionally the porphyry fragments contain 1–2 mm large amygdules filled with hematite and polygonal quartz.

In the agglomerate around Palsivaara, coarser fragments occur. They vary in size between 2 and 20 cm, exceptionally 80 cm, for example 150 m north of the summit of the hillock (Fig. 29). The fragments are dominated by a grey to dark-grey, sometimes violet-grey, slightly schistose syenite-porphyry which contains sparse phenocrysts, about 1 mm in size, of albite with inclusions of sericite, allanite and magnetite (Fig. 30). The groundmass between the phenocrysts consists of anhedral laths of albite 0.02–0.05 mm in length and mostly oriented at random, but occasionally displaying a trachytoidal texture. In the groundmass, there occur subordinate to small amounts of magnetite, sericite, calcite, and quartz. Biotite, apatite and allanite are accessories. Fragments of similar rocks, but without phenocrysts, are rather common. More rarely, fragments of a brown-grey, non-schistose syenite-porphyry are found with square-shaped, or more seldom, lath-shaped phenocrysts (4–5 mm in size) of a grey-brown, fresh feldspar.

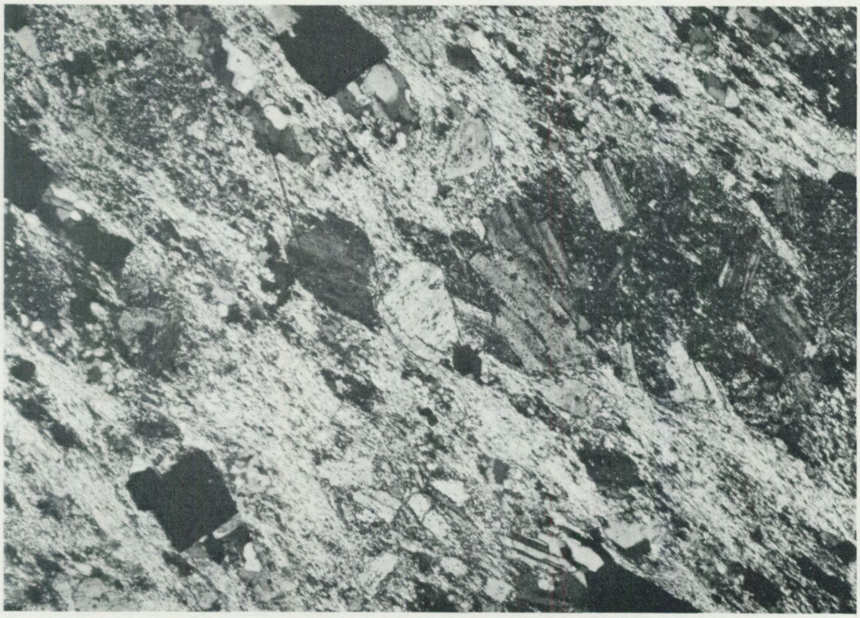

Fig. 30. Agglomeratic syenite-porphyry. Fragments of albite and syenite-porphyry in a matrix of sericite and some albite. Black grains are magnetite. West of Kirkasjärvi. Crossed nicols, x 38.

In the agglomerate around Palsivaara, fragments of sericite quartzite are found only sporadically, in contrast to their abundance in the southern–central part of the syenite-porphyry. The quartzites are grey, light-brown or grey-red, dense and sometimes with a diffuse layering. Dominant minerals are quartz and sericite, whereas calcite, magnetite and sometimes biotite are subordinate. The quartzites occasionally contain rounded or sub-angular grains (0.2–0.8 mm in size) of quartz and sericite-altered albite.

The matrix of the agglomerate is a brown-grey to dark-grey, markedly schistose, sericite-rich aggregate with small grains of a grey or grey-brown albite. Amygdules 1–3 mm in size and filled with limonite or calcite and quartz are common. The matrix, and in part also the fragments, are cut by veins, up to 5 mm wide, with calcite and quartz, sometimes also chlorite.

Under the microscope, the matrix is rich in 0.1–0.3 mm long, lath-shaped fragments of a sericite-altered albite which are often broken and bent and corroded by the groundmass. The albite fragments are mostly oriented at random (Fig. 31), but sometimes they lie more or less parallel with the schistosity. The groundmass between the fragments is fine-grained and foliated with sericite and subordinate quantities of quartz, albite and iron oxide. At Olofs kulle and Syväjärvi the latter is mostly hematite and at Palsivaara mostly magnetite. Accessories are apatite, zircon, tourmaline, and epidote. At Syväjärvi, the matrix of the agglomerate is somewhat different; it has a green colour and is composed of chlorite, sericite and quartz and minor amounts of

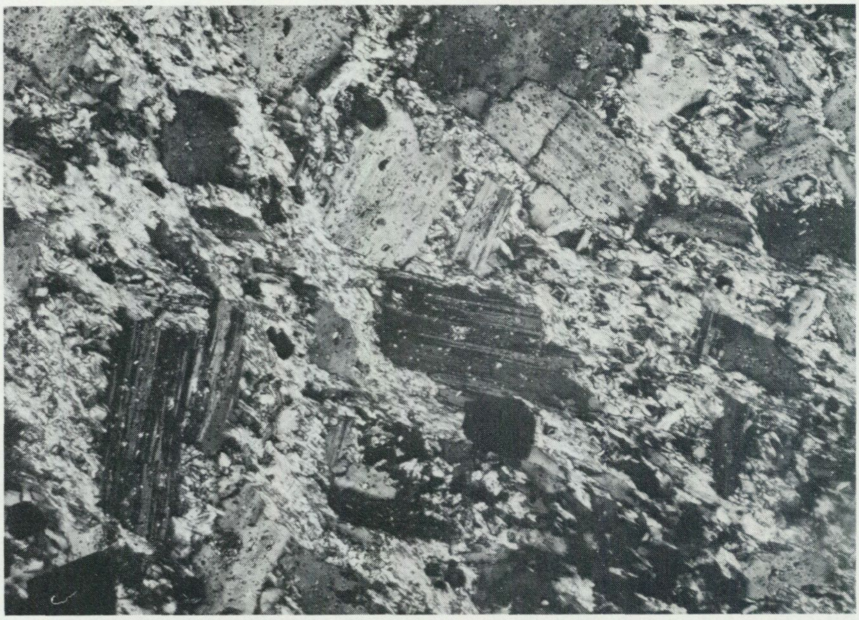

Fig. 31. Matrix in agglomeratic syenite-porphyry. Albite in a groundmass of sericite. Black grains are magnetite. Kirkasjärvi. Crossed nicols, x 100.

biotite, calcite and hematite. At Olofs kulle, the matrix contains irregular, angular and crushed grains (0.05–0.5 mm in size) of quartz which are elongated along the schistosity. These are probably fragments.

In the agglomerate around Palsivaara, there are relatively large areas where coarser fragments are not present. (Fig. 32). The rock is similar to the matrix of the agglomerate and apparently represents a tuff. 1 mm long lath-shaped fragments of a red to red-brown albite occur abundantly in a grey, schistose sericite-rich groundmass. In the area immediately south and east of the summit of Palsivaara, the tuff contains fragments of albite, up to 6 mm in size and often almost rounded. They are composed of several individuals which are irregularly intergrown. The albite fragments are crushed and cut by narrow veins with biotite, sericite and quartz. The foliated groundmass consists of grains (0.02 mm in size) of sericite and anhedral albite. Iron oxides (magnetite or hematite), quartz and occasionally chlorite and biotite, occur in subordinate and small amounts. Zircon, apatite and epidote are accessories. ''Skeleton'' crystals of magnetite, about 0.5 mm in size, are rather common. The interstices between the magnetite lamellae are filled with quartz, sericite, apatite, and calcite.

Depositional structures are encountered only rarely in the tuff. South of the summit of Palsivaara, there is a very diffuse layering which strikes N85°E and dips vertically. Northeast of the summit of Palsivaara, immediately south of the contact with the Kurravaara conglomerate, there is a 5 m thick and at least 100 m long intercalation of layered tuff which strikes approximately E–W and dips 60–70°S. It consists of

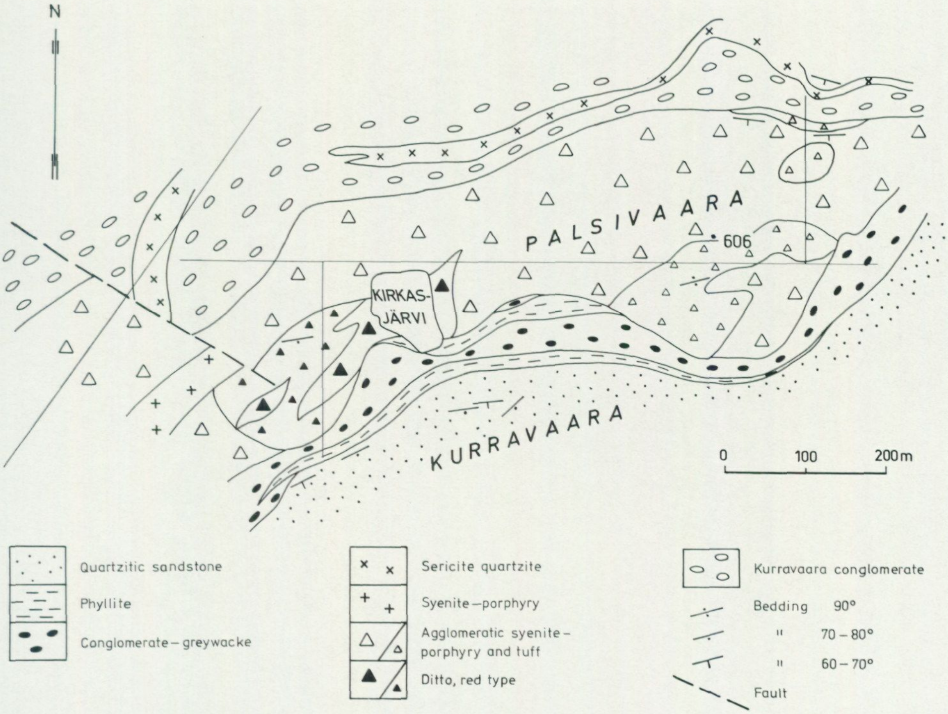

Fig. 32 Geological sketch map of Palsivaara and northern part of Kurravaara. Straight lines are base-lines used for the mapping.

alternating layers of somewhat varying grain-size which grade into each other (Fig. 33). There are minor occurrences of dark-grey, fine-grained, foliated layers which are up to 30 cm thick and have only small extensions along the strike. Their grain-size is about 0.02 mm and they are composed of sericite and quartz, small quantities of albite and iron oxide, and accessory amounts of allanite, tourmaline and apatite. These layers contain small corroded fragments of a sericite-altered albite and of syenite-porphyry (Fig. 34). The rest of the layered tuff is somewhat more coarse-grained: crushed and corroded fragments, up to 1 cm in size, of sericite-altered albite and syenite-porphyry are abundant in a sericite-quartz-rich matrix. The syenite-porphyry has a groundmass of sericite, albite and magnetite in which phenocrysts (0.2–0.6 mm in size) of sericite-calcite-altered albite occur. In addition there are small amounts of quartz fragments and narrow ''skeleton'' crystals, up to 1 mm long. The outer parts of the latter consist of magnetite, and the interstices are filled with sericite, hematite and scapolite.

It is probable that the layered tuff has, at least partly, been formed by normal sedimentary processes and thus represents a mixed pyroclastic-epiclastic rock.

The chemical compositions of the agglomerate and tuff are shown in Table 3. The samples of the agglomerate comprise only the matrix, fragments larger than 0.5 cm

Fig. 33. Layered tuff. Palsivaara.

have been avoided. The analyses show the same chemical features as found in the syenite-porphyry of the Lower Hauki Formation: relatively high potassium and aluminium contents and comparatively low sodium, magnesium and calcium contents. The tuff at Palsivaara (analysis No. 3) is similar to the syenite-porphyry in the foot wall unit, except for a low magnesium content. The low K/Na ratio is particularly apparent; this feature is related to the fact that a large part of the tuff is composed of albite.

Agglomeratic syenite-porphyry, red type

At Hopukka, Välivaara and Kirkasjärvi, the agglomeratic syenite-porphyry has a pale-red to grey-red colour on the weathered surfaces due to a high content of small fragments of a fresh feldspar. It is otherwise similar to the agglomeratic syenite-porphyry described above. As already mentioned, this red variety was designated by Sundius (1915) as a quartz-bearing porphyry of the same type as that in the hanging

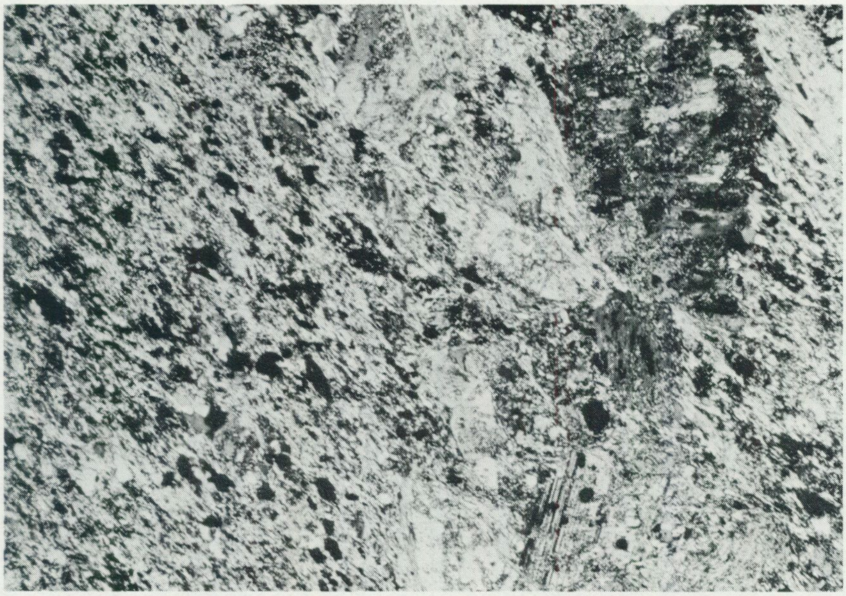

Fig. 34. Layered tuff. To the left, a fine-grained layer with sericite, quartz and some albite and hematite (black). To the right, fragments of albite and syenite-porphyry in a matrix of sericite. Palsivaara. Crossed nicols, x 38.

wall of Kiirunavaara and Luossavaara. The similarity between these rocks is, however, confined to the red colour and abundance of small feldspar laths.

At Välivaara and Hopukka, the red agglomerate is rich in potassium feldspar. At Välivaara, the agglomerate is encountered some hundred metres southeast and east of the summit. Angular and irregular fragments of microcline, approximately 1 mm in size, and sub-angular fragments, 1–10 cm large, of a red-grey to tile-red syenite-porphyry occur in a red-grey, schistose matrix consisting of microcline, quartz and sericite (Figs. 35 and 36). The syenite-porphyry contains phenocrysts, up to 3 mm in size, of sericite-calcite-altered microperthite and microcline-bearing albite in a matrix of 0.05 mm large grains of microcline, magnetite and sericite. More or less strongly pressed fragments of a brown-white, dense quartzite have also been encountered. 1–2 cm large, limonite-filled vesicles are common in the matrix between the fragments. Locally, the matrix is rich in carbonate and contains narrow schlieren of quartz.

The agglomeratic syenite-porphyry at Hopukka is similar to that at Välivaara. The porphyry fragments are, however, much more schistose and crushed than those at Välivaara.

The red agglomerate at Kirkasjärvi, extending east-west on both sides of the lake (Fig. 32), is rich in coarser fragments, usually measuring 10–20 cm in size but occasionally approaching 60 cm in length, as on the eastern shore of the lake. A pale-red, schistose and crushed syenite-porphyry with 1–3 cm large albite phenocrysts dominates among the fragments (Figs. 37 and 38). Some fragments almost totally lack

Fig. 35. Agglomeratic syenite-porphyry, red type. Välivaara.

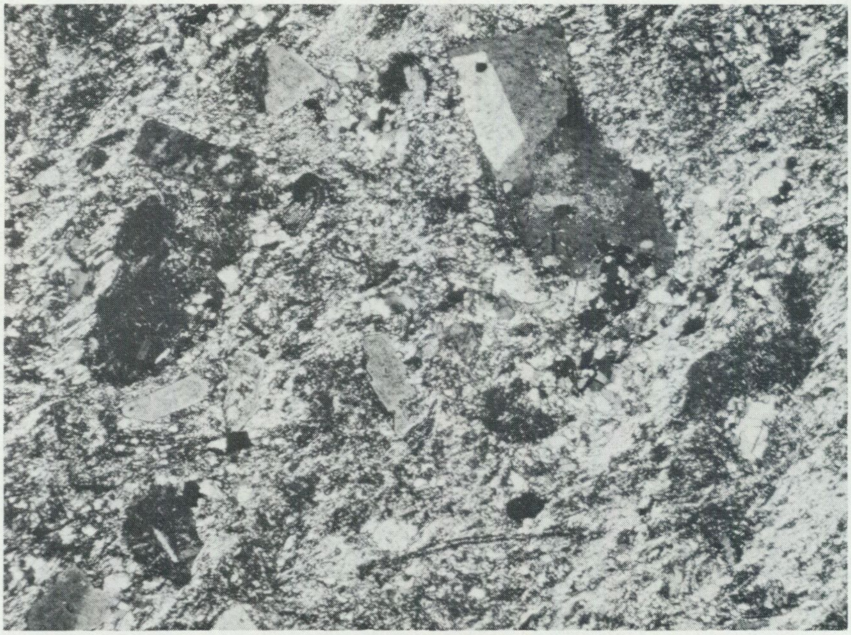

Fig. 36. Agglomeratic syenite-porphyry, red type. Fragments of microcline and potash-rich syenite-porphyry in a matrix of quartz, potash-feldspar and sericite. East-northeast of Välivaara. Crossed nicols, x 38.

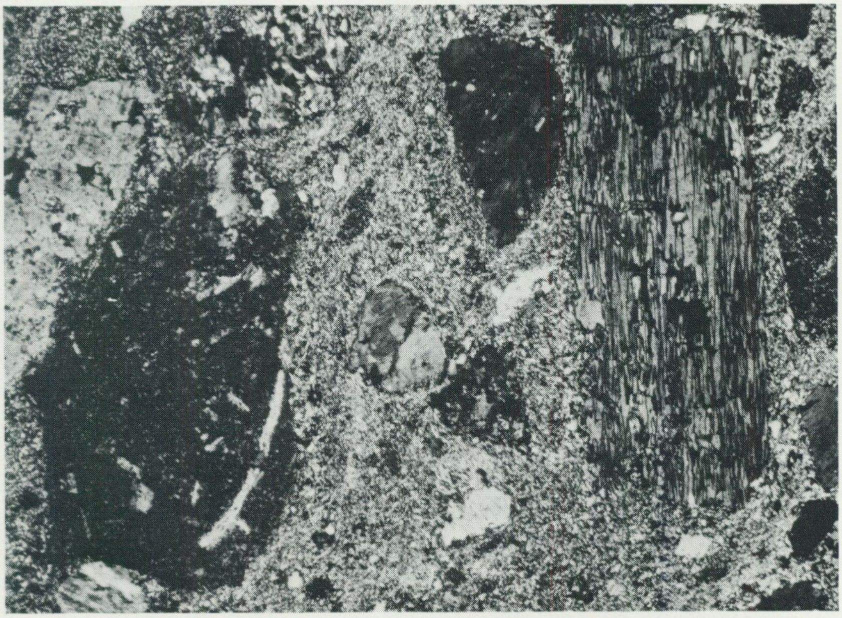

Fig. 37. Agglomeratic syenite-porphyry, red type. Fragments of albite and syenite-porphyry in a matrix of sericite and some quartz. Black grains are magnetite. Southwest of Kirkasjärvi. Crossed nicols, x 38.

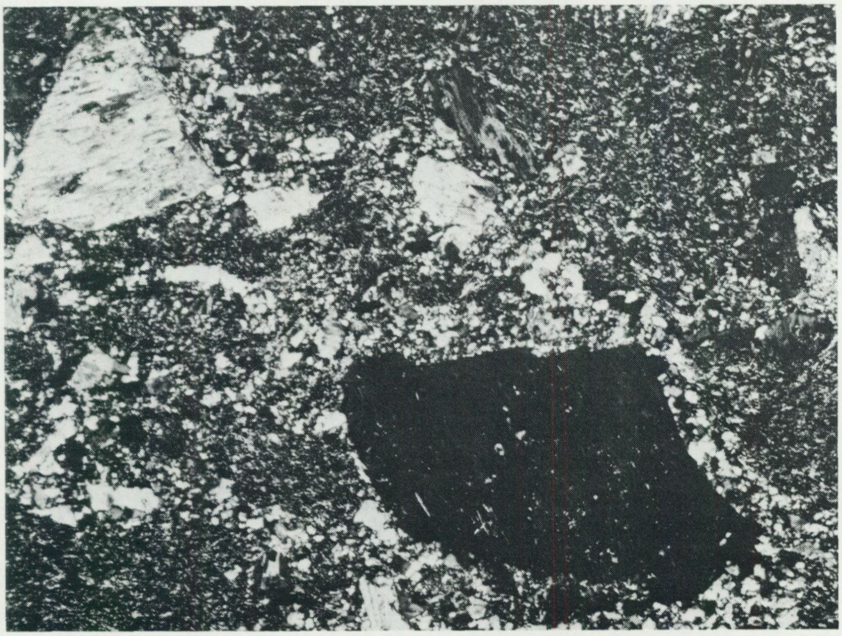

Fig. 38. Pebble of syenite-porphyry in agglomeratic syenite-porphyry, red type. Phenocrysts of albite in a matrix of albite which is veined by quartz and sericite. West of Kirkasjärvi. Crossed nicols, x 38.

phenocrysts and are thus felsitic. Fragments of a grey or green-grey, markedly schistose syenite-porphyry with phenocrysts (1 mm in size) of a completly sericite-altered feldspar are present in minor amounts. Long and narrow deformed fragments of a black-violet, dense, iron oxide-rich quartzite occur in small quantities.

A large part of the rock at Kirkasjärvi just described is devoid of coarser fragments: it is a tuff which in a markedly schistose, sericite-rich matrix contains abundant, mostly irregular but occasionally also lath-shaped fragments (1–5 mm in size) of albite. They make up 30–50 per cent of the rock. The albite is ''striped'', faintly brown coloured, somewhat turbid and strongly sericite-altered. Sometimes the albite is rather well preserved and unaltered. The albite fragments are usually corroded by the matrix which consists of 0.02 mm large grains of albite and sericite, the latter mineral often dominating. Quartz, calcite and magnetite occur in small amounts. Accessory minerals are apatite and zircon. West of Kirkasjärvi, there is a narrow intercalation of a layered tuff which strikes about N80°E.

The red variety of the agglomeratic syenite-porphyry is chemically similar to the main part of the rock (Table 3). The relatively high content of potassium in the agglomerate at Välivaara is without doubt a primary feature, related to the presence of potassium feldspar.

Sericite-rich breccia

Between Entiejärvi and Doktorns kulle, there is a sericite-rich breccia which is surrounded by light sericite quartzite and syenite-porphyry, the latter in part agglomeratic. The breccia, which is rich in fragments and strongly deformed, is of uncertain origin. No primary features can be discerned in the rock fragments. The breccia may be a totally altered agglomerate, similar to that in the syenite-porphyry.

The breccia has a grey or brown-grey, markedly schistose, sericite-quartzite-rich matrix, which commonly contains amygdules 1–10 mm large and filled with white-grey, dense quartz. The amygdules are elongated parallel to the schistosity. Vesicles filled with a limonite-like powder are present in small numbers. The fragments are about 1–10 cm in size, angular and often elongated in the direction of the schistosity (Fig. 39). North-northeast of Matojärvi the strain has been intense; the fragments are up to 25 cm long but only a few centimetres across. The fragments originate from rocks of the Lower Hauki Formation. The dominant types are brown to pale-red, grey-green or green-white sericite quartzites which are composed of fine-grained, polygonal quartz and small amounts of hematite and sericite. Occasionally some chlorite is also present. Less common are fragments of red-violet or grey hematite-impregnated quartzites, dark, hematite-rich quartzites and white, dense quartz.

Under the microscope, the matrix between the fragments is seen to vary somewhat in composition. It is foliated and mostly composed of 0.01 mm large grains of sericite and quartz (Fig. 40). In addition there are irregular, corroded, angular fragments (0.1–0.5 mm in size) of quartz which are built up of several grains with spinous boundaries. The quartz has an undulating extinction due to deformation. Hematite is

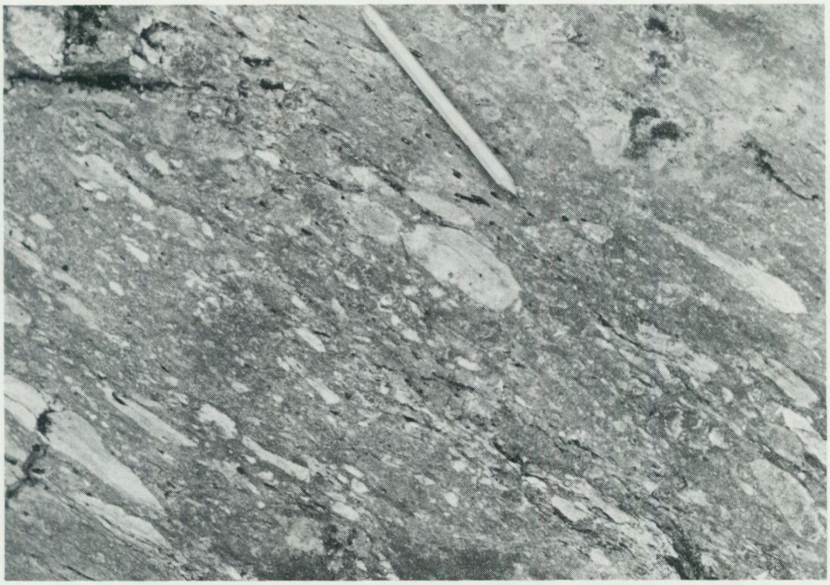

Fig. 39. Sericite-rich breccia. Fragments of sericite quartzite in a sericite-quartz-hematite-rich matrix. North-northeast of Entiejärvi.

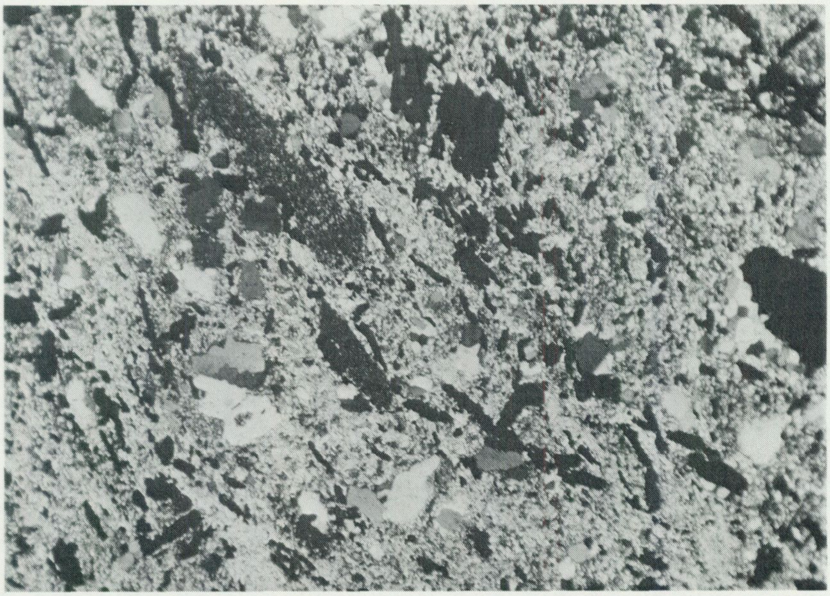

Fig. 40. Sericite-rich breccia. Fragments of quartz, hematite (black) and hematite-rich quartzite (grey; left, upper part) in a matrix of sericite and quartz. Doktorns kulle. Crossed nicols, x 25.

present in subordinate amounts either evenly distributed or as 0.1–0.5 mm long and narrow, spinous grains, sometimes rather rich in quartz. Accessory minerals are tourmaline, zircon and apatite. At the northern part of Haukivaara, the matrix is dominated by sericite and chlorite whereas quartz and hematite are found in minor amounts. Accessories are allanite, apatite and biotite. Between Haukijärvi and Haukivaara the matrix is relatively rich in irregular laths or rounded grains (0.1–0.5 mm in size) of a somewhat turbid albite.

Light sericite quartzite

The light sericite quartzite occurs in the southern–central parts of the Lower Hauki Formation, from Haukivaara to just north of Syväjärvi. Its largest extent is met with to the south at Haukivaara, the thickness of the individual horizons here being up to 200 m. From the Rektor iron ore and further north, the quartzite mostly forms relatively narrow horizons.

The light sericite quartzite is a light brown-grey, light-grey, pale-brown, or pale-green, dense, markedly schistose rock. The fracture surface is often concoidal. Sometimes the rock contains small light-brown or light-grey spots of a weathered feldspar(?). The sericite quartzite immediately to the south of the Henry iron ore locally exhibits a very diffuse layering which strikes NNE and dips 80°E.

The sericite quartzite is dominated by anhedral, densely packed grains of quartz (0.02–0.04 mm in size) and with simple boundaries (Fig. 41). Sericite, sometimes forming narrow schlieren, is subordinate, and hematite occurs in small amounts. Accessory minerals are chlorite, apatite, zircon, sphene, and barite. Anhedral grains of quartz, up to 0.5 mm in size, which occasionally are oriented in the direction of the schistosity, are also present in the matrix. Occasional bent and schlieren-like fragments up to a few mm in size of a very fine-grained, hematite-rich quartzite have further been found.

The present composition of the light sericite quartzite is a secondary feature brought about by silicification in connection with the hydrothermal processes that affected the rocks of the Lower Hauki Formation. The quartzite is devoid of primary structures. The original nature of the quartzite is therefore not apparent. It seems appropriate, however, to assume the existence of a lava rock of acid composition. The coarser quartz grains are therefore phenocrysts which have undergone recrystallization. In the ''Rektor porphyry'' which is definitely a lava flow (cf. p. 58) there are similar compositional–textural features; that is, quartz phenocrysts in a fine-grained aggregate of polygonal quartz formed by silicification of the original groundmass. As already described (p. 23), there are intercalations of a sericite quartzite in the Kurravaara conglomerate similar to that in the Lower Hauki Formation. However, these intercalations, possibly intrusions, contain feldspar (albite) occurring either as phenocrysts or in the matrix. Probably these intrusions represent better preserved parts of the original rock.

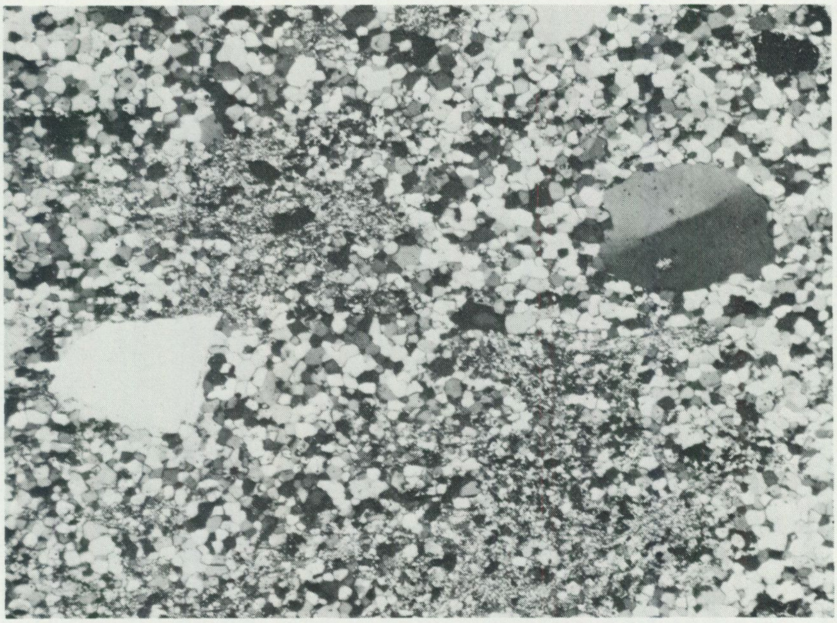

Fig. 41. Light sericite quartzite. Quartz phenocrysts in a matrix of quartz, sericite and some hematite (black). North-northwest of Olofs kulle. Crossed nicols, x 38.

Siliceous hematite ore and hematite-rich sericite quartzite

In the light sericite quartzite there are narrow intercalations of a lean, siliceous hematite ore. They are most abundant around Haukivaara. The immediate host rock of the ore is usually a grey, dense hematite-bearing sericite quartzite. Occasionally the hematite ore is surrounded by a light sericite quartzite. The thickness of the intercalations is mostly between 5 and 10 m, more rarely as little as 1 m. The thickness of the hematite ore south of Hopukka is about 40 m and south-southeast of Olofs kulle about 20 m.

The hematite ore is black-grey, fine-grained, lustrous and mostly markedly schistose. A dense, lustreless ore occurs at Hopukka. Locally the ore is rich in quartz and sericite and the colour therefore varies between grey and light-grey. The quartz occurs as an even impregnation, small schlieren or rounded aggregates. Occasionally, such as south of Hopukka, there is a diffuse layering in which 0.5 mm thick layers rich in hematite and quartz alternate. The siliceous hematite ore also exhibit a diffuse banding in the Rektor deposit, the banded parts passing successively over into the homogeneous ore. East of Matojärvi and north of Olofs kulle, in the hematite, there are abundant limonite-filled cavities (about 1 mm in size) giving the ore a cavernous appearance.

The ore consists of narrow grains of hematite 0.02–0.2 mm in length, often mutually parallel and assembled into large aggregates, and of anhedral grains of quartz

Fig. 42. Siliceuos hematite ore with fragments of sericite quartzite. Olofs kulle.

(0.03–0.05 mm in size), which often form irregular, schlieren-like aggregates. Sericite is sometimes abundant as small laths or as aggregates and schlieren. A pale-green chlorite is found in small amounts. Accessory minerals are barite, allanite, tourmaline, and zircon. The hematite ore south of Hopukka is relatively rich in barite and allanite.

In part, the hematite ore is magnetite-bearing but the content of this mineral is rather low. The hematite ore north of Entiejärvi contains small, irregular remnants of magnetite in the centres of the hematite grains. The low magnetite content in the hematite ores of the Hauki Formation has been described by Frietsch (1966). The hematite can be either primary, or secondary, formed from magnetite.

The hematite ore often contains fragments of sericite-rich rocks (Fig. 42). However, fragments are largely missing in the ore south of Hopukka and between Nukutusvaara and Syväjärvi. The content of fragments is mostly rather high; in the ore north and northeast of Olofs kulle they make up 20–30 per cent of the rock. Locally the content can be still higher, the fragments then lying densely packed in the hematite. The fragments usually have sizes of about 0.1–5 cm, but north-northeast of Olofs kulle fragments up to some decimetres in size occur. The fragments are usually angular and oriented in the direction of the schistosity. Fragments which have a schlieren-like appearance are present in small numbers. The dominant rock type among the fragments is a light-brown or grey-white, dense sericite quartzite, which in part is hematite-bearing. In some quartzites there are diffuse bands of hematite. The quartzite

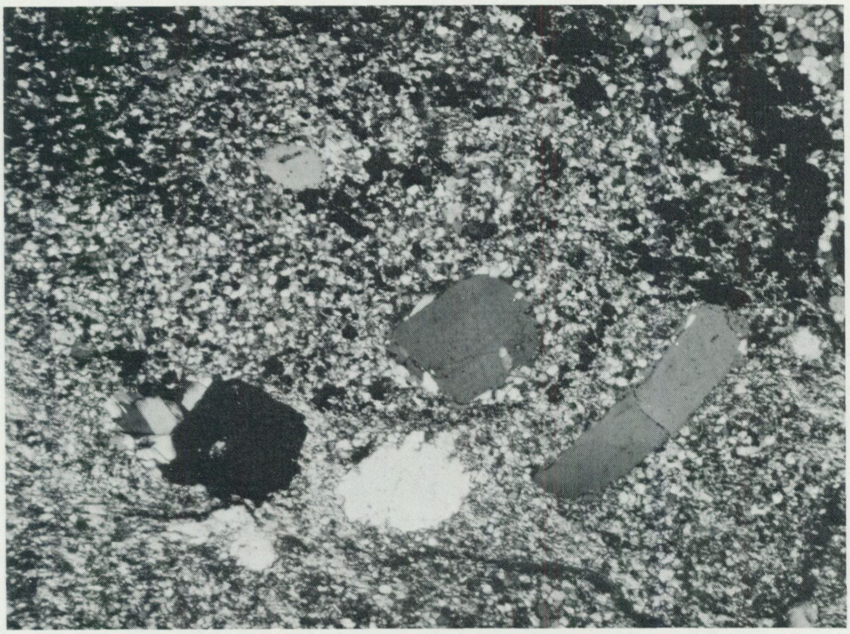

Fig. 43. Hematite-rich sericite quartzite. Phenocrysts of quartz in a matrix of quartz, sericite and hematite (black, dominating in the upper part). North-northeast of Olofs kulle. Crossed nicols, x 38.

is made up of quartz grains (0.03–0.5 mm in size) with straight, simple boundaries, further some sericite and hematite. There are also fragments of a hematite ore rather similar to the ore in which the fragments occur. Less usual are fragments of grey quartz, green sericite schist and dark-grey, hematite-bearing quartzite.

South-southwest of Olofs kulle there is a hematite ore, about 200 m long and 2 m across, which contains an intercalation of schistose ''Rektor porphyry'', this in turn cut by narrow, parallel veins of hematite and quartz. In the hematite ore, there are densely packed fragments of the ''Rektor porphyry'' making up almost 50 per cent of the volume. Further towards the south-southwest, in the ''Rektor porphyry'', there is a narrow and rather short intercalation of a light sericite quartzite in which a siliceous hematite ore with fragments of the ''Rektor porphyry'' is found.

The hematite-rich sericite quartzite which surrounds the siliceous hematite ore has, depending on the amount of hematite present, a light-grey, grey or dark-grey colour. Locally, such as south of Hopukka, the quartzite exhibits a diffuse stratification with narrow layers of hematite and quartz. The quartzite often contains small cavities filled with limonite or quartz. The quartzite is dominated by grains (0.05 mm in size) of quartz with simple and straight boundaries (Fig. 43). Hematite and sericite occur in subordinate or small amounts. Accessories are apatite, allanite, tourmaline, and barite. Angular grains (about 0.5 mm in size) of a quartz with undulating extinction are present in the quartzite. They are sometimes crushed and corroded by the matrix.

The hematite-rich sericite quartzite is probably of similar provenance as the light sericite quartzite, namely a silicified volcanic rock of acid composition. However, in the hematite-rich quartzite the hydrothermal alteration has meant an addition of large amounts of both silica and iron, and in those parts where the latter dominated, the siliceous hematite ores were formed. The occurrence in the ore of fragments of sericite quartzite and ''Rektor porphyry'' implies contemporaneous tectonic movements. Formation only by replacement could scarcely have given rise to this structural development.

''Rektor porphyry''

The stratigraphically lowermost member in the southern and central parts of the Lower Hauki Formation is a peculiar volcanic rock called by Geijer (1950) the ''Rektor porphyry''. It extends between the Rektor and Nukutus iron ores; between the Rektor deposit and Olofs kulle it seems to form a continuous horizon. The thickness of the porphyry is mostly up to 30 m, but locally attains 50 m, for example, at the Rektor deposit. The foot (western) wall consists of quartz-bearing porphyry, and in the Rektor and Henry deposits of apatite-rich magnetite-hematite ore. The hanging (eastern) wall consists of syenite-porphyry, light sericite quartzite and siliceous hematite ore. In the area between the Rektor deposit and Olofs kulle the ''Rektor porphyry'' contains intercalations of light sericite quartzite and siliceous hematite ore. The latter occurs, in addition, as intercalations in the ''porphyry'' at the Rektor deposit. The contact between the ''porphyry'' and the surrounding rocks is sharp and in most cases straight. The contact is only irregular against the apatite-rich magnetite-hematite ore. The ore behaves like an intrusive body and sends brecciating schlieren into the ''porphyry''. In addition, the ore is rich in angular, irregular fragments of the ''porphyry'' which vary in size between some centimetres and several metres. In the northern part of the Rektor ore, there are, according to Geijer (1950), 10–20 m large inclusions of the ''porphyry''. The fragments of the ''porphyry'' are metasomatically altered and rich in sericite, quartz and calcite, sometimes also tourmaline. Elongated patches or aggregates (up to several decimetres long) of sericite, sharply separated from the less altered rock, are common.

The ''Rektor porphyry'' is a quartz-feldspar rock in which the relative amounts of these minerals vary considerably. Farthest south, at the Rektor deposit, the ''porphyry'' is dominantly a tile-red, dense, weakly schistose feldspar rock which contains small, scarcely visible, irregular spots of grey-white quartz, or more rarely, carbonate. Sometimes there are millimetre-thick quartz bands in the feldspar matrix. In the Rektor open pit, the ''porphyry'' contains 1–3 mm thick bands of magnetite and hematite. The banding is in all cases parallel with the schistosity. This rock, called the ''homogeneous Rektor porphyry'' by Geijer (1950), is composed mainly of a brown, turbid potash-feldspar. A large content of red pigment prevents a closer determination of the character of the feldspar. The feldspar forms equidimensional, or sometimes somewhat rounded, grains which are 0.2–0.3 mm in diameter. They lie close together and

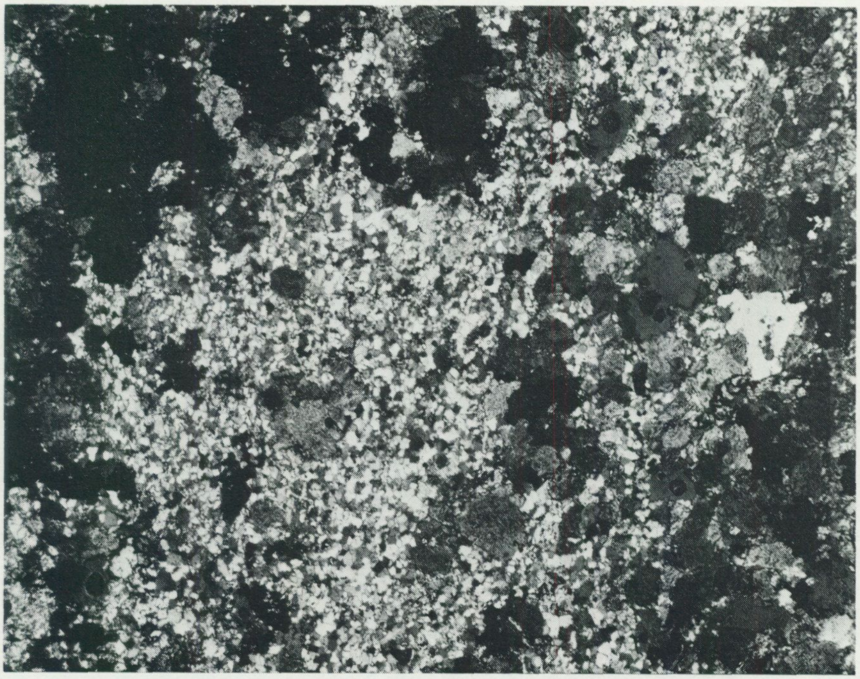

Fig. 44. ''Rektor porphyry''. Potassium feldspar (grey, anhedral grains) in a matrix of quartz and some sericite. Black=iron oxides. Rektor deposit. Crossed nicols, x 25.

are intergrown with complicated borders. A ''wandering'' extinction of the feldspar is sometimes seen. In the peripheral parts of the grains, albite is present in small amounts. Aggregates of a fine-grained quartz occur between the feldspar grains.

The immediate hanging wall of the iron ore in the Rektor open pit consists of a grey-brown or grey-red, fine-grained, weakly schistose ''Rektor porphyry'' which often exhibits a delicate layering with up to 1–10 mm thick bands of magnetite and hematite. The ''porphyry'' consists of approximately equal amounts of quartz and brown, turbid potash-feldspar. The quartz occurs as polygonal grains with straight and simple boundaries; their diameter is 0.03–0.06 mm. The feldspar, diffusely ''striped'' or with a ''chess-board'' texture, forms 0.2–0.3 mm long, broad laths with a weak idiomorphic development. They lie mostly as isolated grains or aggregates in the quartz matrix, but on the other hand, there are parts where the feldspar dominates (Fig. 44). In the quartz-rich matrix, there are also anhedral grains of quartz about 0.2–0.3 mm in diameter. Just inside the boundaries of these grains, a straight dust (iron oxide?) line frequently shows the original euhedral habit, the present anhedral form being due to authigenic growth. The above mentioned bands of magnetite and hematite are a secondary feature in the rock, the iron oxides grow both in the quartz and the feldspar. The iron oxides are accompanied by sericite and calcite, the latter in part ankeritic.

Fig. 45. Stratified ''Rektor porphyry''. Southwest of Olofs kulle.

Locally the ''porphyry'' is soaked with calcite and sericite. In addition, small amounts of apatite, fluorite and zircon belong to the association.

By increasing content of quartz, the feldspar-rich ''porphyry'' passes into a variety which Geijer (1950) called the ''porphyritic Rektor porphyry''. It has its main extension between the Rektor iron ore and Olofs kulle. This variety is composed of a matrix of grey-white, dense, weakly schistose quartz in which spherulites, 1–5 mm in diameter, of a brown-red feldspar have grown. The feldspar often forms narrow aggregates, up to 1 cm long and elongated in the direction of schistosity. Locally, the rock is clearly stratified, 1–5 mm thick bands of spherulitic feldspar then occurring in the quartz matrix. These are oriented along the schistosity, but only with a relatively restricted extension in this direction (Fig. 45). In some cases, a structure resembling cross-bedding is present. Narrow bands of hematite and magnetite oriented in the direction of schistosity are rather common.

Under the microscope, the matrix of this ''porphyritic Rektor porphyry'' is seen to consist of grains 0.03 mm in size of quartz with simple boundaries, small amounts of hematite and sericite and accessory amounts of apatite and zircon (Fig. 46). The feldspar in the spherulites and the band-formed aggregates is a brown, turbid potash-feldspar which partly encloses small grains of quartz and albite. It forms anhedral grains (0.1–0.2 mm in size) which are mostly irregularly intergrown. In the spherulites, the outer grains are radially arranged. The feldspar exhibits a ''wandering'' extinction. Anhedral, rounded quartz grains, about 0.5 mm in diameter, are present in small amounts in the quartz matrix. A dust pigmentation shows the original habit and indicates a secondary enlargement of the quartz.

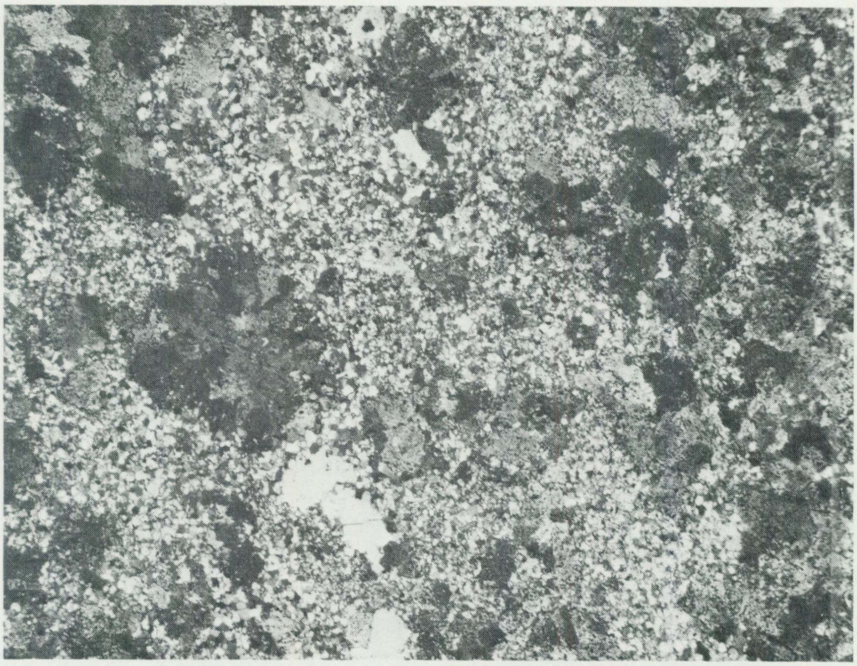

Fig. 46. Banded ''Rektor porphyry''. Potassium feldspar, partly as spherulites, in a matrix of fine-grained quartz and some sericite. To the right a ''band'' rich in feldspar. In the lower part, larger quartz grains (phenocrysts?) with dust pigmentation. Southwest of Olofs kulle. Crossed nicols, x 25.

In the Henry deposit, the hanging wall of the iron ore is a ''Rektor porphyry'' which contains abundant phenocrysts of white-grey quartz and red feldspar (Fig. 47) in a brick-red, dense, non-schistose feldspar matrix. The rock contains up to 3–4 mm long and 1–2 cm thick schlieren-like aggregates of sericite together with some calcite and apatite. Microscopic examination shows that the ''porphyry'' is without doubt an ignimbrite. The matrix has a pseudofluidal texture and is composed of more or less parallel shards of devitrified glass (Figs. 48 and 49). Most of the shards are rather flattened but some of them have a typical Y-shape. The shards have a brownish colour and are made up of a crypto- to micro-crystalline aggregate of feldspar and quartz. Generally the minerals form a granular mixture on so minute a scale that the individual grains cannot be resolved by the microscope. The shards are surrounded by quartz occurring as polygonal grains about 0.03 mm in diameter. In this shard–polygonal quartz matrix, there are phenocrysts (0.2–0.5 mm in size) of turbid, red-pigmented and somewhat sericite-altered potassium feldspar and quartz with undulating extinction. The habit is anhedral to subhedral; some of the feldspar phenocrysts are however euhedral, forming, in the main, broad laths. Both the feldspar and the quartz phenocrysts show resorption embayments. In many cases the glass shards bend smoothly around the phenocrysts. There are some spots, up to 10 mm in size, in which the

Fig. 47. ''Rektor porphyry'' with phenocrysts of feldspar and quartz. Henry deposit. Rock sample, x 2. Photo and copyright K. E. Samuelsson 1978.

amount of glass shards is small. A fine-grained polygonal quartz here dominates. In the spots, phenocrysts of potassium feldspar also occur.

The extension of this well preserved pyroclastic flow at the Henry deposit is not further known. In those parts where it is veined and brecciated by the apatite-rich hematite-magnetite ore, the primary volcanic texture is destroyed (Fig. 50). The ore veins, which are rich in sericite, calcite and apatite and contain accessory amounts of tourmaline, have introduced large quantities of calcite and sericite into the ''porphyry'' (Fig. 51). Here the less altered rock is composed of a fine-grained quartz in which subhedral, mostly table-shaped grains of a turbid potash-feldspar occur. To some extent, the feldspar grains are surrounded by a brownish, micro-crystalline quartz-feldspar aggregate, possibly representing better preserved parts of the groundmass. Some larger grains of quartz are also present.

The ''Rektor porphyry'' is, without doubt, an acid volcanic rock in which recrystallization and metasomatic alteration have destroyed the primary textures. The original rock was possibly a pyroclastic flow with a glassy texture and phenocrysts of feldspar and quartz. Devitrification has altered the glass to a quartz-feldspar mixture of minute grain size. The spherulites of feldspar have been formed by this process around scattered nuclei. It seems probable that the coalescence of spherulites into bands has been developed along particular surfaces in the flow where lamellar movements promoted the growth of the spherulites. The flinty quartz mass which is dominant in

Fig. 48. ''Rektor porphyry''. Quartz phenocryst in a matrix of glass shards, in between these quartz (grey-white). Henry deposit. Ord. light, x 50.

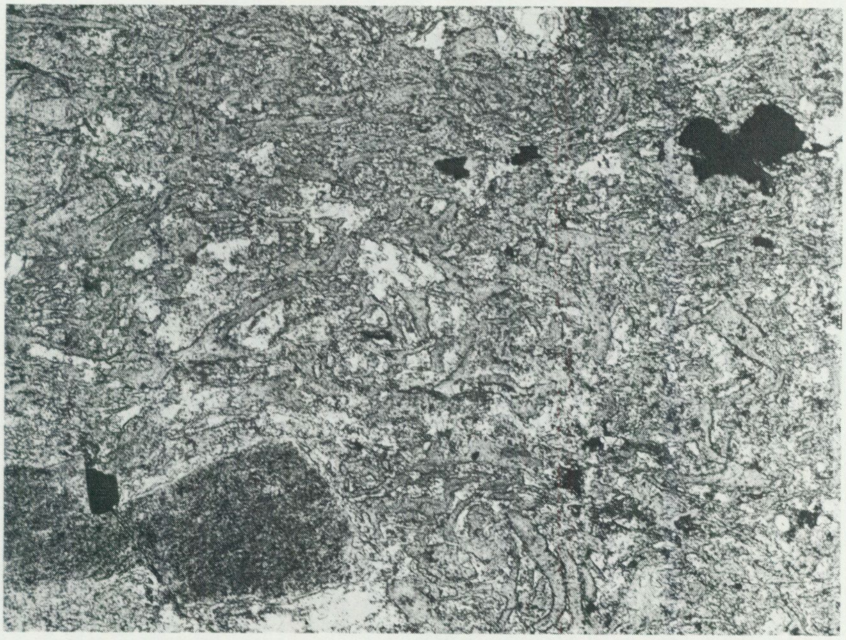

Fig. 49. ''Rektor porphyry''. Feldspar phenocrysts in a matrix of glass shards and quartz (grey-white). Black=hematite. Henry deposit. Ord. light, x 42.

Fig. 50. Fragments of ''Rektor porphyry'', partly sericite-altered (white patches), in apatite-rich hematite ore. Henry deposit. Scale 1:1. Photo and copyright K. E. Samuelsson 1978.

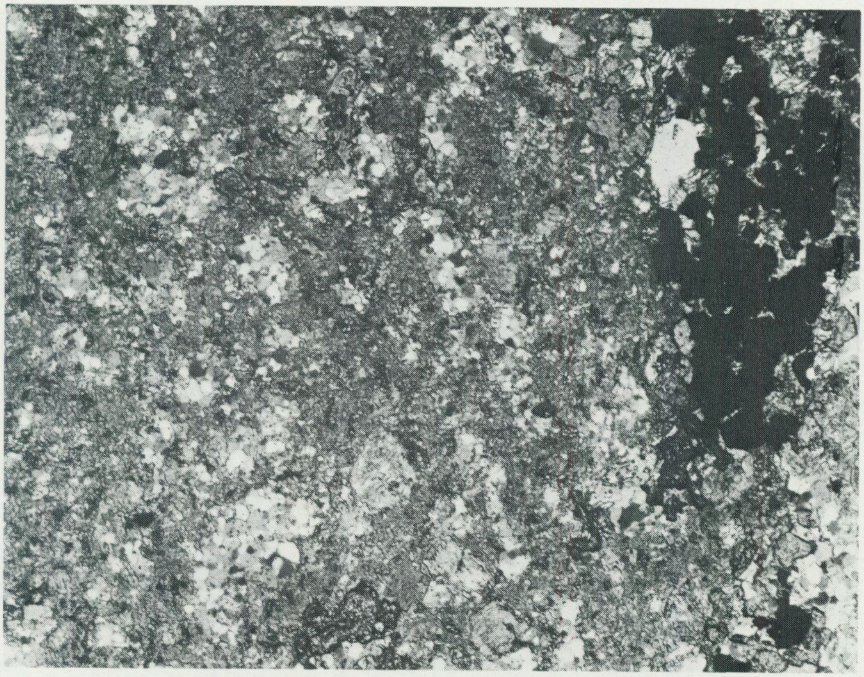

Fig. 51. ''Rektor porphyry'', fragment in apatite-rich hematite ore. Anhedral grains of potassium feldspar (light grey) in a fine-grained matrix of quartz. The slightly darker grains scattered throughout the rock are sericite and in part calcite. To the right, hematite with some quartz, calcite and apatite. Henry deposit. Crossed nicols, x 42.

the ''porphyritic'' variety is a product of later silicification, but still connected with the volcanic activity. It is the same type of silicification that is found in the light sericite quartzite and the siliceous hematite ore.

An outstanding chemical feature of the ''Rektor porphyry'' is that potassium strongly dominates over sodium. The ignimbrite in the Henry deposit contains 8.0 % K_2O and 1.6 % Na_2O (Table 4). A determination of alkalies in a ''homogeneous Rektor porphyry'' of the Rektor deposit gave 7.83 % K_2O and 3.45 % Na_2O (Geijer 1950). Such a preponderance of potassium is unusual in the volcanic rocks of the Porphyry group, not only in the Kiruna area but also in other areas where these rocks occur. As has been described previously, there are restricted parts of the syenite-porphyry in the foot wall unit at Hopukka and Välivaara which are potassium-dominated. In addition, the red variety of the agglomeratic syenite-porphyry of the Lower Hauki formation at Välivaara is rich in potassium. At Ekströmsberg, Piedjastjåkka and Skuokimjåkk, all localities southwest of Kiruna, there are potash-rich acid volcanic rocks in the Porphyry group (Frietsch 1974). In most cases, the high content of potassium seems to be a primary feature. As regards the ''Rektor porphyry'', it seems probable that the main part of the potassium is primary, even if it cannot be ruled out that part of it has been added by hydrothermal alteration. The presence of locally

TABLE 4. Chemical analysis of ''Rektor porphyry''. Henry deposit. Weight per cent. Analyst: G. Svedenbäck.

SiO_2	72.6	Niggli	values
TiO_2	0.20	al	39.9
Al_2O_3	12.5	fm	18.8
Fe_2O_3	2.1	c	5.2
FeO	1.1	alk	36.0
MnO	0.03	si	392
CaO	0.9	k	0.77
MgO	0.7	ti	0.97
Na_2O	1.6	mg	0.29
K_2O	8.0	h	7.1
$H_2O>105°$	0.4	ω	0.63
$H_2O<105°$	0.3		
P_2O_5	0.04		
S	0.07		
BaO	0.12		
	101.66		
–O=S	0.02		
	101.64		

restricted extrusions rich in potassium within the sodic or alkali-intermediate volcanic rocks is still an unsolved problem.

Quartz veins

Secondary quartz veins are relatively common within the rocks of the Lower Hauki Formation. They have been found in the light sericite quartzite and the siliceous hematite ore in the area north of Entiejärvi, in the Nukutus and Rektor magnetite-hematite ores, as well as in the ''Rektor porphyry'' at the Rektor ore and southwest of Olofs kulle. Quartz veins also occur in the quartz-bearing porphyry at Hopukka. The veins are mostly irregular and 1–20 cm wide; though, exceptionally, as in the area to the north of Entiejärvi, up to 50 cm wide. They generally strike E–W, i.e. in a direction perpendicular to the general strike of the rocks, and have a steep dip. The contacts with the host rock are sharp. In the Nukutus deposit, the veins contain fragments of the ore. The main mineral of the veins is white, coarse quartz. Other minerals, which mostly occur as euhedral crystals, 1–5 cm in size, are specularite, calcite, ankerite, and occasionally red, potash-feldspar (microcline?)

QUARTZITE GROUP

The rocks of the Quartzite group, formerly designated the Vakko Formation or the Upper Hauki Series, consist of (from older to younger): 1, conglomerate and greywacke, 2, phyllite and 3, quartzitic sandstone with conglomeratic intercalations. These rocks form a horizon about 1.5 km wide. It is bounded to the west by the rocks of the Lower Hauki Formation and the Kurravaara conglomerate. In the south, at Porfyrberget, the Quartzite group borders upon the quartz-bearing porphyry. To the east, the Quartzite group is bounded by an amphibolite. As already mentioned (p. 9), the contact is a dislocation that possibly dips steeply eastwards.

Fig. 52. Basal conglomerate. Pebbles of quartz-bearing porphyry (light), hematite ore (grey to black) and phyllite (grey, to the right of pencil) in a hematite-rich matrix. Doktorns kulle.

CONGLOMERATE AND GREYWACKE

The stratigraphically lowest members of the Quartzite group are conglomerate and greywacke. South of the Hauki iron ore, there is a narrow layer in which only the greywacke is present. These rocks, which in general measure between 50 and 100 m across, are strongly schistose, and the pebble-material is oriented in the direction of the schistosity.

The lowermost unit is a basal conglomerate. It is encountered at Doktorns kulle, Olofs kulle and Nukutusvaara, but seems to be absent further north. At Doktorns kulle and Olofs kulle, the contact with the light sericite quartzite of the Lower Hauki Formation is exposed. The contact is sharp, without any special features. As already described (p. 33), there is, at Olofs kulle, a small unconformity between the rocks of the Lower Hauki Formation with a vertical schistosity, and the basal conglomerate with a schistosity dipping 60°E.

The basal conglomerate, measuring about 5 m across, is rich in hematite, which occurs both as pebbles and in the matrix. The pebbles are closely packed and make up the greater part of the rock. The size of the pebbles is usually between 1 and 10 cm, but occasionally, as at Olofs kulle, they attain 50 cm and at Doktorns kulle 90 cm. The pebbles are angular to sub-angular, occasionally rounded. Frequent are pebbles of hematite ore of two different types. The most common type is a fine-grained, somewhat schistose, hematite ore in which quartz is evenly distributed, or more rarely, occurs as narrow layers or aggregates. Allanite is a typical accessory mineral. At Olofs

Fig. 53. Conglomerate. South of Olofs kulle.

kulle, there are pebbles of a fine-grained, siliceous hematite which contains fragments of a light sericite quartzite. All these pebbles emanate from the siliceous hematite ores in the Lower Hauki Formation. The second type of hematite contains relatively great amounts of apatite, further some sericite and quartz. These pebbles emanate from the main apatite iron ores as shown, for example, by the similarity of the distribution of the trace elements in the hematite (Frietsch 1970). According to Geijer (1931a, p. 204), most of the pebbles probably came from the main ore body of Luossavaara. When exposed to erosion, the magnetite has, according to Geijer (1956), been superficially changed to martite before the pebbles were incorporated into the conglomerate.

The basal conglomerate contains small amounts of fragments of a somewhat sericite-altered quartz-bearing porphyry (Fig. 52). At Olofs kulle, there are abundant fragments from the Lower Hauki Formation; light-brown or grey sericite quartzite with millimetre-thick irregular schlieren of hematite, and grey or violet quartzite impregnated with hematite. At Doktorns kulle, the conglomerate contains small fragments of a pale-red feldspar.

The matrix of the basal conglomerate is light-grey to dark-grey, dense, schistose and consists of quartz, sericite and hematite in varying amounts. No bedding has been observed. The sericite is present as fine needles and the quartz occurs as anhedral grains 0.1 mm in size. The hematite, which sometimes dominates, forms anhedral grains, often angular but also rounded. The hematite is secondary after magnetite; it

Fig. 54. Greywacke. South of Kirkasjärvi.

shows traces of an octahedral texture and in some grains there are small, irregular remnants of magnetite. Accessories are zircon and tourmaline.

To the east, the basal conglomerate, rich in hematite, passes into a normal conglomerate. The thickness of the latter is about 50–60 m at Doktorns kulle and 20–30 m at Olofs kulle. Further east, the conglomerate passes into a greywacke. This change is connected with a decrease both in the size of the pebbles and in their number. Thus the size of the pebbles is about 10 cm in the west (Fig. 53) and about 1 cm in the east. East of the conglomerates, a greywacke without any coarser fragments occurs (Fig. 54). Only at Doktorns kulle, near the overlying phyllite, there is a narrow layer of the conglomerate in the greywacke.

The matrix of the conglomerate is grey, strongly schistose and built up of a fine-grained aggregate of quartz and sericite, some hematite or magnetite, and allanite and apatite as accessories (Fig. 55). 1–10 mm large vesicles filled with limonite are common. The iron oxides occur as anhedral grains (0.1 mm in size) which are evenly

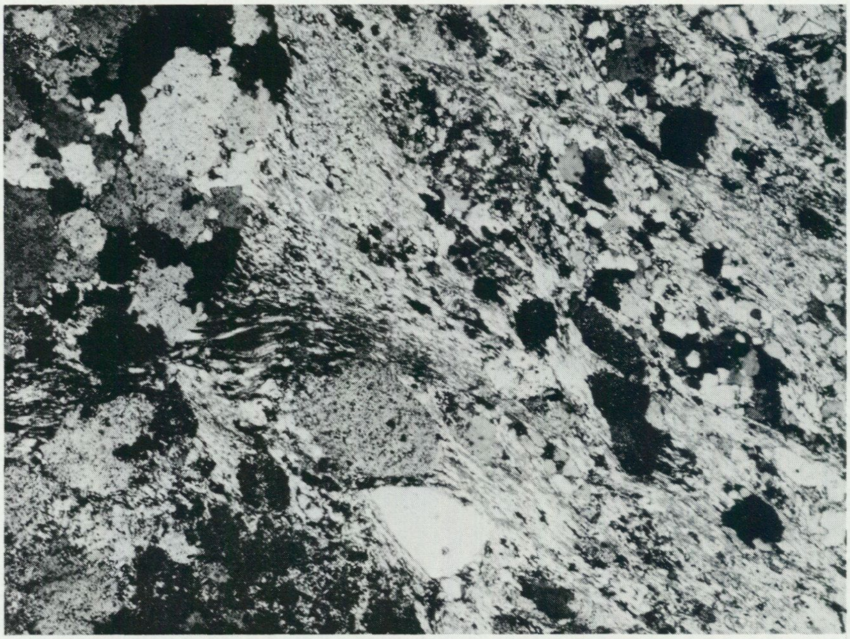

Fig. 55. Matrix in conglomerate. Fragments of quartz-bearing porphyry (lower left corner) and quartz in a matrix rich in sericite. Black grains are magnetite. Kirkasjärvi. Crossed nicols, x 38.

distributed, or, to a lesser extent, occur as 1–2 mm thick layers. The hematite contains lamellae of magnetite in an octahedral texture indicating an origin due to martitization.

The pebbles and fragments of the conglomerate vary between 1–20 cm in size, usually around 2–3 cm, and are angular to sub-rounded. They are strongly pressed and oriented in the direction of schistosity. The dominant type is a quartz-bearing porphyry, which is generally well-preserved, but in some cases schistose and sericite-altered. It is similar to the hanging wall porphyry at Kiirunavaara and Luossavaara. Fragments of a grey-black, fine-grained, siliceous hematite ore are common. Somewhat subordinate are fragments of grey-brown, grey-violet or red violet jaspilite quartzite with alternating layers, 0.5–10 mm thick, of quartz and hematite. The quartzite usually contains abundant sericite and subordinate amounts of albite. In addition, there are fragments of a chlorite- or sericite-altered syenite-porphyry, a grey phyllite and a green-white sericite quartzite. The hematite ore and the quartz-sericite-rich rocks mentioned are most certainly derived from the Lower Hauki Formation; the syenite-porphyry, however, might in part emanate from the foot wall of the main ore bodies.

On the hillock of Kurravaara, east of Doktorns kulle, and northeast of Entiejärvi, the conglomerate gradually passes eastwards into a greywacke which lacks coarser fragments. It has a grey or brown-grey, dense, markedly schistose matrix in which layering is occasionally observed. Rusty spots or limonite-filled cavities (up to 1 mm in size) are locally rather common. The matrix is composed of sericite, quartz, small amounts of iron oxides and accessory amounts of tourmaline, allanite and zircon. In this matrix, there are angular fragments about 0.5–2 mm in size, sometimes up to 2 cm, of quartz-bearing porphyry, red jaspilite quartzite, light-brown sericite quartzite, siliceous hematite ore, and occasionally sericitized syenite-porphyry rich in magnetite.

PHYLLITE

The phyllite has its main extension between Porfyrberget and Nukutusjärvi, whereas in the northern part of the Kurravaara area it only occurs on the Kurravaara hillock. The phyllite, which has a thickness of about 50 m, is bounded to the west by the conglomerate-greywacke and to the east by the quartzitic sandstone. South of Haukivaara, the conglomerate-greywacke is missing and the phyllite lies directly on the rocks of the Lower Hauki Formation. On the Kurravaara hillock, there is a repetition of the phyllite. This horizon occurs in a lower stratigraphic position between the Lower Hauki Formation and the conglomerate-greywacke. In the south, at Haukijärvi, a phyllite lies within the quartzitic sandstone and is partly bounded to the west by the quartz-bearing porphyry. This irregularity is due to the northeast-striking fault here occurring.

The phyllite is grey to green-grey, sometimes with violet or brown shades. Often it contains irregular limonite-filled cavities which are 1–2 mm large. Layering is relatively common. Thus some decimetres across, one may find brown- or violet-coloured

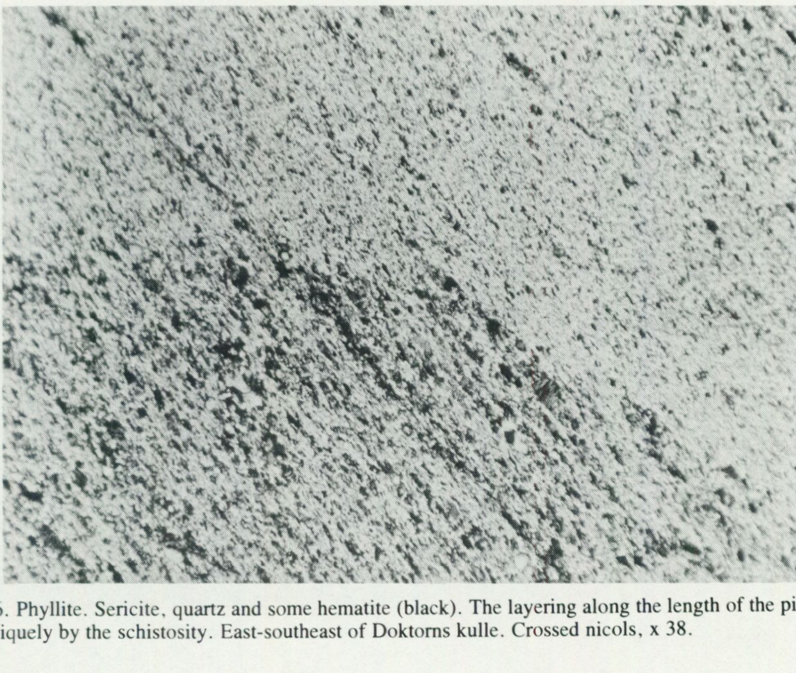

Fig. 56. Phyllite. Sericite, quartz and some hematite (black). The layering along the length of the picture is cut obliquely by the schistosity. East-southeast of Doktorns kulle. Crossed nicols, x 38.

layers which are 1–2 mm thick, occasionally 1–2 cm, and these are usually slightly folded. In the area between Porfyrberget and Doktorns kulle, the schistosity and the layering of the phyllite dip 20–50°E. Around Olofs kulle, the dip of the schistosity is steeper. Northeast of Entiejärvi, the layering in the phyllite is somewhat dislocated along the planes of schistosity.

The phyllite is fine-grained, foliated and composed of quartz, which sometimes dominates, sericite and pale-green or colourless chlorite (Fig. 56). Occasionally small amounts of hematite are found. Accessories are apatite, tourmaline and zircon. In the bedded parts, the dark layers are quartz- and chlorite-dominated and the light layers are sericite-dominated. The phyllite south of Kirkasjärvi is rich in chlorite; in addition sericite, biotite and quartz occur in small amounts. Minute vesicles (0.3–1 mm) filled with quartz, biotite and magnetite are found in the aggregate.

QUARTZITIC SANDSTONE

The quartzitic sandstone makes up the greater part of the rocks of the Quartzite group. It has a thickness varying between 1 000 and 1 500 m. The sandstone contains narrow intercalations of conglomerate.

The quartzitic sandstone is a light-brown or grey-brown, mostly non-schistose rock of homogeneous composition. Rather often it contains yellow-brown spots, about 1 mm in size, which are due to weathering of the feldspar. Layering is rare except on the Kurravaara hillock where layers are relatively abundant. The layers (1–2 mm thick) consist of iron oxides (Fig. 57), often slightly folded and with short extension along

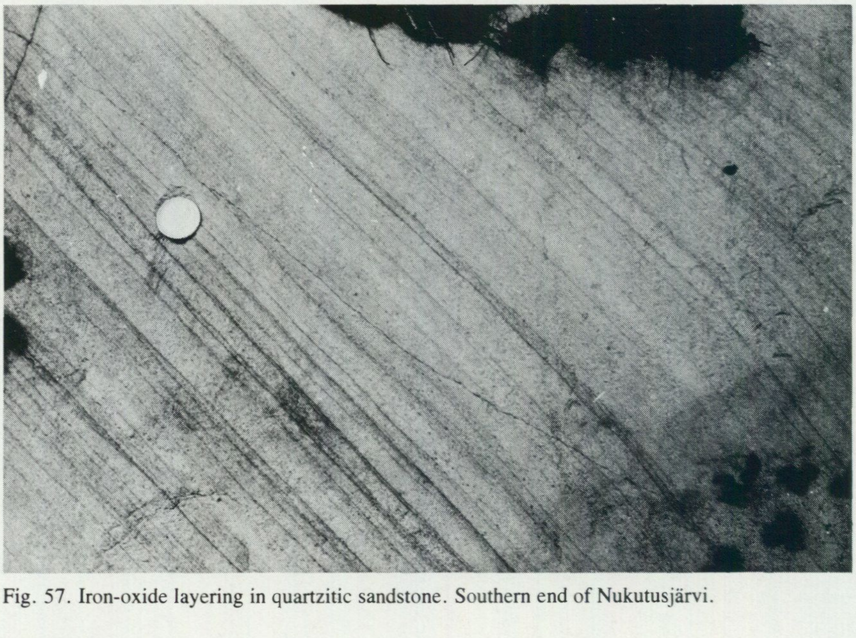

Fig. 57. Iron-oxide layering in quartzitic sandstone. Southern end of Nukutusjärvi.

Fig. 58. Quartzitic sandstone. Fragments of quartz, albite and quartz-bearing porphyry in a matrix rich in sericite. Southeast of Kirkasjärvi. Crossed nicols, x 100.

the strike. In the southern and central parts of the Kurravaara area, the layering strikes NNE or NE; in the northern part, on the Kurravaara hillock, the strike is roughly E–W, varying between WNW and WSW. The dip is mostly 60–70°E or S but can locally be less. Thus at Nukutusvaara it is 45°E. Cross-bedded layers occur sporadically at Nukutusvaara; they indicate way-up to the east.

In the southernmost part, near the NE–SW oriented fault between Porfyrberget and Haukijärvi, the sandstone is locally deformed and schistose. The sandstone southwest of Haukijärvi has been altered into a green-brown, phyllitic rock rich in sericite. The conglomeratic layers which occur here are almost totally destroyed and can only be recognized with difficulty. The conglomeratic intercalation north of Porfyrberget has also suffered from strong compression and is largely destroyed.

The quartzitic sandstone consists of angular or sub-angular fragments (0.1–0.4 mm in size) which are frequently oriented in the direction of schistosity (Fig. 58). Crushed quartz showing undulatory extinction and pressure lamellae is most common among the fragments. The quartz fragments are often densily packed and grow together with irregular grain boundaries. Fragments of fresh or slightly sericite-altered albite, microcline with ''stripes'' of albite and quartz-bearing porphyry occur in small amounts.

The matrix between the fragments is a fine-grained aggregate (grain size 0.02–0.05 mm) of sericite and subordinate quartz. Accessories are magnetite, zircon and tourma-

TABLE 5. Composition of quartzitic sandstone (volume per cent)

		Nukutus-vaara	Kurra-vaara	Olofs kulle
	sericite (and quartz)	25.3	19.0	37.6
Matrix	magnetite	2.4	0.2	5.4
	zircon	0.2	0.1	0.4
Fragments	quartz	68.2	61.0	50.5
(0.1–0.6	albite	3.6	3.8	0.4
mm in size)	quartz-bearing porphyry	0.3	0.2	5.4
		100.0	100.0	100.0

line. In the iron oxide-rich layers, there is a somewhat higher content of zircon. The matrix makes up about one-third to one-fifth of the volume (Table 5).

The conglomeratic layers in the sandstone have thicknesses of about 5–20 m. They occur in two horizons: one in the stratigraphically lowermost part of the sandstone, near the phyllite, and the other in the centre of the sandstone. The boundaries between the sandstone and the conglomeratic layers are diffuse, and the sandstone still contains some pebbles at rather large distances from the conglomerate. This is particularly evident on the southern part of the Kurravaara hillock, where there is a slow decrease in the number of pebbles. Occasionally, as at Sandstensberget (immediately south of Haukijärvi), the boundary is sharp (Fig. 59).

The matrix of the conglomerate is the same sandstone as described above. The pebbles which are 2–10 cm in size, occasionally up to 40 cm (Fig. 60), are mostly well-rounded but also sub-angular to angular; in the latter case, they are mainly

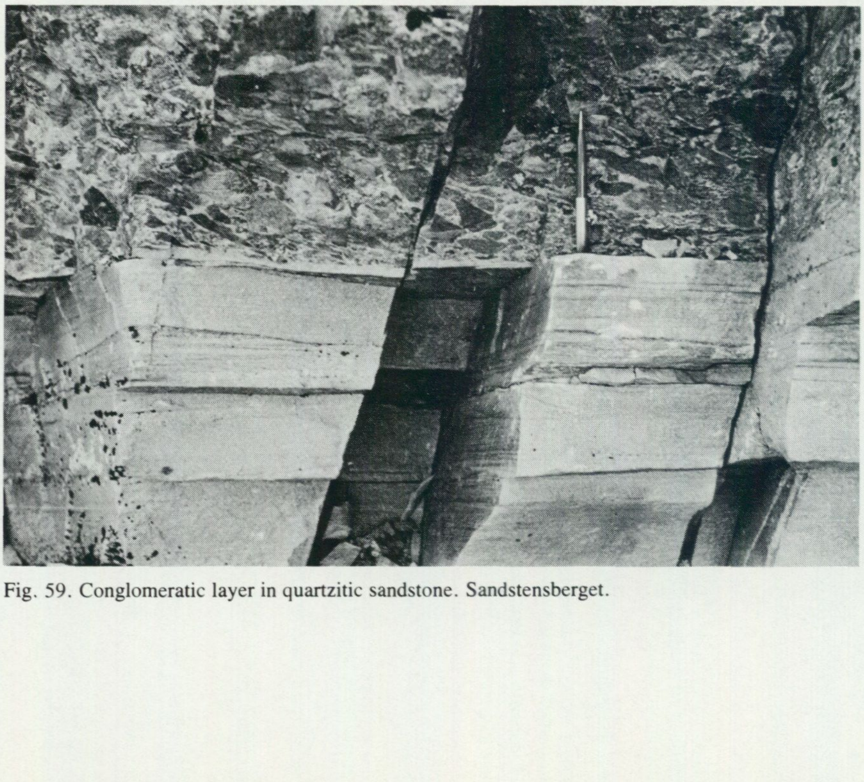

Fig. 59. Conglomeratic layer in quartzitic sandstone. Sandstensberget.

Fig. 60. Conglomeratic layer in quartzitic sandstone. Southeast of Olofs kulle.

phyllites. The dominant pebble type is a somewhat sericite-altered quartz-bearing porphyry. In addition, there are pebbles of a grey-violet, sericite- and hematite-altered syenite-porphyry and of a schist consisting of a fine-grained aggregate of sericite, quartz and hematite. Fragments of grey, grey-violet or red jaspilite quartzite, grey-black hematite ore and white, glassy quartz occur infrequently. All these rocks probably emanate from the Lower Hauki Formation.

AMPHIBOLITE

The quartzitic sandstone borders to the east upon an amphibolite which is in turn bounded by acid volcanic rocks of the Porphyry group. The contact between the quartzitic sandstone and the amphibolite is a fault line. As mentiondd earlier (p. 7), the amphibolite has been assigned both to the Greenstone group and the Porphyry group. In the opinion of the present author, relationship to the Porphyry group is more probable. Chemical and clastic sediments, which are typical in the basic volcanic rocks of the Greenstone group, are not known to occur in the amphibolite. In addition, the amphibolite is porphyritic, a feature which is not usually encountered in basic volcanic rocks of the Greenstone group whereas it is common in the Porphyry group.

The amphibolite is a dark-grey, fine-grained amphibole-feldspar rock. In general it has a weak schistosity which is either vertical or dips steeply towards the southeast. Locally, as along the Torne river, the schistosity is rather pronounced. The amphibolite contains centimetre-wide schlieren of quartz with some pyrite and chalcopyrite.

Fig. 61. Amphibolite. Phenocrysts of albite in a matrix of albite, some hornblende and magnetite (black). Tiekuvaara. Crossed nicols, x 32.

These lie parallel with the schistosity. At the Torne river, the amphibolite contains 1–5 dm wide schlieren of calcite with some grains of bornite. Centimetre-wide veins of amphibole also occur here. A schistose amphibolite with narrow schlieren of quartz, biotite and sericite is found at Tiekuvaara.

The amphibolite is composed of albite, forming polygonal or somewhat flattened grains about 0.05 mm in diameter, and light-green hornblende, forming subhedral grains up to 0.6 mm in length. Brown-green biotite and magnetite occur in small amounts. The rock is often porphyritic, with subhedral laths (up to 2 mm long) of a fresh or somewhat biotite- or sericite-altered albite (Fig. 61). Scapolite is a common constituent, mostly present in small or accessory quantities. In outcrops 1 km ESE of Haukijärvi, however, the amphibolite is composed of hornblende, some biotite and scapolite, the latter occurring as irregular grains (up to 1 mm in diameter) or aggregates composed of smaller grains.

AGE RELATIONS OF THE KURRAVAARA CONGLOMERATE

The Kurravaara conglomerate lies stratigraphically between the Kiruna greenstone (about 1 900–2 200 Ma old) and the rocks of the Porphyry group (about 1 600 Ma old) as well as the still younger rocks of the Quartzite group. As has been stated earlier, there is a normal succession between all these rocks which occur in a monoclinal sequence. The age relations of the Kurravaara conglomerate is, however, a question much debated by different authors. Two principal hypotheses prevail, implying that the conglomerate is formed either during the final stage of the greenstone volcanism and thus prior to the porphyries, or later than the porphyries.

Lundbohm (1910) and Sundius (1915) considered the conglomerate to be a substratum of the porphyries, the latter being comagmatic with the Kiruna greenstone. Both authors were aware of the fact that the pebbles of the conglomerate are predominantly volcanic rocks similar to the overlying porphyries. According to Lundbohm, however, there are pebbles of tuffs nearly corresponding to those in the greenstone. In addition, some of the pebble-free, stratified layers in the conglomerate resemble these tuffs. Sundius interpreted the conglomerate as a re-worked volcanic agglomerate formed in a littoral environment. The denudation of the greenstone was insignificant, this being indicated by well-preserved pillow structures close to the contact with the conglomerate. Some of the pebble material, however, was derived from the greenstone. Thus for example, at Valkeasiipivaara there are pebbles of a coarse greenstone (uralite diabase) in the lower part of the conglomerate which are similar to the intrusive types of the greenstone. According to Sundius, there is no great difference in time between the conglomerate and the greenstone, both being older than the porphyries.

When discussing the provenance and age relationship of the Kurravaara conglomerate, Geijer (1931a) followed mainly the opinion of Sundius. Geijer emphasized that compositional and textural differences exist between the volcanite pebbles and the Kiruna porphyries. The most common varieties among the Kiruna porphyries are rare in the conglomerate. The Kiruna porphyries have a higher content of potassium and pyroxene or uralite than the volcanic rocks in the conglomerate. In the conglomerate, albitophyres dominate, whereas they are insignificant in the Kiruna porphyries. Also, the albitophyres in both formations are different. In the conglomerate, the albite forms thin tables, preferentially in a trachytoidal arrangement, which indicates kinship with the greenstone. In the albitophyres of the Kiruna porphyries, the feldspar forms shorter laths, arranged at random and with complicated grain boundaries.

From regional stratigraphic considerations, Ödman (1957) concluded that the Kurravaara conglomerate and the basic volcanic rocks of Karelian age, comprising the Kiruna greenstone, were younger than the acid–intermediate volcanic rocks of Svionian age, comprising the Kiruna porphyries. In addition, the composition of the pebbles material in the Kurravaara conglomerate indicated derivation from the Kiruna porphyries. Geijer (1958) raised objections to this interpretation, stating that most of the pebbles are so closely related to the underlying greenstone that the Kiruna porphyries must be excluded as the provenance. Geijer also stressed the significance of the magnetite pebbles which contain uralite with ophitically enclosed laths of albite, a feature found in the Kiruna greenstone but alien to the Kiruna porphyries.

According to Offerberg (1967) the pebbles of the Kurravaara conglomerate derive their origin from somewhat older rocks than the Kiruna porphyries, a possible source being the intercalations of porphyries in the Greenstone group in the southern part of the Kiruna map sheet. In addition, in the northwestern part of the map sheet, there are porphyries of the Kiruna foot-wall type which are underlain by several other porphyry beds, partly with a composition resembling that of the predominant pebbles of the Kurravaara conglomerate.

Formations similar to the Kurravaara conglomerate are rare in Northern Sweden. The only certain counterpart is a conglomerate at Sautusvaara east of Kiruna on the Vittangi map sheet. The Sautusvaara conglomerate is underlain by metasediments (tuffites and schists) of the Greenstone group and overlain by an albite porphyrite of the Porphyry group (Eriksson and Hallgren 1975). The underlying metasediments pass into the conglomerate either directly or via a 2–3 m thick diopside skarn. Most of the pebbles in the conglomerate are volcanic rocks of intermediate, or more rarely, of acidic, composition. Pebbles of metasediments are represented by quartz-biotite-rich schists, skarn-scapolite rocks (altered marls), jaspilite quartzites, and magnetite-quartz ores. The matrix of the conglomerate contains diopside, hornblende, epidote, and magnetite; in addition, small rock fragments, quartz, calcite, and some sphene and apatite are present.

Eriksson and Hallgren (1975) interpreted the Sautusvaara conglomerate as a clastic formation deposited at an early stage of the porphyry eruptions. A conglomerate formation was thus recognized at the base of the Porphyry group, as a part of the latter.

The Kurravaara and Sautusvaara conglomerates are similar formations with regard to their fragment material, their depositional environment and their stratigraphic position. In the Sautusvaara conglomerate, however, a great part of the pebbles are metasediments which almost certainly originate from the underlying Greenstone group. As in the Kurravaara conglomerate, the porphyries in the Sautusvaara conglomerate are texturally somewhat different from those of the Porphyry group, particularly the magnetite-syenite-porphyries (Eriksson and Hallgren 1975).

In the opinion of the present author, the following observations are relevant with regard to the age and provenance of the Kurravaara conglomerate:

1. The Kiruna greenstone contains intercalations of the conglomerate, indicating that the formation of the conglomerate began while the basic volcanism was still active. If the Kurravaara and the Sautusvaara conglomerates are equivalent formations, the conditions at Sautusvaara, with a gradual change from the underlying metasediments to the conglomerate, indicate a close relationship with the Greenstone group.

2. Even if the volcanic rock pebbles of the Kurravaara conglomerate and the volcanic rocks in the overlying Kiruna porphyries in many cases are similar, mineralogical and textural differences exist as shown by Geijer (1931a) as well as Eriksson and Hallgren (1975). It should also be pointed out that the volcanic rock pebbles and the volcanic rocks in the Kiruna porphyries are chemically somewhat different. The syenite-porphyry (albitophyre) in the conglomerate is sodium extreme whereas at Kiirunavaara and Luossavaara it is alkali intermediate (Table 6). There are, however, nodular-bearing syenite-porphyries at Nukutusjärvi and west of Syväjärvi which are

TABLE 6. Chemical analyses of syenite-porphyry in Kurravaara conglomerate and foot wall unit. Weight per cent.

	Syenite-porphyry					Magnetite-syenite-porphyry		
	Kurravaara conglomerate		Foot wall unit			Kurravaara conglomerate	Foot wall unit	
	1	2	3	4	5	6	7	8
SiO_2	50.0 –59.8	52.2 –57.2	59.71–61.24	45.2 –48.5	57.1 –60.8	41.1 –56.8	35.8 –45.6	45.32
TiO_2	0.08– 0.29	0.44– 0.74	0.66– 2.14	1.12– 1.29	0.62– 1.12	0.40– 1.20	0.55– 0.91	1.15
Al_2O_3	17.0 –19.5	17.9 –19.7	13.95–16.18	15.11–16.1	16.4 –17.3	7.28–14.6	10.3 –11.7	13.09
Fe_2O_3	1.80–19.62	6.96–10.29	3.20– 4.89	15.47–17.74	2.60– 8.37	14.27–33.6	20.38–30.73	21.74
FeO	0.04– 4.98	2.51– 3.54	1.19– 2.96	5.91– 6.56	1.07– 3.12	4.74– 9.90	8.37–10.84	7.12
MnO	0.03– 0.10	0.03– 0.04	0.07– 0.36	0.06– 0.12	0.02	0.08– 0.18	0.01– 0.05	0.04
MgO	0.33– 3.24	1.54– 1.60	1.17– 4.23	0.51– 1.19	0.48– 2.25	0.99– 2.62	1.56– 9.04	0.18
CaO	2.26– 4.04	2.17– 3.10	2.91– 5.04	0.98– 2.88	2.24– 3.16	2.60– 5.42	0.93– 1.60	2.19
BaO	0.01– 0.04	0.01– 0.03	0.05	0.02– 0.03	<0.01– 0.01	0.03– 0.16	<0.01– 0.02	–
Na_2O	7.85– 9.64	6.98– 7.71	5.13– 7.25	5.60– 8.00	8.20– 8.52	2.20– 4.50	3.17– 5.90	7.51
K_2O	0.08– 1.18	0.33– 0.59	2.04– 4.53	0.08– 1.08	0.46– 1.05	0.20– 2.70	0.44– 4.00	0.17
P_2O_5	0.16– 0.46	0.25– 0.37	0.01– 0.44	0.46– 1.26	0.50– 0.53	0.06– 0.34	0.02– 0.46	0.32
CO_2	0.24– 2.96	0.18– 1.26	0.51	0.31– 2.75	1.14– 2.00	0.89– 3.71	0.33– 1.47	1.26
H_2O	–	–	0.22– 0.74	–	–	–	–	0.24
Cl	–	–	–	–	–	0.03– 0.07	0.02	–
F	0.02– 0.08	–	–	0.01– 0.02	0.15– 0.19	<0.01	0.09	–

1. Pebbles of albitophyre, Kurravaara and Valkeasiipivaara. Parák (1975, Table 3, analyses Nos 1, 2, 6 and 7).
2. Pebbles of syenite-porphyry, Kurravaara and Valkeasiipivaara. Parák (1975, Table 3, analyses Nos 5, 9 and 10).
3. Syenite-porphyry, Kiirunavaara and Luossavaara. Geijer (1931a, p. 180, analyses 14–18).
4. Syenite-porphyry with magnetite nodules, west of Henry, Parák (1975, Table 6, analyses Nos 1–3).
5. Nodular syenite-porphyry, west of Syväjärvi. Parák (1975, Table 6, analyses Nos 4–6).
6. Pebbles of magnetite-syenite-porphyry, Kurravaara. Parák (1975, Table 4, analyses Nos 1–4 and 6–10).
7. Magnetite-syenite-porphyry, west of Syväjärvi. Parák (1975, Table 5, analyses Nos 1–5).
8. Magnetite-syenite-porphyry, north of Luossavaara. Geijer (1910, p. 67, analysis No. 12).

sodium dominant (analyses Nos. 4 and 5, Table 6). The Kiruna porphyries have also a somewhat higher content of magnesium and calcium than the porphyry pebbles, this being related to a higher content of femic minerals.

3. The distribution of the different rocks occurring as pebbles in the Kurravaara conglomerate is uniform over the whole area covered. In the northern part of the Kurravaara area, where no Kiruna porphyries are present, the content of porphyry pebbles in the conglomerate is the same as in the southern part. There is thus no direct spatial relationship to the rocks of the Porphyry group.

4. The matrix of the Kurravaara conglomerate is different from that in the fragmented rocks of the Porphyry group. In the latter, there are several occurrences of intraformational conglomerates on the Kiruna and Vittangi map sheets. These have a matrix consisting of quartz, feldspar (microcline and albite), biotite, and muscovite. This differs markedly from the matrix in the Kurravaara conglomerate with biotite, chlorite, epidote, and calcite, or the matrix of the Sautusvaara conglomerate with diopside, hornblende, epidote, and magnetite. In both formations, the composition of the matrix indicates relationships with the rocks of the Greenstone group.

5. The sericite quartzite intercalations in the Kurravaara conglomerate at Palsivaara are possibly metasomatically altered lava rocks, similar to those in the Lower Hauki Formation, which were intruded into the Kurravaara conglomerate. The conglomerate ought therefore to be older than the rocks of Porphyry group.

In summary, it seems more reasonable to consider the Kurravaara conglomerate as a clastic deposit, formed at a late stage of the volcanism which produced the Kiruna greenstone, and it is thus older than the Kiruna porphyries.

THE GEOLOGICAL EVOLUTION

The rocks in the Kurravaara area belong to a monoclinal sequence which, in the main, is conformable. To the north, the rock sequence lies on the Archean basement which does not outcrop in the Kurravaara area. The basement which is composed of a gneissose granite, about 2 750–2 800 Ma old, is overlain by a conglomerate with pebbles of the granite. This means that, prior to the formation of the rock sequence, the basement was subjected to folding, metamorphism and erosion, indicating a large discontinuity.

The Kiruna greenstone, which is the lowermost unit of the sequence, was extruded onto the basement around 1 900–2 200 Ma ago. The volcanic rocks are sodium-rich spilites, often with pillow structures indicating formation in a sub-aquatic environment. Two phases of deposition of chemical and clastic sediments were associated with the volcanism. In the Kurravaara area only the later phase is present, appearing as tuffites. In the final stage of the volcanism, the Kurravaara conglomerate was formed. The underlying basic volcanic rocks and sediments were only exposed to a limited extent. In both the Kiruna greenstone and the Kurravaara conglomerate, there are minor intrusions of ultrabasites and basites, possibly related to the same volcanism which produced the Kiruna greenstone.

The next main event took place about 1 600 Ma ago when the rocks of the Porphyry group, with the syenite-porphyry, quartz-bearing porphyry and the intermediate and acid lavas of the Lower Hauki Formation, were deposited. The Lower Hauki Formation was metasomatically altered at a late stage of the volcanism; to some extent these processes affected the uppermost parts of the quartz-bearing porphyry and the syenite-porphyry.

Before the deposition of the sediments of the Quartzite group, the rock sequence in the Kurravaara area ought to have been tilted slightly. The uplift possibly occurred in connection with incipient orogenic activity, mainly as epeirogenic movements. The rocks of the Quartzite group in the Kurravaara area, as well as in other occurrences in Norrbotten, form relatively long and narrow basins where the boundaries to the surrounding rock units are largely made up of dislocations. In the Kurravaara area, the eastern boundary is a fault. In the southern part, minor dislocations form the contacts to the west.

The sedimentation of the Quartzite group begun with rapid deposition of erosion products from the Porphyry group (quartz-bearing porphyry, apatite iron ore and rocks of the Lower Hauki Formation). The phyllite and the quartzitic sandstone were deposited as the basin subsided further.

The final phase of evolution comprised regional metamorphism and folding, and the rock sequence in the Kurravaara area attained its present relatively steep dip. This possibly occurred in connection with the intrusion of the late-kinematic Lina granite about 1 525 Ma ago.

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GFF=Geologiska Föreningens i Stockholm Förhandlingar

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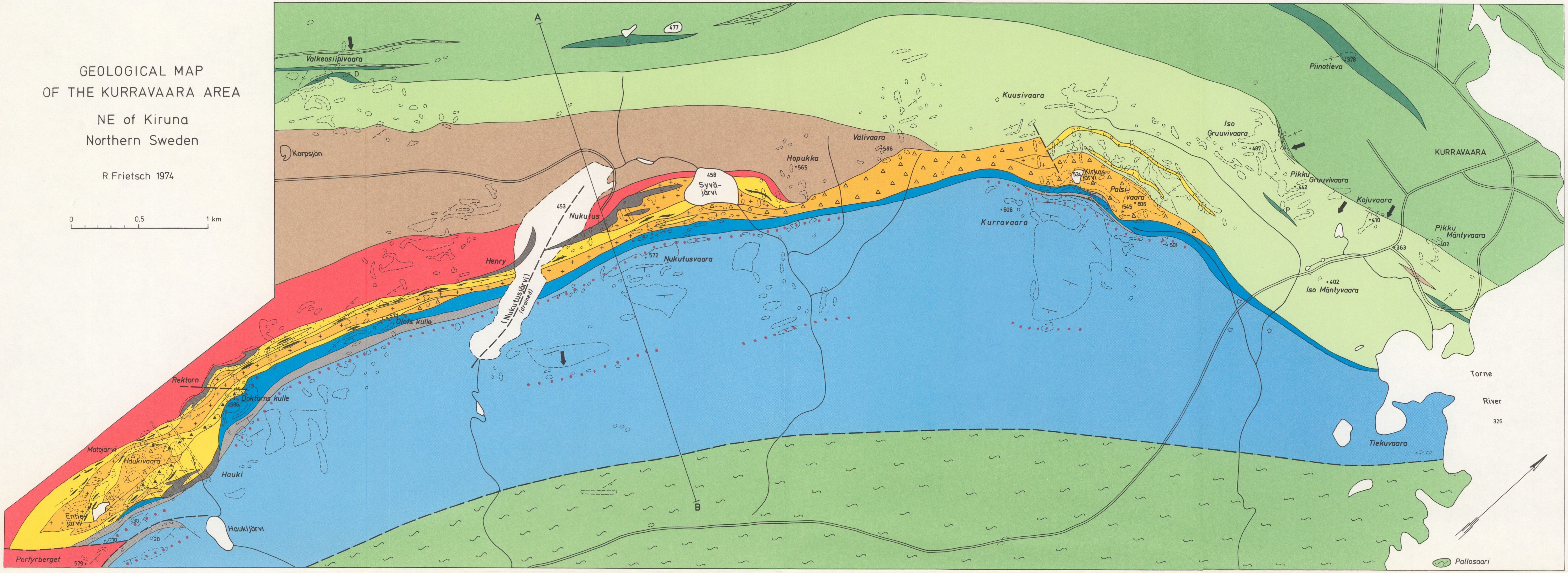
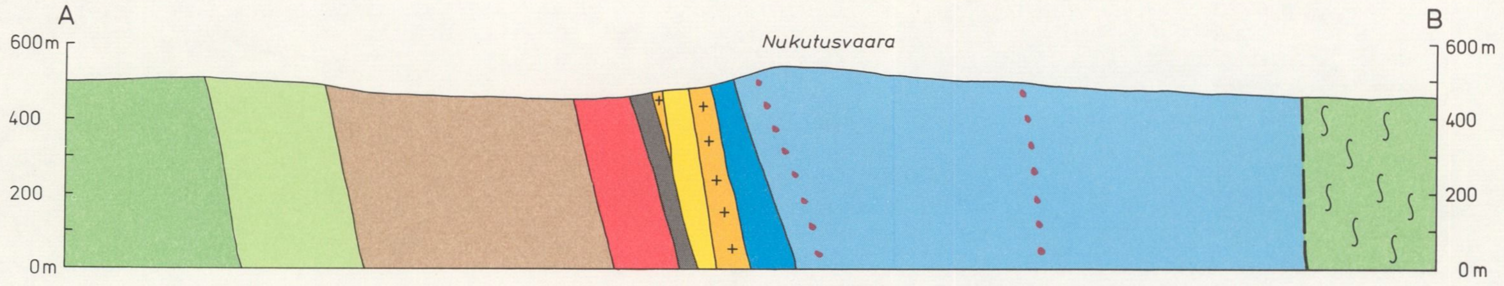
GEOLOGICAL MAP OF THE KURRAVAARA AREA

NE of Kiruna Northern Sweden

R. Frietsch 1974





QUARTZITE GROUP
- Quartzitic sandstone (with conglomerates)
- Phyllite
- Conglomerate - greywacke (with basal conglomerate)

PORPHYRY GROUP
Lower Hauki Formation
- Syenite-porphyry
- Agglomeratic syenite-porphyry
- Sericite-rich breccia
- Light sericite quartzite
- Sericite quartzite with siliceous hematite ore
- "Rektor porphyry"
- Quartz-bearing porphyry
- Syenite-porphyry
- Apatite-rich hematite-magnetite ore

SCHIST-CONGLOMERATE GROUP
- Kurravaara conglomerate

GREENSTONE GROUP
- Kiruna greenstone
- Tuffite

- Ultrabasite, P = porphyrite, D = uralite diabase
- Syenite-porphyry in Kurravaara conglomerate
- Amphibolite

- Outcrop
- Local boulders
- Trench
- Bedding 90° 70-90° 50-70° <50°
- Schistosity
- Fold axis
- Fault
- Way-up determination

PRISKLASS H

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