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The granulite complex and adjacent rocks in Lapland, northern Finland

by Kauko Meriläinen

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THE GRANULITE COMPLEX AND ADJACENT ROCKS IN LAPLAND, NORTHERN FINLAND

BY

KAUKO MERILÄINEN

WITH 60 FIGURES AND 42 TABLES IN TEXT

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The granulite complex and adjacent rocks are divided into four subareas: 1) the granite gneiss complex, 2) the Apukasjärvi, Vätsäri and Kuorboaivi schist zones, 3) the granulite complex and 4) the West Inari schist zone. The petrology of rocks, the stratigraphy of supracrustal rocks and the tectonics are briefly described. Numerous analyses of the mineral compositions and twenty-three chemical analyses mainly of the rocks of the granulite complex are presented.

Whole rock common lead, Rb-Sr and zircon ages indicate that the rocks of the granite gneiss complex were uplifted or metamorphosed about 2 500 Ma ago, in all likelihood under the conditions of the amphibolite facies, contemporaneously with the adjacent rocks. The older rocks, dated by the whole rock common lead (2 865 Ma) or the zircon (2 730 Ma) method, are relicts preserved in the cores of some anticlines (blocks). The rocks of the granite gneiss complex were remetamorphosed during the Karelian epoch. Zircon, titanite, common lead potash feldspar and Rb-Sr mineral ages indicate an age of c. 1 900 Ma for this event.

According to Rb-Sr and zircon ages, the rocks of the granulite complex were granulitised or uplifted about 2 150 Ma ago. Whole rock common lead ages indicate that about 2 020 Ma ago, some early Karelian infracrustal rocks were emplaced into the granulite complex and the adjacent rocks. According to zircon and monazite ages the rocks of the granulite complex were remetamorphosed diaphthoretically under conditions of low-grade granulite facies and high-grade amphibolite facies c. 1 900 Ma ago. This episode is limited by the emplacement of a post-granulitic quartz diorite. Postorogenic Karelian granites, quarts-syenite porphyry dykes and olivine diabases with common lead, Rb-Sr, zircon and titanite ages of c. 1 730 Ma, show that the granulite complex had stabilised before the emplacement of these rocks.

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INTRODUCTION

The bedrock for the general geologic map of Inari—Utsjoki was mapped on a scale of 1: 400 000 by the Geological Survey in the summers of 1955 to 1962 inclusive. The field studies were supplemented by excursions lasting for a few weeks each summer from 1963 to 1972. In the course of these, samples were gathered for age determinations, and tectonic observations were checked. The geologic map of the area was published by the Geological Survey in 1965 (Meriläinen 1965).

The original intention was to publish a general geologic map of Inari—Utsjoki together with an explanation to its rocks and a special study of the granulite complex. However, in 1963 age determinations were added to the programme, thus necessitating a shift in emphasis. Not only were rocks to be described but also, and most important, the stratigraphy and some tectonic structures were to be established by means of tectonic elements and information from dating.

The study area in which the granulite complex predominates comprises some 24 000 km^2 in Finnish Lapland. It is located between latitudes 68°20′ and 70°10′N and logitudes 24°20′ and 29°25′E. The location and main geological features of the area are shown in Fig. 1.

Previous investigations

The systematic investigation of North Lapland began in 1866 after the discovery of gold in gravel on the banks of the river Tenojoki (Laine 1952, 1955). A. M. Järnström, who had investigated the bedrock over a large area of Inari and Utsjoki as early as 1868, was given the task in 1872 of carrying out geological and mineralogical studies directed at revealing the source of the gold. The result of his work was the first significant study of the bedrock of North Lapland.

In his study, A. M. Järnström (1874) described the granulite complex and its immediate environment. After examining the problem of the granulites of Saxony, he applied the term granulite to the garnet gneisses of North Lapland. He distinguished five granulite varieties. For those who are familiar with the granulite complex of North Lapland, his descriptions are informative. On the basis of his field studies, Järnström interpreted the granulites as metamorphosed sediments.

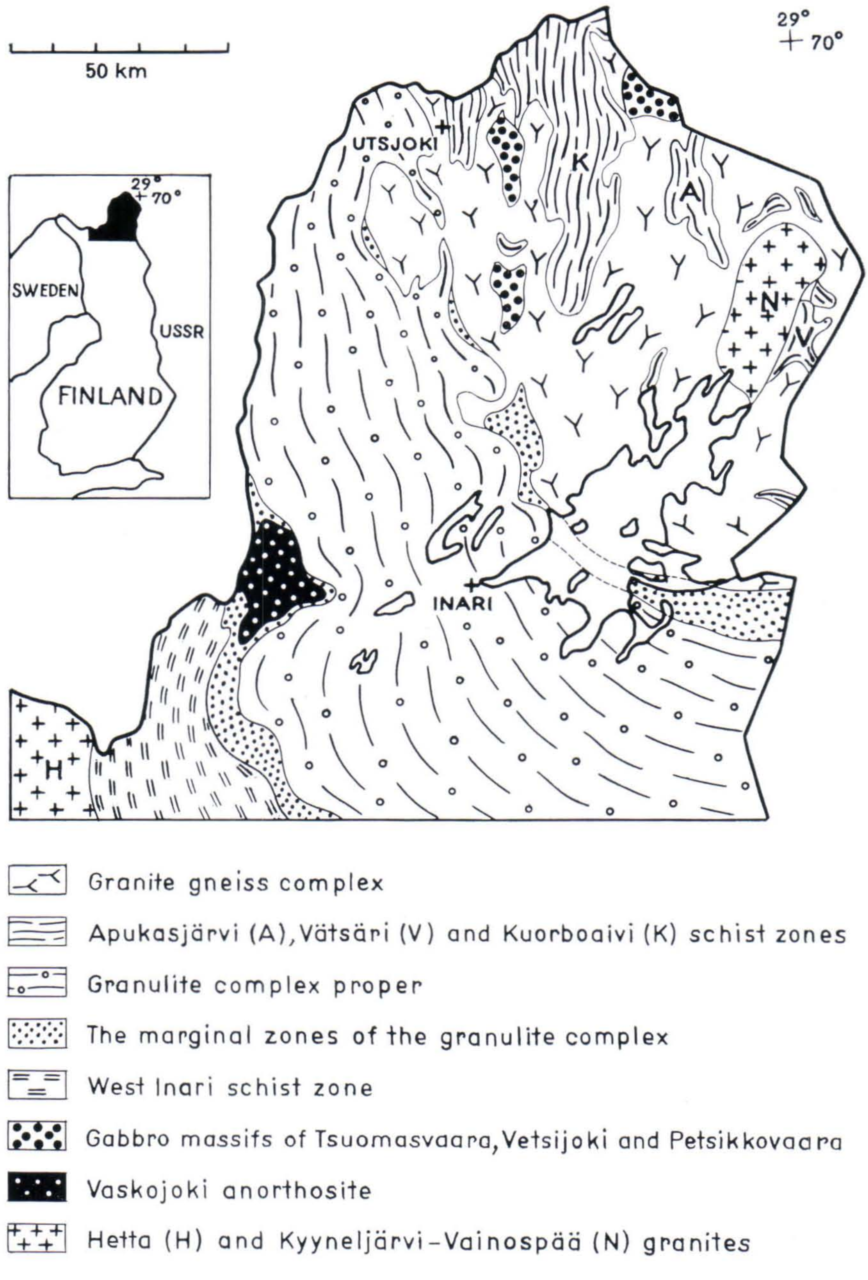

Fig. 1. Location of study area and main features of bedrock.

The studies by A. F. Tigerstedt (1882) in the northeastern parts of the granulite complex (Finnish territory) and the mapping of the bedrock of North Lapland from 1898 to 1908 added nothing essentially new to the granulite problem. The geologic map produced by J. J. Sederholm (1897, 1911) reveals, however, a pattern of the bedrock of North Lapland and the whole of Finland that is roughly equivalent to that of the present day owing to the influence of concurrent investigations carried out elsewhere in the country.

In the opinion of Eskola (1932), the acid granulites are magmatic and form, together with the basic and ultrabasic rocks of the granulite complex, a differentiation series: 1) peridotites, 2) norites, 3) hypersthene quartz diorites, 4) acid granulites, 5) granulite aplites. According to Sahama (1936), Eskola's classification was as follows: 1) peridotites, 2) norite granulites, 3) charnockite granulites, 4) plagioclase granulites, 5) normal granulites and 6) laanilite granulites. Later, Eskola (1952) accepted a sedimentary origin for the acid granulites. Eskola observed no relict structures in the granulites indicating that they were derived from either plutonic rocks or sediments. Hence, he based his interpretation on chemical analyses, on mineral compositions he investigated microscopically, and on special varieties such as graphite- and sillimanite-bearing granulites and diopside-bearing gneisses, because he felt that it was not possible to convincingly establish the origin of the acid granulites merely on the basis of their chemical compositions. In Eskola's opinion, the ultrabasic granulites, i.e., the ultrabasic rocks of the granulite complex, are peridotites and pyroxenites in chemical composition; the hypersthene diorites (charnockites and enderbites) are plutonic rocks, whereas the basic granulites, whose composition corresponds to that of basalts, andesites and dacites, are probably volcanic lavas, sills or dolerites.

J. J. Sederholm (1932) interpreted the granulites as migmatites that formed when the granitic magma intruded the older granites, gneisses, metabasites, anorthosites and sedimentary schists during intense tectonic movements.

E. Mikkola (1928, 1932, 1941) and Th. G. Sahama (1936, 1945) commonly use »granulite series» or »granulite formation» in their works but mainly as descriptive terms. However, it is evident that Sahama (1945, p. 43) considers the granulites as plutonic rocks.

K. Meriläinen (1959) has advanced the opinion that the acid garnet gneisses are largely derived from various psammites (greywackes, subgreywackes, plagioclase-bearing quartzites) and pelites. Volcanic materials in the form of lavas, tuffs and possibly sills also occur locally among the sediments. The plutonic rocks are peridotites, norites, pyroxenites and quartz diorites.

The metamorphism, i.e., granulitisation, of the rocks of the granulite complex of Lapland, has been investigated chiefly by P. Eskola (1920, 1929, 1939, 1946, 1952, 1957, 1961). Since then, a short study has been published by K. H. Scheumann (Scheumann, Bossdorf and Bock 1961), who has long investigated the granulites of Saxony. Under the guidance of the present author, Scheumann spent some days studying roadside outcrops (garnet-cordierite gneisses and coarse-grained garnet-quartz-feldspar gneisses) in the eastern part of the granulite complex. However, it is beyond the scope of the present study to discuss granulitisation as a phenomenon of the granulite facies.

The large-scale tectonic and stratigraphic features of the bedrock of North Lapland were first presented by J. J. Sederholm in his geologic maps of Finland and Fennoscandia on a scale of 1: 8 000 000 (1911 b, 1932), 1: 2 500 000 (1897) and 1: 2 000 000 (1911 a, 1929). In these, the granulite complex and the area to the east of it are usually classified as Archean formations analogous with the granite gneisses and gneiss granites of East Finland.

Sahama (1945) considers the granulite complex as eruptive rocks. According to him, the complex assumed its present mineral composition, that is, became granulitised, after the intrusion of the late Karelian Hetta granite but before the emplacement of the postorogenic granites (Nattanen, Lohivaara, Pomovaara).

Simonen (1960 a, c) consideres the granulite complex as part of a granite gneiss complex that was granulitised during the Karelian orogeny. The tectonic map of Europe (Holtedahl, Kratz, Magnusson and Simonen (1964) includes the granulite complex in the Belomorian, i.e. formations older than the Karelian, whose rocks were granulitised during the Karelian orogeny.

Von Gaertner (1962) is of the opinion that the rocks of the granulite complex are older than the Karelian and probably also older than the Belomorian.

Quartz orientation diagrams and macroscopically visible lineations studied by Th. G. Sahama (1933, 1936) reveal that the granulite complex was deformed in two stages. The macroscopically visible lineations indicate that during the first deformation phase the movements were directed as differential overthrusts from NE to SW. In the northern parts of the complex, the direction of overthrust was ENE → WSW, but farther south the direction changes to NE → SW and finally to NNE → SSW in the eastern parts of the complex. On the basis of the quartz orientation diagrams, it can be concluded that a lineament with a northeast orientation was formed in the northern parts of the complex and a lineament with a northwest orientation in its central and southern parts during the second granulitic deformation phase.

According to Kranck (1936), microtectonic structures (including those based on the forementioned quartz orientation diagrams) can only be applied with great care when large-scale tectonic structures are analysed. It may indeed well be that the micro- and macrostructures observed in a mass as huge as that of the granulite complex are formed during only one movement phase. In the light of observations on the structural geology, Kranck presumed that the granulite complex was a gigantic movement zone whose rocks were all uniformly metamorphosed. The mechanical deformation was probably synchronous with the granitisation of the rocks in the complex, although the main phase of the deformation took place after the granitisation. Later, the granites and pegmatites again intruded and injected the sheared rock complex. The granulitisation took place deep down in the earth's crust during the horizontal movements and the whole shear zone acted plastically in relation to the masses above and below it. Conditions such as these appear to arise chiefly in the upper parts of the uplifting granitising zones. In Kranck's opinion, the strike of foliation and the directions of movements suggest that the granulite complex and the Petsamo formation deformed simultaneously.

Väyrynen (1938, 1954) suggests that the westward movements, as demonstrated by Sahama's quartz orientation diagrams, were of the Rückfaltung type. The position of the granulite complex in the Karelian zone indicates that its main deformation phase was contemporaneous with the folding of the Karelian formations accompanied by movements directed southeastward.

The bedrock southwest of the granulite complex, which is included in this study, has been investigated by E. Mikkola and Th. G. Sahama (1936), Th. G. Sahama (1945) and V. Marmo (1960). These are all special studies. The first one deals with ultrabasic rocks, the second with the trace elements of the rocks in Central Lapland and the last with the Pahta-Autsi serpentinites in the headwaters of the river Repojoki. In addition to these special topics, the bedrock of each investigation area is briefly described.

Previous knowledge of the area east and northeast of the granulite complex is based almost entirely on maps (*e.g.* Sederholm 1932, Eskola 1952, Simonen 1960 b, Meriläinen 1965). The only publication worthy of note with a description of the rock types is that by A. M. Järnström.

Radiometric dating of the rocks in the study area has been carried out mainly at the Geological Survey of Finland (Annual Reports on the activities for the years 1964—1974).

The present study

This study describes the rocks in northern Finnish Lapland, the stratigraphy of its supracrustal rocks, some tectonical features of its rock complexes or areas and the geochronology. It also includes a short summary and discussion.

THE GRANITE GNEISS COMPLEX

The granite gneiss complex is marked by the monotony of its rock types, which are mainly migmatic and veined granite gneisses and gneissose granodiorites, quartz diorites and granites. The monotony is relieved by sporadic supracrustal rocks (quartz-feldspar gneisses, biotite gneisses, hornblende gneisses and amphibolites). In addition, a few ultrabasic intrusives have been encountered as have also locally abundant occurrences of diabases and granitic pegmatites cutting all the forementioned rocks. In places, the supracrustal rocks form small zones with which the ultrabasic rocks are usually associated. The granite gneiss complex and its tectonic structure suggest that at least some of these zones are parts of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones, and hence, they are described in conjunction with the rocks of the schist zones in question.

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Fig. 2. Folded and migmatised granite gneiss. Inarijärvi, Tourissaaret. Photo K. Meriläinen.

As a whole the granite gneiss complex is homogeneous. However, in the outcrops its rock types, in particular the granite gneisses, but often also the acid and intermediate infra- and supracrustal rocks, are heterogeneous, strongly folded migmatic veined gneisses cut by granite and granitic pegmatite veins (Fig. 2). Hence, it was not possible to establish whether the granite gneisses were originally infra- or supracrustal rocks, and they are treated as a separate group.

Granite gneisses

The granite gneisses are encountered throughout the granite gneiss complex, but most typically in and around the lake Inarijärvi, in the centre of the complex. They are very well exposed on the shores of the lake, so much so that a great diversity of structures can be recognized and traced, *e.g.*, streaky, banded, veined-gneissose, agmatitic and brecciated structures. The veined gneiss structures is due to the irregular, light-coloured, biotite-poor or biotite-free veins and dark bands or schlieren in the rock (Figs. 3 and 4). Their boundary with the host rock is sharp or gradual. Locally light-coloured veins predominate in the rock. The granite gneisses grade into acid and intermediate infracrustal rocks (granodiorites, quartz diorites and granites) and supracrustal rocks. Varieties containing potash feldspar porphyroblasts occur in

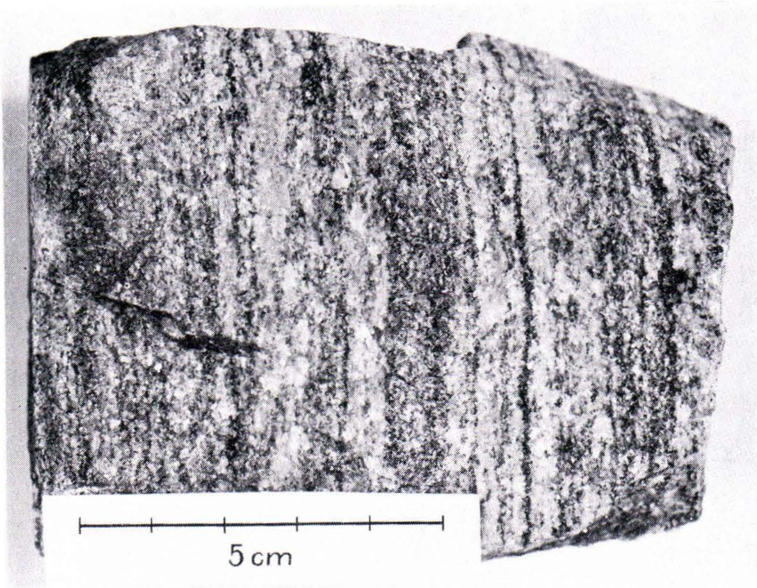

Fig. 3. Granite gneiss. Inarijärvi, Kotkavuono. Photo E. Halme.

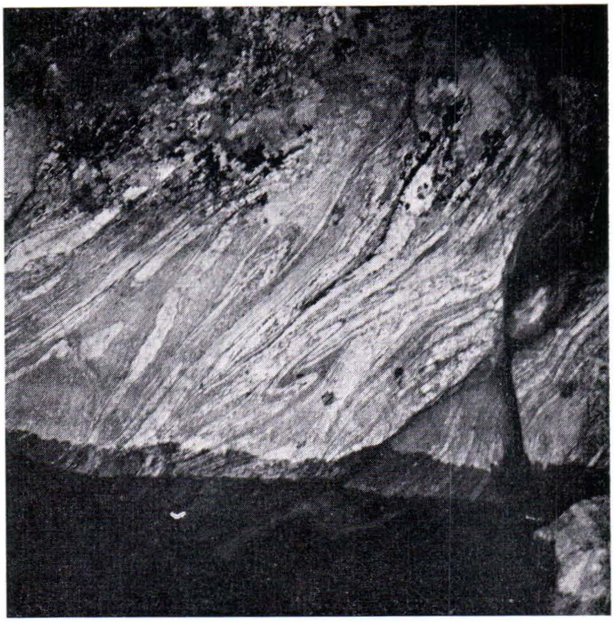

Fig. 4. Folded and veined granite gneiss. Inarijärvi, Palkissaari. Photo K. Meriläinen.

Table 1
Mineralogical composition of granite gneisses.

	1	2	3
Quartz	34.9	32.2	23.7
K-feldspar	8.6	10.1	7.7
Plagioclase	48.5	53.7	62.3
Biotite	0.6	2.3	2.5
Muscovite	3.1	—	2.4
Chlorite	1.9	—	—
Hypersthene	—	0.8	—
Accessories	2.4	0.9	1.4

1. Inari, Surnuvuono, Mustavaara, 68/KM/60.
2. Inari, Petsijärvi, 22/PV/58.
3. Inari, Virtaniemi, Tervavuono, 109/KM/57.

the environment of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and the development of porphyroblasts was obviously concurrent with the development of porphyroblastic potash granites in the same areas. The typical granite gneisses are often intensely folded, particularly in the Inarijärvi area.

The granite gneisses are granoblastic and often also cataclastic in structure. In their mineral composition they are quartz-plagioclase-biotite rocks (Table 1). Potash feldspar is sparse, but when more abundant it is due to the introduction of potash feldspar-rich veins. There are usually a few percent of biotite. Some epidote is often found and occasionally hornblende. Accessories are apatite, zircon, titanite, allanite and opaques.

The granite gneisses were probably formed through migmatisation from acidic supracrustal rocks as well as quartz diorites, granodiorites and granites.

Supracrustal rocks

The supracrustal rocks of the granite gneiss complex are quartz-feldspar gneisses, biotite gneisses, hornblende gneisses and amphibolites. They often grade into granite gneisses and infracrustal rocks, in which they also occur as small bodies and relicts. The supracrustal rocks were metamorphosed largely under the conditions of the amphibolite facies, but sometimes also under those of the epidote-albite-amphibolite facies.

Quartz-feldspar gneisses

Quartz-feldspar gneisses are grey in colour, sometimes with a slightly pinkish hue, and fine- to medium-grained (Ø = 0.5—2 mm) rocks. Foliation is moderately developed, and locally relict bedding has been preserved as clear banding parallel to the

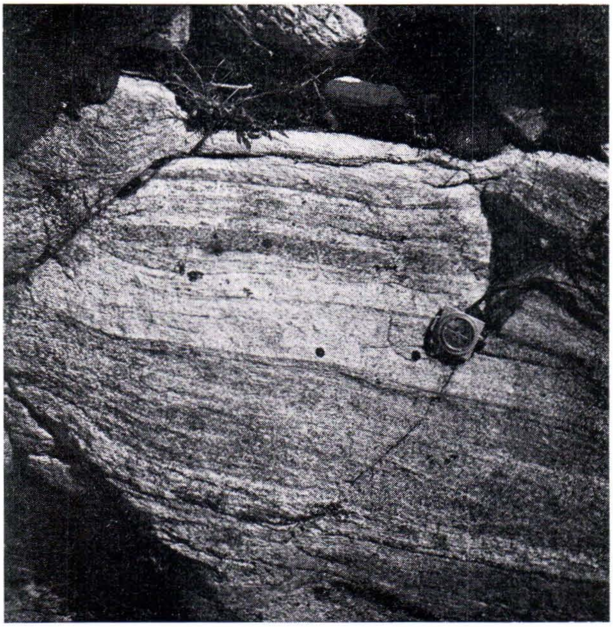

Fig. 5. Interbedded quartz-feldspar gneiss and hornblende gneiss. Inarijärvi, Tervavuono. Photo K. Meriläinen.

foliation. The layered structure is emphasized by the alternation of quartz-feldspar gneiss bands with mica gneiss bands and occasionally even with amphibolite and hornblende gneiss bands (Fig. 5).

The quartz-feldspar gneisses are granoblastic. Their main minerals are quartz, plagioclase and biotite. In addition, some feldspar occurs and occasionally also hornblende. Accessories are apatite, epidote, allanite, titanite, opaques and zircon. Macroscopically and in mineral composition the quartz-feldspar gneisses of the granite gneiss complex are similar to those in the marginal zones of the granulite complex and in the schist zone of Apukasjärvi, Vätsäri and Kuorboaivi (see Tables 4, 27 and 31). It is probable that the quartz-feldspar gneisses were derived largely from arkose sands.

Biotite gneisses

Biotite gneisses are grey, fine- to medium-grained (Ø = 0.5—2 mm) rocks with well-developed foliation. They commonly display the banded structure of intensely folded veined gneisses. The banded structure is due to the relict bedding of the rock (Figs. 6 and 7).

Fig. 6. Biotite gneiss with relict bedding. Darker layers are often hornblende bearing. Inarijärvi, island at western edge of Varttasaari. Photo K. Meriläinen.

Fig. 7. Hornblende gneiss and amphibolite bands in biotite gneiss. Inarijärvi, island at western edge of Varttasaari. Photo K. Meriläinen.

The biotite gneisses are granoblastic in texture. Their main minerals are plagioclase, potash feldspar, biotite and quartz with minor garnet, hornblende and epidote. The accessories are apatite, opaques and zircon. Plagioclase is always present in considerably greater abundances than potash feldspar, the latter often being no more than a minor constituent of the rock. Biotite seldom constitutes more than 20 percent of the rock. The mineral composition of the biotite gneisses described here is similar to that of the biotite gneisses in the Kuorboaivi schist zone (see Table 5). They are probably derived from greywackes.

Hornblende gneisses

Hornblende gneisses alternate locally with amphibolites and quartz-feldspar gneisses as irregular bands and beds. In mineral composition they are transitional types between quartz-feldspar gneisses and amphibolites. Main minerals are plagioclase (An_{30-40}), hornblende and quartz. In addition, epidote, diopside and biotite occur locally. Some of the bands are calc-silicate gneisses rich in epidote and/or diopside. The hornblende gneisses are similar to those in the schist zone of Kuorboaivi and in the marginal zones of the granulite complex. It seems likely that the hornblende gneisses were originally mainly tuffaceous sediments.

Amphibolites

Although sparsely distributed on a regional scale, amphibolites are found in numerous outcrops as small bodies, long streaks or minute relicts conformable with the foliation or as inclusions in the granite gneisses and infracrustal rocks (Figs. 8 and 9). Locally they occur as bands and beds alternating randomly with other supracrustal rocks.

Amphibolites are black-green in colour, distinctly foliated, locally banded and fine- to medium-grained ($\varnothing = 0.5$—2 mm) rocks. The texture is granoblastic, nematoblastic or blasto-ophitic. Main minerals are hornblende (60—70 %) and plagioclase (An_{35-45}), with minor amounts of quartz and sometimes epidote or garnet. Accessories are opaques, titanite and apatite.

Most of the amphibolites in the granite gneiss complex are basic diabases that were probably metamorphosed in conjunction with the movements. On the other hand, the amphibolites interbedded with quartz-feldspar gneisses and hornblende gneisses could be mainly metamorphosed lavas and tuffs.

Infracrustal rocks

The infracrustal rocks of the granite gneiss complex are quartz diorites, granodiorites and granites concordant with the supracrustal rocks. In some places they are veined gneisses and even folded rocks, whereas in others they are almost homogeneous and weakly foliated. The infracrustal rocks are cross cut by diabases and granitic pegmatites.

Fig. 8. Amphibolite relicts in folded migmatic granite. Inarijärvi, Tourissaaret. Photo K. Meriläinen.

Fig. 9. Amphibolite and hornblende gneiss brecciated by granite. Inarijärvi, Poropeskansaaret. Photo K. Meriläinen.

Granites

In mineral composition the granites are trondhjemites, oligoclase granites and microcline granites.

The *trondhjemites and oligoclase granites* are weakly foliated or gneissose, grey-white gneiss granites. Their gneissose character is emphasized by the presence of biotite-poor veins and bands that are often grey or almost white, and locally by portions and bands of supracrustal rocks. Only seldom is it possible to distinguish megascopically the trondhjemites and oligoclase granites from each other. In structure the trondhjemites are hypidiomorphic or granular, frequently even cataclastic. Main minerals are plagioclase (An_{15-25}) and quartz. In addition, some biotite and a percent or two of potash feldspar are found. Accessories are apatite, zircon and opaques. The oligoclase granites can be distinguished from the trondhjemites by the more abundant potash feldspar content of the former (Tables 2 and 9).

Microcline granites are commonly porphyroblastic, pinkish or pinkish grey gneiss granites exhibiting intense or moderate foliation. Macroscopically, the microcline granites may be homogeneous over extensive areas, whereas locally they contain relicts and portions of supracrustal rocks. The porphyroblastic microcline grains commonly display cataclastic fracturing accompanied by deformation into elliptical augen. Locally and especially in the eastern part of the Apukasjärvi schist zone, the porphyroblastic microcline grains are often euhedral. Texturally, the microcline granites are hypidiomorphic or granular and often cataclastic. Main minerals are microcline, plagioclase (An_{10-20}), quartz and biotite. Chlorite is present as an alteration product, and the accessories are apatite, titanite, fluorite, zircon, orthite and opaques (Table 2).

Table 2
Mineralogical composition of granites.

	1	2	3	4
Quartz	29.8	30 5	20.7	9.7
K-feldspar	11.4	34.0	45.3	57.9
Plagioclase	49.6	26.3	26.2	24.7
Biotite	7.3	0.7	5.1	7.1
Chlorite	—	7.0	+	—
Muscovite	—	0.7	+	+
Accessories	1.9	0.8	2.7	0.6

1. Granite. Inari, Kittilompolo, 32/KM/58. A 213, sample number of radiometric isotope age.
2. Porphyroplastic potash granite. Norway, Neiden, 14/KM/68, A 113.
3. Porphyroplastic potash granite. Inari, Pirivaara, 3/KM/67, A 226.
4. Porphyroplastic potash granite. Utsjoki, Roavvi Tievja, 37/KM/63, A 207.

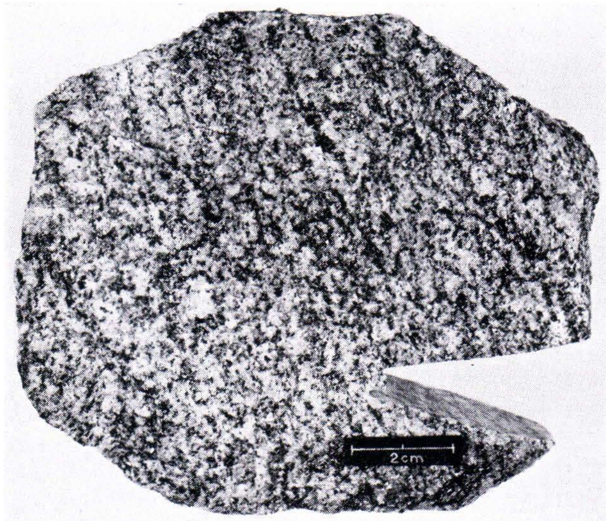

Fig. 10. Gneissose and cataclastic quartz diorite. Inarijärvi, Partakonlahti. Photo Erkki Halme.

Granodiorites and quartz diorites

Granodiorites and quartz diorites are grey, slightly or moderately gneissose rocks. They are distinctly richer in biotite than the trondhjemites and oligoclase granites and hence, are also darker in colour. The rocks are medium-grained (Ø = 1—3 mm) and often cataclastic even macroscopically (Fig. 10).

Texturally, the granodiorites and quartz diorites are hypidiomorphic or granular and frequently cataclastic. The cataclastic texture may be intensive, encompassing the

Table 3
Mineralogical composition of quartz diorites and granodiorites.

	1	2	3	4
Quartz	25.1	25 2	19.6	32.5
K-feldspar	22.9	22.1	3.2	1.3
Plagioclase	36.7	24.3	57.5	54.0
Hornblende	0.5	4.0	11.2	0.3
Biotite	13.8	12.7	8.1	6.0
Epidote	—	—	—	+
Accessories	1.0	1.7	0.4	3.5
An	25	23	nd	26

1. Granodiorite. Inari, Akulahti, 115 a/PV/58, A 212.
2. Granodiorite. Inari, Partakonlahti, 110/PV/58.
3. Quartz diorite. Inari, Kuorpasaari, 21/KM/64, A 167.
4. Quartz diorite. Inari, Virtaniemi, Suovavaara, 8/KM/67, A 227.

whole rock in the outcrops, or it may be restricted to thin zones or microscopic fractures in an otherwise hypidiomorphic rock. The main minerals of the granodiorites are plagioclase (An_{25-30}), potash feldspar, quartz and biotite. In addition, hornblende is usually present and is locally even more abundant than biotite. Accessories are potash feldspar, apatite, titanite, orthite or allanite, zircon and opaques (Table 3). The occurrence of potash feldspar and usually greater amout of biotite over hornblende in granodiorites distinguishes them from the quartz diorites. Both the granodiorites and the quartz diorites differ from the trondhjemitic granites in the diversity of their accessory minerals.

Diabases

The diabases penetrate the acid supra- and infracrustal rocks of the granite gneiss complex as concordant sills or dykes cutting or even brecciating the foliation (Figs. 11 and 12). The diabases are penetrated by granitic pegmatites.

Diabases are black-green in colour and often difficult to identify because of amphibolitisation, which took place in conjunction with tectonic movements (see p. 15). However, some of them have retained their characteristic appearance, and sometimes ophitic structure is visible. Furthermore, many of the diabases are slightly porphyritic: some plagioclase grains are larger than the other minerals in the rock or plagioclase and quartz together form amygdaloidal clusters.

Fig. 11. Diabase cutting granite gneiss. The diabase is cut by faults. Inarijärvi, island in Surnuvuono. Photo K. Meriläinen.

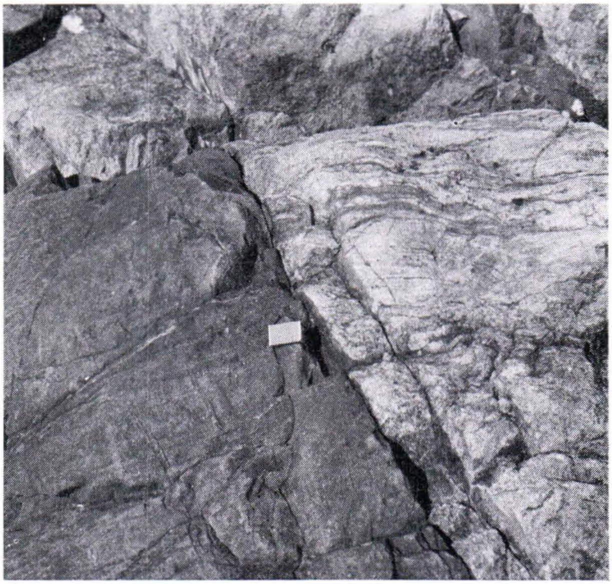

Fig. 12. Diabase cutting granite gneiss. The strike of foliation of the migmatic granite gneiss is almost perpendicular to the direction of the diabase. Inarijärvi, island in Surnuvuono. Photo K. Meriläinen.

Main minerals are hornblende and plagioclase. The saussuritised plagioclase was probably primarily andesine. As a result of epidotisation, the plagioclase in one of the diabases is albite (An_5). Additional minerals in the diabases are often quartz and chlorite, the latter also being an alteration product. Accessories are opaques, titanite and apatite.

Pegmatite granite veins

The granitic pegmatites in the granite gneiss complex are younger than the diabases. They are slightly pinkish or grey and coarse-grained (Ø = more than 5 mm to several centimetres) rocks. The pegmatites usually cut the foliation of the supra- and infracrustal rocks, but they may also be concordant with it. This concordancy particularly applies to the apophyses in the thick veins. The apophyses are generally rich in potash feldspar and have intruded the veined gneisses parallel to their oldest veins and schlieren.

In mineral composition the pegmatites are either quartz-plagioclase-biotite rocks or quartz-plagioclase-potash feldspar-biotite rocks. The latter are often zoned, the edges of the veins enriched in plagioclase, the centre in quartz and the intervening part in potash feldspar. Accessories are apatite, monazite, zircon, magnetite and orthite.

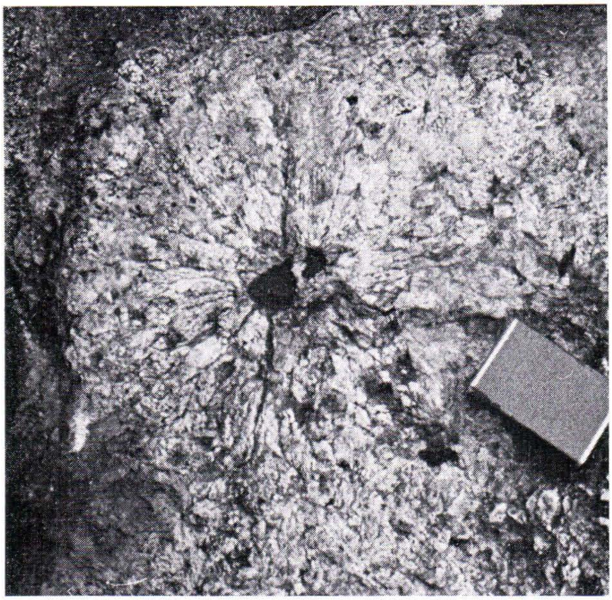

Fig. 13. Orthite crystals in granite vein. Thin fractures radiate from orthite crystal. Inarijärvi, Kaamassaari, Andresnuora. Photo K. Meriläinen.

Orthite occurs locally as black, pitch-like crystals up to 1 to 2 cm in length from which thin fissures radiate into the surrounding feldspar (Fig. 13). A preliminary 207 Pb/206 Pb ratio for this orthite yielded an age of 1890 Ma.

Tectonic structure

The tectonic structure of the granite gneiss complex is complicated. The rocks of the complex have been deformed several times, which has obscured the oldest structures. Indeed the present structures originated mainly during the deformation of the rocks of the granulite complex and the Apukasjärvi, Vätsäri and Kuorboaivi schist zones.

Foliation and bedding

Foliation is well developed in the rocks of the granite gneiss complex and visible throughout the whole complex. Locally, the foliation is conformable with the original bedding in the quartz-feldspar gneisses, biotite gneisses, amphibolites and hornblende gneisses. The bedding is most conspicuous in those places where different types of supracrustal rocks alternate with each other. The bedding and foliation are often intensively folded (Fig. 14). In some localities the foliation is cut by a younger foliation that developed during later deformations (transverse foliation).

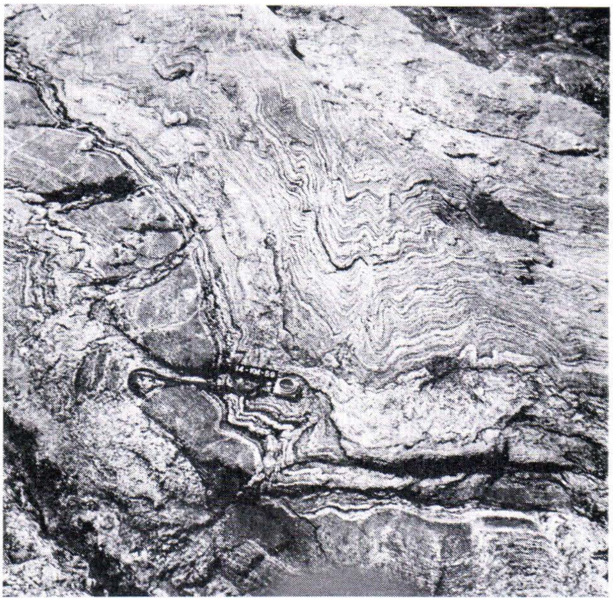

Fig. 14. Intensely folded biotite gneiss with a boudinaged amphibolite intercalation. Inarijärvi, island on western edge of Varttasaari. Photo K. Meriläinen.

The general trend of the foliation in the granite gneiss complex is approximately N—S (NNW, N, NNE). However, in the vicinity of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and the granulite complex it conforms to their trend. Significant areal variations are also encountered in the dip of the foliation. Hence, in the northern parts of the complex the dip is from 10 to 40°, in and around Inarijärvi 30 to 60°, but along the eastern margin of the granulite complex and in many narrow zones it is 70 to 90°. The dip is usually to the west (NW, W, SW), but sometimes also to the east, e.g., in the western parts of the Apukasjärvi and Kuorboaivi schist zones (Figs. 15 and 16).

Folding

Strike and dip data on foliation indicate that the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and the northeastern marginal zone of the granulite complex are in synclinoriums relative to the granite gneiss complex. The main part of the granite gneiss complex between these is an extensive dome-shaped anticlinorium that can be divided into a few blocks bordered by zones with subvertical foliation (Meriläinen 1970). Similar zones, as steeply dipping as the former, further divide these blocks into smaller ones, some of which are clearly dome-shaped (anticlines). Minor synclines

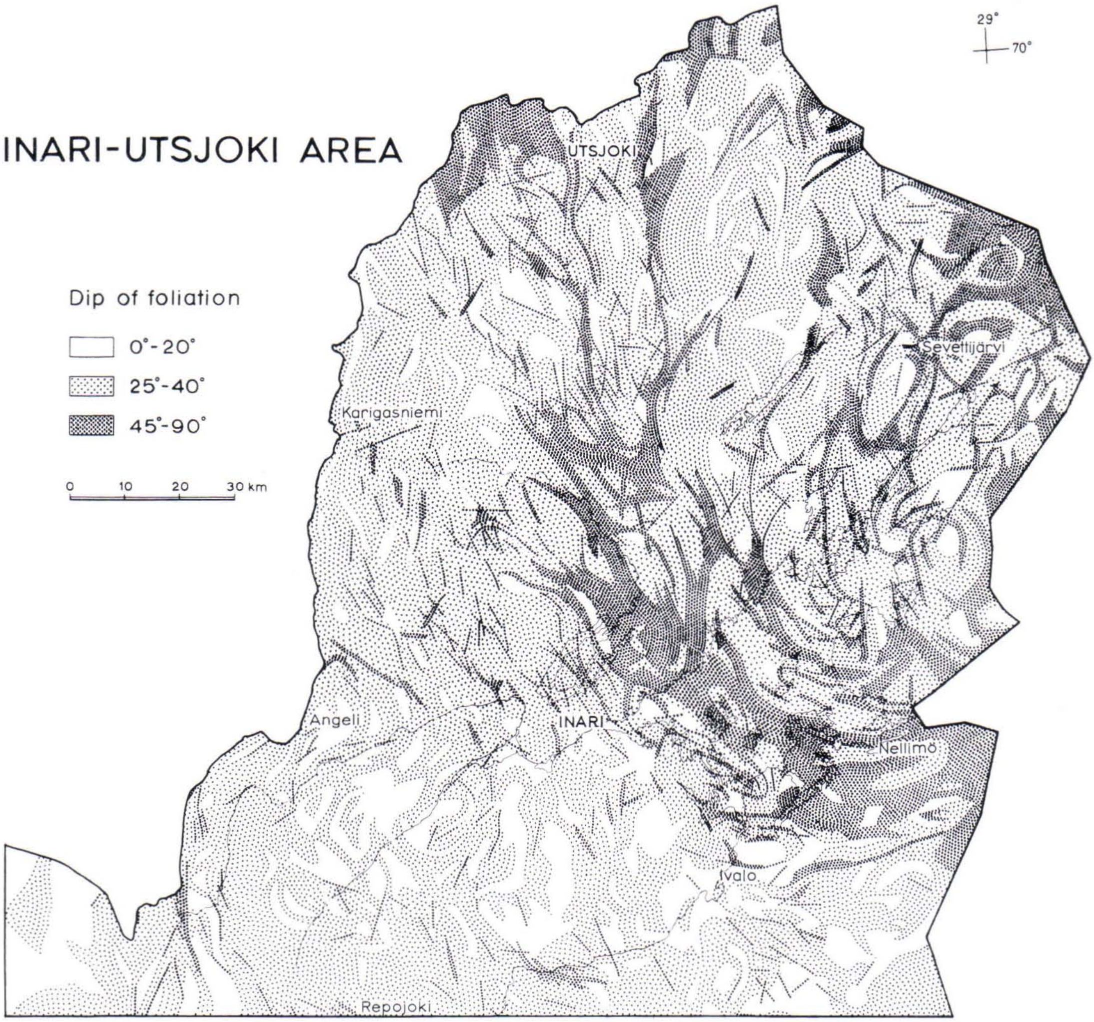

Fig. 15. Map showing dips of foliation: 0—20°, 25—40° or 45—90°. Some tectonic macroblocks can be delineated.

with rocks typical of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones occur locally between these anticlines. As relicts of synclines compressed into the spaces between the dome-shaped anticlines of the granite gneiss complex, they represent the deepest sections, i.e., axial depressions, of the forementioned schist zones. These synclines usually continue even in the country rocks either as trends of foliation or as fracture zones. Owing to the dome-shaped anticline structures, the traces of the axial planes of these minor synclines differ considerably from one another: Nitsjärvi NNE,

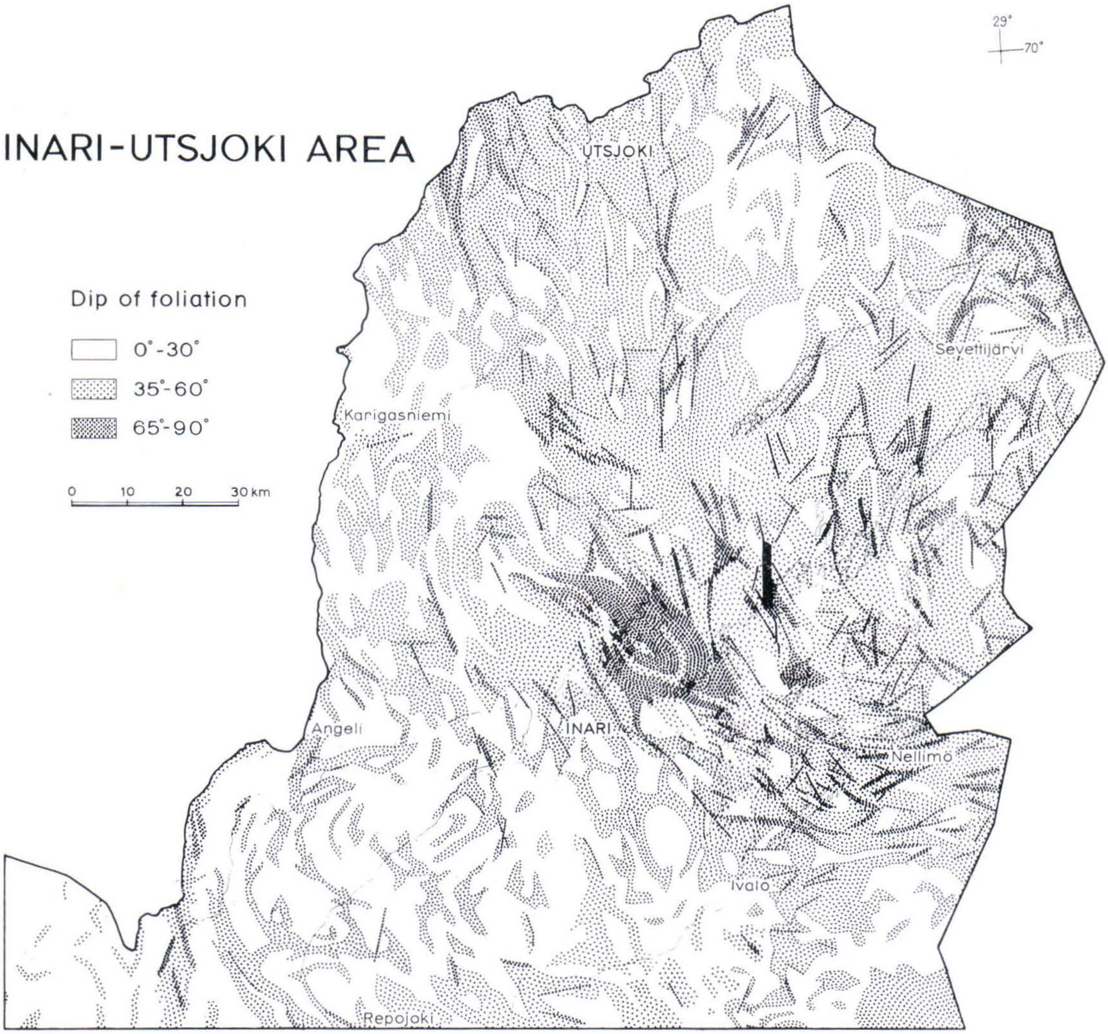

Fig. 16. Map showing dips of foliation: 0—30°, 35—60° or 65—90°.

Vuoskujärvi EW, Paudijärvi NE and Surnuvuono NNE. The B axes of the synclines are gentle and parallel to their length, whereas the longitudinal direction of the anticlines is regularly roughly N or NE.

The dome-shaped anticline and anticlinorium structures accentuate the fact that the majority of the tectonic structures in the granite gneiss complex developed during the folding and later redeformation of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones. The general trend of the oldest foliation is roughly NW. It is axial plane foliation that probably developed during the regional metamorphism of the oldest rocks in the granite gneiss complex. Later movements have deformed this foliation so often and so thoroughly that the tectonic structures which developed are often barely discernible from each other (see Wiik 1966). The Apukasjärvi, Vätsäri and Kuorboaivi schist zones were folded probably as the result of compression acting towards E or W during the Prekarelian epoch. During the early Karelian orogenic stage several of the zones with a N, NNE or NE trend were intruded by early Karelian ultrabasic and basic plutonic rocks: anorthosites, serpentinites, peridotites and gabbros. Later, possibly synchronously with the diaphthoretic metamorphism of the granulite complex, the rocks of the granite gneiss complex were redeformed once more with movements acting towards NNE or SSW. Several subvertical faults and foliation directed northwest or north indicates to this tectonic activity both in the granite gneiss complex and the granulite complex, particularly in and around the Inarijärvi area.

Tectonic and metamorphic alterations in the granite gneiss complex during the phases of the Karelian orogeny are clearly demonstrated by radiometric dating: Titanites in the infracrustal rocks, dating 2 730 Ma and 2 500 Ma by the zircon method, are roughly 1 900 Ma old and the Rb-Sr mineral isochron for the porphyroblastic potash granite of Roavvi Tievja and the common lead secondary isochron of the potash feldspar in the rocks of the granite gneiss complex reveals that the Karelian metamorphism took place some 1 900 Ma ago.

THE APUKASJÄRVI, VÄTSÄRI AND KUORBOAIVI SCHIST ZONES

The Apukasjärvi, Vätsäri and Kuorboaivi schist zones have a greater areal extent than that indicated on the geologic map (Meriläinen 1965). The quartz-feldspar gneisses, for instance, should have been depicted separately even though they are rare and their boundary with the granite gneiss complex is vague. Since the rocks of some minor schist zones (Nitsjärvi, Paudijärvi, Vuoskujärvi and the amphibolites adjacent to Paatsjoki) composed mainly of amphibolites and infracrustal ultrabasic rocks belong tectonically to the rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones, the latter form an incoherent and heterogeneous area around and partially also within the major part of the granite gneiss complex (Fig. 1).

The rocks of the Apukasjärvi and Vätsäri schist zones are chiefly amphibolites. Furthermore some quartzites, mica gneisses, quartz-feldspar gneisses and hornblende gneisses occur. In the Vätsäri schist zone there are also magnetite- and amphibole-banded, cherty quartzites. Infracrustal rocks are ultrabasic rocks, gabbros and granites.

The Kuorboaivi schist zone differs from the Apukasjärvi and Vätsäri zones by the abundant mica gneisses and infracrustal ultrabasic rocks, gabbros, granites, granodiorites and quartz diorites.

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The supracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are locally veined gneisses cross cut by granite dykes. Granite dykes are more sparse in the amphibolites and plutonic rocks. Thus, in the amphibolites of the Apukasjärvi schist zone the granite veins do not occur at all, whereas in the Vätsäri schist zone at Tuulispää the amphibolites are like a gigantic breccia cut by granite of the Kyyneljärvi type (p. 37). In some places, the infra- and supracrustal rocks are intruded by diabases.

Supracrustal rocks

The supracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are quartzites, magnetite- and amphibole-banded cherty quartzites, quartz-feldspar gneisses, mica gneisses, hornblende gneisses and amphibolites. They were metamorphosed mainly under the conditions of the amphibolite facies but locally also under those of the epidote-albite amphibolite facies.

Quartzites

Quartzites occur in many places along the margins of the Apukasjärvi and Vätsäri schist zones and occasionally in the marginal belts of the Kuorboaivi schist zone. The quartzites are layers some metres, at the most some tens of metres thick, grading into and alternating with quartz-feldspar gneisses. In some places, they also contain mica gneiss layers.

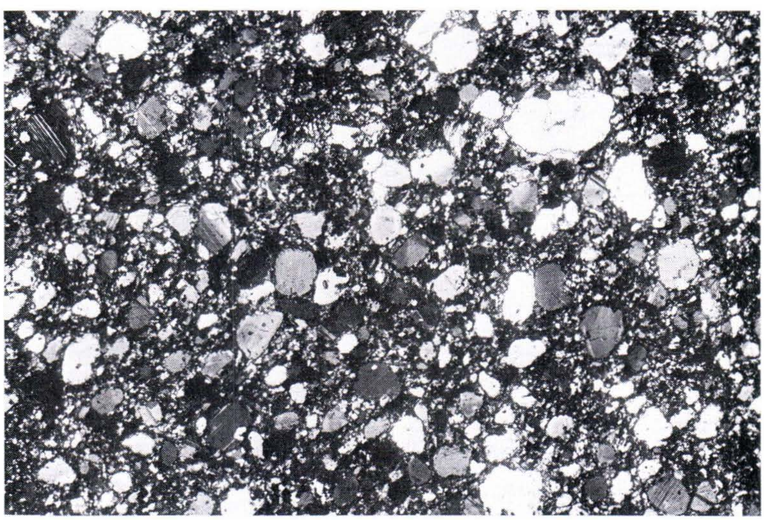

Fig. 17. Clastic quartzite in Apukasjärvi schist zone. Inari, Isokivennokka. Magn. 25x. Photo E. Halme.

The quartzites are grey or white, highly foliated and fine-grained (Ø = 0.5—2 mm) rocks. In texture, they are granoblastic, sometimes blastoclastic or even clastic (Fig. 17). Main minerals are quartz, plagioclase (An_{15-25}) and potash feldspar. In addition sericite, muscovite and/or biotite frequently occur and sometimes also epidote and/or hornblende. Some of the quartzites are quartz-rich orthoquartzites, whereas others contain feldspar, mainly potash feldspar, in such abundance that their composition approaches that of an arkose. Accessories are apatite, zircon and opaques.

Magnetite- and amphibole-banded, cherty quartzites

Magnetite- and amphibole-banded, cherty quartzites are to be found in the deposit underlying the amphibolites of the Vätsäri schist zone, where the amphibolites are interbedded with quartz-feldspar gneisses and biotite gneisses. Magnetite- and amphibole-banded, cherty quartzites are a maximum of some metres thick.

In the magnetite-banded, cherty quartzites dark magnetite-rich layers (Ø = 0.2—10 mm) are interbedded with quartzite layers. Magnetite and quartzite layers thicker than approximately 0.2 to 0.5 mm have been formed through the mergence of several thin layers (Fig. 18). The texture is granoblastic. Main minerals are quartz, magnetite and hornblende. The relative abundances of magnetite and hornblende vary. Furthermore plagioclase and biotite frequently occur. Accessories are apatite and carbonate, whilst sericite is an alteration product of feldspar.

In the amphibole-banded, cherty quartzites, magnetite is replaced by amphibole. The amphibole is either tremolite, grünerite or common hornblende. The tremolite is greenish grey in colour. Locally the amphibole bands are thicker than the quartzite layers, in which case the rock is quartzite-banded amphibolite. Some magnetite also

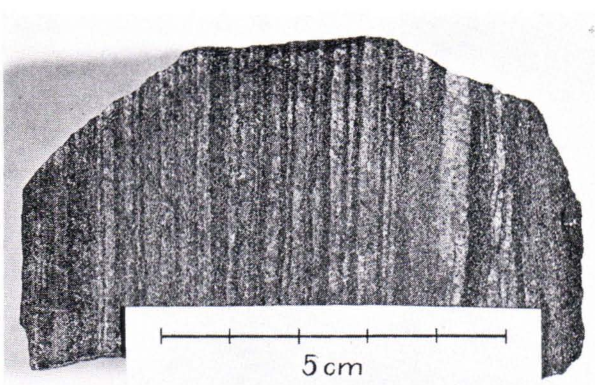

Fig. 18. Amphibole- and magnetite-banded quartzite (banded ironstone) in Vätsäri schist zone. Inari, Aittojärvet. Photo E. Halme.

occurs either as bands or disseminations. ZnS, CuFeS, FeS and FeS_2 have been encountered as opaque accessories.

The magnetite- and amphibole-banded cherty quartzites were formed during a period of volcanic activity. Their structures exhibit two types of graded bedding: 1) regular succession of beds of quartzite and magnetite resembling the graded bedding of sediments deposited in water under the influence of seasonal variations, 2) irregular amphibole-rich or amphibolite beds that truncate the forementioned regular graded bedding. They were probably formed during random eruptions of ash and lava.

Quartz-feldspar gneisses

Quartz-feldspar gneisses border the central part of the Apukasjärvi and Vätsäri schist zones, i.e., they occupy the base of the synclinorium. Quartzite and mica gneiss layers are locally encountered in the quartz-feldspar gneisses.

The quartz-feldspar gneisses are greyish, distinctly foliated and fine- to medium-grained (Ø = 0.2—2 mm) rocks. Their texture is granoblastic or blastoclastic and frequently even cataclastic. Main minerals are quartz, plagioclase (An_{15-30}) and potash feldspar. In addition, sericite and muscovite and/or biotite often occur. Locally the sericite content is so abundant that the term sericite schist could be applied to the rock. Accessories are apatite, zircon and opaques (Table 4).

The mineralogy of the quartz-feldspar gneisses and the arkose-quartzites is not significantly different, since they both contain abundant feldspars and are often sericitic. In the outcrops, however, the arkose-quartzites are more homogeneous than the quartz-feldspar gneisses. In their main features these quartz-feldspar gneisses are similar to those in the marginal zones of the granulite complex. The latter, however, do not contain sericite. On the other hand, hornblende is often encountered, whereas it is sparsely distributed in the quartz-feldspar gneisses of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones.

Table 4
Mineralogical composition of quartz-feldspar gneisses.

	1	2	3
Quartz	32.9	57.5	29.3
K-feldspar	22.0	0.5	14.2
Plagioclase	32.2	36.5	45.2
Biotite	—	—	1.4
Muscovite	10.3	—	4.6
Accessories	0.8	0.8	1.0
An	12	32	12

1. Inari, Apukasjärvi, Skietsharasoaivi, 115/SL/62.
2. Inari, Vätsäri, Kattalompolo, 31/MV/58.
3. Inari, Vätsäri, Äälisjärvi, 39/KM/62.

Mica gneisses

Mica gneisses are fairly common in the schist zones of Apukasjärvi, Vätsäri and Kuorboaivi. In the latter zone, however, their position and abundance are only roughly known owing to the paucity of outcrops.

In the schist zones of Apukasjärvi and Vätsäri the mica gneisses underlie the amphibolites of the synclinorium. Since mica gneisses are easily weathered they are only sporadically visible along the fringes of the amphibolite zone. However, they seem to occur almost continuously along the western margin of the schist zone. The tectonic structure of the area suggests that the mica gneisses north of Vainospää are closely associated with the Apukasjärvi schist zone.

The mica gneisses are dark grey or grey brown as a result of weathering. Their foliation in the Vätsäri and Apukasjärvi schist zones is characterised locally by minor folds that are similar to those in the amphibolites overlying them. The grain size varies from fine to medium (Ø = 0.2—2 mm). The texture of the mica gneisses is grano- or lepidoblastic, sometimes even blastoclastic. Main minerals are quartz, biotite and plagioclase (An_{13-25}) with minor amounts of muscovite or sericite and sometimes garnet (almandine) and potash feldspar. The latter, however, is usually only one of the accessory minerals. Other accessories are titanite, opaques, apatite, zircon, epidote and chlorite. A striking feature of the rock is the abundance of mica and the almost total absence of potash feldspar (Table 5). Varieties with approximately 20 to 30 percent biotite are the most common of the mica gneisses.

Table 5
Mineralogical composition of mica gneisses.

	1	2	3	4	5	6	7	8	9
Quartz	51.7	42.3	37.9	36.9	33.9	28.1	27.9	20.4	19.4
K-feldspar	3.7	—	1.1	0.8	—	—	—	—	—
Plagioclase	27.2	15.2	28.4	15.7	39.3	52.8	46.5	41.9	39.6
Biotite	17.0	42.3	17.1	41.7	24.8	14.5	24.4	25.4	16.8
Chlorite	—	—	+	—	—	—	—	+	6.9
Muscovite	—	—	5.5	—	—	—	—	—	—
Hornblende	—	—	—	—	—	4.1	—	—	—
Epidote	—	—	+	2.7	—	+	—	11.9	15.6
Garnet	—	—	—	—	2.0	+	—	—	—
Accessories	0.4	0.2	+	2.7	+	0.5	1.2	0.4	1.7
An	13	25	25	22	26	35	38	34	20

1. Inari, Apukasjärvi, 123/PV/59.
2. Inari, Rovioja, 104/SL/59.
3. Inari, Kivilompolo, 45/KM/62 (chem. anal. in Table 6.).
4. Inari, Kuorboaivi, 4/HN/58.
5. Utsjoki, Ailigas, 145/KM/60.
6. Utsjoki, Vetsijoki, 131/KM/60.
7. Utsjoki, Vardoaivi, 124/KM/60.
8. Utsjoki, Vetsijoki, 196/PV/58.
9. Utsjoki, Loktavaara, 113/KM/60.

Table 6
Chemical composition of biotite gneiss. Inari, Kivilompolo, 45/KM/62.
Anal. P. Ojanperä 1963.

	Weight per cent	Norms	
SiO_2	68.64	Q	31.50
TiO_2	0.58	or	14.40
Al_2O_3	15.42	ab	28.24
Fe_2O_3	0.75	an	7.26
FeO	3.28	c	4.62
MnO	0.04		
MgO	2.15	en	5.38
CaO	1.56	fs	4.51
Na_2O	3.34	mt	1.09
K_2O	2.43	il	1.11
P_2O_5	0.08	ap	0.20
CO_2	0.00		
H_2O^+	1.42	fem	12.30
H_2O^-	0.12		
	99.81		

	Mode	Niggli values	
Quartz	37.9	al	41.05
Potash feldspar	1.1	fm	29.70
Plagioclase	28.4	c	7.58
Biotite	17.1	alk	21.67
Chlorite	+		
Muscovite	5.5	si	310.62
Epidote	+	ti	1.98
Accessories	+	p	0.16
		h	21.42
An	25		
		k	0.32
		mg	0.49
		qz	123.94

The chemical composition of the mica gneisses, determined by analyses of biotite-muscovite-plagioclase gneiss from Kivilompolo, Vätsäri, (Table 6) differs from that of some other gneisses e.g. the argillaceous mica schists of southern Finland, mainly owing to the considerably lower Fe_2O_3 and FeO content and markedly higher Na_2O content. On the other hand, the chemical composition of the mica gneiss is comparable to the average composition of greywackes as given by Pettijohn or to the light-coloured layers of the schist with graded bedding (greywacke slates) in the Tampere region (see Simonen 1953). However, some of the mica gneisses of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are considerably richer in biotite than the analysed and hence, their chemical composition corresponds to that of micaceous shale. The mica gneisses of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones probably derive from shales and greywackes.

Hornblende gneisses

Hornblende gneisses occur in the lower part of the amphibolite deposits as beds and bands alternating with amphibolites, quartz feldspar gneisses and mica gneisses. Epidote- and/or diopside-rich beds (calc-silicate gneisses) are also commonly encountered among them.

The hornblende gneisses are grey green or green and lighter in colour than the amphibolites. They are fine- to medium-grained (Ø = 0.2—2 mm) rocks with a granoblastic texture. In mineral composition they represent transitional types between amphibolites and quartz-feldspar gneisses and/or biotite gneisses, i.e., they are hornblende-biotite-plagioclase gneisses and hornblende-plagioclase gneisses. Main minerals are quartz, plagioclase (An_{30-45}), hornblende and biotite. The proportion of hornblende and biotite varies considerably. Potash feldspar is usually absent or it may be a minor constituent. Other minor constituents are chlorite, epidote and garnet. Accessories are titanite, apatite and opaques (Table 7).

Calc-silicate gneisses differ from the hornblende gneisses mainly in the abundance of epidote and/or diopside in the former. Sometimes, however, they contain small amounts of carbonate and the amphibole is often light-coloured tremolite.

The hornblende gneisses were primarily tuffaceous sedimentary rocks, which is emphasized by their mineral composition and close association with the amphibolites. The calc-silicate gneisses were probably tuffaceous marls from which CO_2 escaped during metamorphism, the remaining CaO being incorporated into various Ca-rich silicates. Southeast of Syrjäpuolijärvi (Vuoskujärvi), a small occurrence of limestone has been encountered among the hornblende gneisses, amphibolites and calc-silicate gneisses.

Table 7
Mineralogical composition of hornblende gneisses.

	1	2	3	4	5
Quartz	33.6	29.6	25.6	25.5	23.4
K-feldspar	—	—	—	—	8.0
Plagioclase	48.7	49.0	47.9	37.6	38.6
Biotite	6.3	2.2	11.7	20.9	1.3
Chlorite	—	—	1.6	—	—
Hornblende	10.4	15.6	11.4	14.0	26.5
Epidote	+	—	—	+	+
Garnet	—	+	—	—	2.2
Accessories	1.2	3.6	1.8	2.0	+
An	30	34	42	40	36

1. Hornblende-plagioclase gneiss. Inari, Kuoppasaaret, 155/PV/57.
2. Hornblende-plagioclase gneiss. Inari, Lusmanuora, 100/KM/57.
3. Hornblende-biotite-plagioclase gneiss. Utsjoki, Kuovloaivi, 129/PV/60.
4. Hornblende-biotite-plagioclase gneiss. Utsjoki, Farfaloaivi, 121/PV/60.
5. Hornblende-plagioclase gneiss. Utsjoki, Kuorboaivi, 137 b/SL/62.

Amphibolites

Amphibolites are the main rock type in the schist zones of Apukasjärvi and Vätsäri. They also abound in the Kuorboaivi schist zone. The amphibolites of the Apukasjärvi and Vätsäri schist zones form the core of the synclinorium. In the lower parts of the deposits the amphibolites are often interbedded with mica gneisses and quartz feldspar gneisses. Locally they contain epidote- and diopside-rich layers, i.e. calc-silicate gneisses. Only quartz veins cut the amphibolites. In some places the amphibolites are wrinkled with minor folds.

Most of the amphibolites are black green, fine-grained (Ø = 0.2—1 mm) and frequently distinctly banded rocks (Fig. 19). The dark bands are hornblende-rich and often consist solely of hornblende. The light-coloured bands are plagioclase-bearing. The texture of the amphibolites is granoblastic. Main minerals are hornblende and andesine with hornblende usually predominating. In addition, small amounts of carbonate and sometimes biotite and quartz are encountered. Carbonates also occur locally as megascopic lenses. Accessories are titanite, opaques and apatite.

The banded amphibolites derive largely from metamorphosed basic lavas and tuffs. The varieties encountered in some localities and which are more homogeneous than the former are probably metamorphosed diabases. Megascopically, they are similar to the diabases cutting the rocks of the granite gneiss complex.

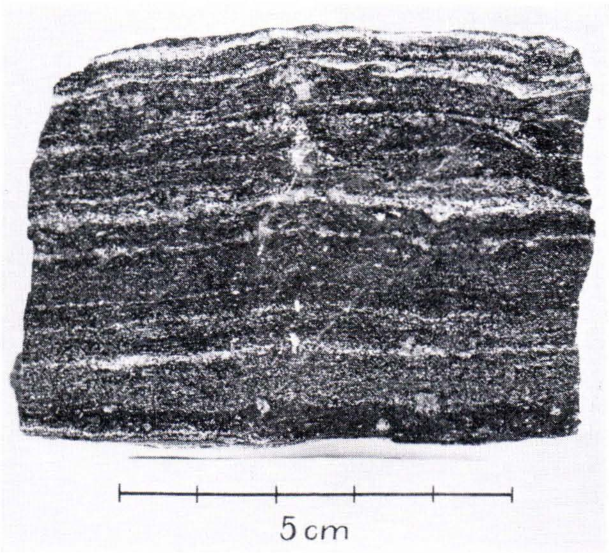

Fig. 19. Layered amphibolite in Apukasjärvi schist zone. Inari, Ahvenselkä. Photo E. Halme.

Infracrustal rocks

The infracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are ultrabasic rocks, gabbros, quartz diorites, granodiorites and granites. Dioritic and quartz diorite varieties are locally associated with the gabbro massifs. The diorites and quartz diorites are often hornblende bearing, in which case they resemble in appearance, mineral composition and probably also in chemical composition, the hornblende-bearing diorites and quartz diorites of the northeastern and southwestern marginal zones of the granulite complex. The infracrustal rocks are concordant to the supracrustal rocks of the schist zones. However, it has been observed that the ultrabasic rocks and gabbros cut sharply the migmatic granite gneisses of the granite gneiss complex.

Ultrabasic rocks

Ultrabasic infracrustal rocks are found in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and in some other areas such as Nitsjärvi, Paudijärvi and Surnuvuono. On the basis of their rock types and specifically their tectonics, the latter belong as discrete relicts to the Apukasjärvi, Vätsäri and Kuorboaivi schist zones. Furthermore, this group also includes the following ultrabasic rocks of the granite gneiss complex: Nilisaari, Harrijoki, Palovaara and Kamajohka.

The ultrabasic rocks are ophiolitic bodies or lenses. Some of them are only a few tens of metres in width and a maximum of a couple of hundred metres in length, whereas others are intrusions or intrusive complexes several kilometres long. At Tsuomasvaara, Utsjoki, ultrabasic rocks are associated with a gabbro massif.

In their mineral composition the ultrabasic rocks are peridotites, serpentinites, anorthosites and hornblendites.

The fresh fracture surface of the massive or slightly foliated *peridotites* is greyish-black. In mineral composition peridotites are

a) olivine-augite rocks
b) olivine-hypersthene rocks and
c) olivine-hornblende rocks

In addition, opaques are usually present, plagioclase sometimes and serpentine as an alteration product of olivine.

Like the peridotites, the *serpentinites* are grey black in colour. Their mineral composition is simple. Besides serpentine, which is the main mineral, olivine and augite and/or cummingtonite and tremolite are frequently met with. Thus, in the serpentinite of Tsuomasvaara relicts of olivine and augite occur in the serpentine mass. The serpentine grains and aggregates often display the shapes of augite or olivine grains, and the groups of olivine or augite grains in the serpentine mass are often mutually homoaxial. Cummingtonite or tremolite frequently occur in the serpentinites of Nitsjärvi and Vätsäri, and the edges of the serpentinite bodies are often of tremolite- or tremolite-serpentine rock. The serpentinites are cut by anthophyllite asbestos veins and they locally also contain vermiculite.

The *hornblendites* are greenish black, foliated hornblende-rich rocks. They are medium- to coarse-grained (Ø = 0.5—2 mm), and hypidiomorphic or granular in texture. Besides hornblende, variable amounts of diopside, plagioclase and garnet are found in the hornblendites. The garnet grains are up to 2 cm in diameter, and locally display pronounced zoning. According to the refraction indices, the garnet is almandine. Its colour is red, $n' = 1.773$ at edge of grain, 1.783 in core. As the plagioclase or diopside content increases the mineral composition of the hornblendites approaches that of gabbros or pyroxenites.

Three *anorthosite* occurrences have been found: at Mutajärvi north of Nitsjärvi, at Haugajärvi and at Kuellipastin in the schist zone of Apukasjärvi.

The Mutajärvi anorthosite is a grey or greenish white, massive or distincly gneissose rock. However, the hornblende-rich or hornblende-bearing streaks in the gneissose rock are indistinct and grade without sharp contacts into the plagioclase-rich host. The texture of the anorthosite is hypidiomorphic and locally cataclastic. Main minerals are plagioclase (An_{50-70}, $n' = 1.571 \pm 3$), which is often completely saussuritised, hornblende and often diopside. Accessories are opaques, apatite, titanite and epidote. The anorthosite of Mutajärvi is both megascopically and in mineral composition analogous to that of the Vaskojoki massif in the southwestern marginal zone of the granulite complex.

The Haugajärvi and Kuellipastin anorthosites differ from those just described in mineral composition, but megascopically the resemblance is striking. The anorthosite of Haugajärvi is a small body in mica gneiss, but that of Kuellipastin is probably a dyke in quartz-feldspar gneiss. Their texture is hypidiomorphic and also often cataclastic. The main mineral of both rocks is zoned plagioclase, with a core of andesine (An_{35}, $\gamma' = 1.554 \pm 3$) at Kuellipastin. Abundant clinozoisite with minor muscovite and antiperthitic potash feldspar is also found. It is probable that the plagioclase of the rock was primarily richer in anorthite but that it has altered by epidotisation into andesine. At the same time the potash feldspar, or some of it at least, exsolved from the lattice of the plagioclase.

Gabbros

There are three large gabbro bodies (Tsuomasvaara, Petsikkovaara and Vetsijoki) and several small ones in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones. They are concordant to the Apukasjärvi, Vätsäri and Kuorboaivi supracrustal rocks but in

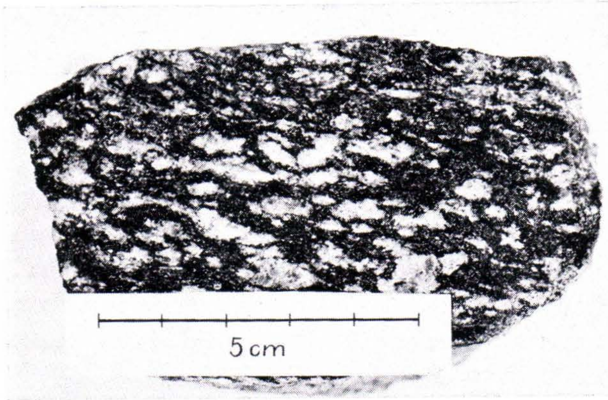

Fig. 20. Foliated cataclastic gabbro with lens-shaped plagioclase crystals that are usually grey-white in colour. Utsjoki, Paltonjärvet. Photo E. Halme.

some places, e.g. at Petsivaara, southwest of Apukasjärvi, the gabbro cuts the veined gneisses of the granite gneiss complex. The rock of the large gabbro massifs is locally diorite and even quartz diorite. A diversity of infracrustal rock varieties such as diorite, gabbro, peridotite and serpentinite are present in the Tsuomasvaara massif. The margin of one peridotite (Harrijoki, northeast of Apukasjärvi) is gabbro, from which apophyses of diabase extend into the porphyroblastic potash granite country rock (Pirivaara). Granite veins locally cut the gabbros.

In the western part of the Kuorboaivi schist zone the gabbros are black-green in colour, often distinctly foliated and medium-grained (Ø = 2.5 mm) rocks. The hornblende, pyroxene and plagioclase crystals are usually lens-shaped, cataclastically granulated grains or clusters of grains (Fig. 20). With recrystallisation the dark (olive-green) plagioclase crystals become lighter or even white. The original dark plagioclase has been preserved in the core of some crystals. The foliation of the gabbros in the eastern part of the Kuorboaivi schist zone (Tsuomasvaara, Petsivaara, Selkäjärvi) is less conspicuous than that of the western part and their gabbroidic structure is better preserved. They are characteristically olive brown in colour.

The texture of the gabbros is ophitic or hypidiomorphic; the deformed varieties are cataclastic and blastohypidiomorphic. The most common mineral assemblages in gabbros are: plagioclase (An_{50-60}), hornblende and diopside; or plagioclase (An_{50-70}), hypersthene, biotite and locally also augite and olivine. In addition, perthitic potash feldspar, quartz and sometimes garnet are encountered locally in the gabbros. Accessories are apatite, allanite, monazite and opaques.

Diorites

Diorites contain plagioclase that is both more abundant and richer in sodium than is the plagioclase found in gabbros.

Quartz diorites

Quartz diorites are grey in colour and often exhibit well-developed foliation. They are either even-grained or porphyritic with plagioclase phenocrysts. In mineral composition the quartz diorites have two varieties: grey hornblende quartz diorite and black-grey biotite quartz diorite.

The *hornblende quartz diorites* are hypidiomorphic or blastohypidiomorphic. The plagioclase crystals in particular often display cataclastic fracturing. Main minerals are hornblende, plagioclase (An_{25-40}), biotite and quartz. Alteration products are sericite, epidote and chlorite. Accessories are titanite, apatite, zircon and opaques (Table 8).

The *biotite quartz diorites* are darker than the former. They are biotite-rich and their texture is porphyritic. The porphyritic crystals are plagioclase which usually displays cataclastic fracturing. In addition to plagioclase (An_{35-40}) and biotite, minor hornblende and quartz and sometimes potash feldspar and garnet are present. Accessories are opaques, apatite, titanite, zircon and allanite (Table 8). The biotite quartz diorites often resemble porphyroblastic mica gneisses, in which form they are manifested east, northeast and southeast of Vardoivi, between Utsjoki and Pulmankijärvi (unlike as marked on the map).

Table 8

Mineralogical composition of quartz diorites.

	1	2
Quartz	18.5	25.2
K-feldspar	—	—
Plagioclase	58.0	37.7
Hornblende	5.6	12.0
Biotite	13.7	22.3
Accessories	4.2	2.8
An	32	40

1. Utsjoki, 4 km NNE from Kuorboaivi, 44/KM/63, A 208.
2. Utsjoki, Farfaloaivi, 121/PV/60.

Granites

The major granites in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones have been denoted on the map as a coherent area (Meriläinen 1965). However, the granite area can be divided into two sub-areas: a southern area consisting of the grey Kyyneljärvi granite and a northern area, the Vainospää fell district, consisting of the pink-grey porphyritic granite and the grey fairly coarse granite of Vainospää. Granites also occur elsewhere in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones, e.g. some grey varieties on the eastern margin of the tectonic window of Kevo (the Kevo block). These, however, cannot be distinguished from similar granites in the granite gneiss complex. The only indication that they possibly belong to the infracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones is afforded by age determinations.

The grey granite at Kyyneljärvi is massive except on the fringes of the massif, where amphibolite and gneiss portions with numerous granite veins are often encountered. Macroscopically it is locally a slightly porphyritic and medium-grained (Ø = 2—4 mm) rock. The phenocrysts are panidiomorphic (Ø = 5—8 mm). The texture of the groundmass is hypidiomorphic with plagioclase (An_{22}), potash feldspar and quartz as main minerals and minor biotite, with chlorite as its alteration product. Accessories are opaques, zircon, apatite and uraninite (Table 9). Owing to its radioactivity the rock shows up distinctly on the aeroradiometric map. The Kyyneljärvi granite contains some different varieties of zircons.

Table 9

Mineralogical composition of granites.

	1	2	3	4	5	6	7
Quartz	28.2	29.0	27.4	24.7	23.6	30.5	22.8
K-feldspar	4.0	5.6	35.0	27.4	44.2	30.0	25.9
Plagioclase	62.6	53.0	33.9	38.3	28.5	33.0	39.3
Biotite	4.2	11.0	2.9	7.3	1.9	4.8	10.7
Muscovite	—	—	—	+	—	+	+
Chlorite	—	—	0.4	+	1.1	+	—
Epidote	—	+	0.4	+	+	+	—
Accessories	1.0	1.4	+	2.0	0.7	1.7	1.3
An	23	nd	22	15	22	nd	nd

1. Trondhjemite. Utsjoki, Nuottalvaara, 159/PV/58, A 211.
2. Trondhjemite. Utsjoki, Keniskoaki, 90/KM/61, A 112.
3. Grey granite. Inari, Kyyneljärvi, 69/Tyni/58 (chem. anal. in Table 10.).
4. Grey granite. Inari, Vainospää, 19 b/KM/58.
5. Reddish grey granite. Inari, Vainospää, 19 a/KM/58.
6. Coarse-grained, grey granite. Inari, Vainospää, A 168 and A 169.
7. Granite. Inari, Päkkevaara, 76/AH/60, A 210.

In chemical composition (Table 10) the Kyyneljärvi granite resembles the Hetta granite (see Mikkola 1941) or the granites of the Svecofennian granite province (see Simonen 1960 a). However, on the basis of the normative Or : Ab : An ratios, the Kyyneljärvi and Hetta granites are granodiorites, since the Or : Ab : An ratio in the Hetta granite is 37.3 : 42.6 : 20.1 and in the Kyyneljärvi granite 46.0 : 45.2 : 8.8. In any case, the Kyyneljärvi granite has high K_2O relative to Na_2O, which is characteristic of granites.

Table 10
Chemical composition of granite. Inari, Kyyneljärvi, 69/Tyni/58.
Anal. P. Ojanperä 1963.

	Weight per cent	Norms	
SiO_2	73.67	Q	31.10
TiO_2	0.16	or	29.63
Al_2O_3	13.92	ab	29.08
Fe_2O_3	0.51	an	5.67
FeO	1.00	c	0.74
MnO	0.04		
MgO	0.26	en	0.65
CaO	1.19	fs	1.23
Na_2O	3.44	mt	0.74
K_2O	5.01	il	0.30
P_2O_5	0.04	ap	0.10
CO_2	0.00		
H_2O^+	0.48	fem	2.94
H_2O^-	0.03		
Rb_2O	0.02		
	99.77		

	Mode	Niggli values	
Quartz	27.4	al	46.43
Potash feldspar	35.0	fm	9.32
Plagioclase	33.9	c	7.24
Biotite	2.9	alk	37.01
Chlorite	0.4		
Epidote	0.4	si	417.62
Accessories	+	ti	0.68
		p	0.10
An	22	h	9.08
		k	0.49
		mg	0.24
		qz	169.22

The pink-grey, porphyritic granite of Vainospää resembles the granite of Kyyneljärvi. It is a medium-grained (Ø = 2—5 mm), slightly foliated or gneissose rock and often distinctly porphyritic (Ø = 7—15 mm) with a hypidiomorphic groundmass. In mineral composition, it is potash granite with a markedly higher content of potash feldspar than of plagioclase (An_{15}). The biotite has partly altered into chlorite. Accessories are apatite, zircon and opaques (Table 9).

The grey granite of Vainospää is coarse (Ø = 5—8 mm) and slightly porphyritic due to the plagioclase and potash feldspar phenocrysts. Mineralogically it is potash granite with approximately 35 % potash feldspar and 35 % plagioclase, the remainder being mainly quartz and a few percent of biotite. Accessories are opaques, apatite, titanite, zircon, fluorite and allanite (Table 9). Macroscopically this granite differs clearly from the pink-grey porphyritic variety.

Stratigraphy and tectonics

The Apukasjärvi, Vätsäri and Kuorboaivi schist zones form synclinoriums between the extensive, dome-shaped anticlinoriums of the granite gneiss complex. The synclinorium structure has been established by observations on the strike and dip of the bedding and foliation. The stratigraphic sequence of the gneisses is based on the observations described above as well as on the associations of the supracrustal rocks.

Foliation and bedding

Foliation is particularly marked in certain sericite-bearing supracrustal rocks, such as quartz-feldspar gneisses and quartzites. It is also usually well developed in amphibolites and mica gneisses. The foliation is frequently conformable with the bedding. The latter is most clearly exhibited in the alternating beds of supracrustal rocks. With the exception of the ultrabasic rocks, the infracrustal rocks are distinctly foliated and even gneissose. In some of them, e.g. the gabbros, a prevailing cataclastic structure is frequently visible even megascopically. The margins of the intrusions of the ultrabasic rocks are often schistose or sheared.

Stratigraphy

The supracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones all have the same stratigraphy. However, the stratigraphy is neither completely uniform nor universally continuous, as is demonstrated by the fact that magnetite-banded quartzites are only rarely encountered. One reason for this is that the magnetite-banded quartzites are seldom more than a couple of metres thick. The lowest stratigraphic unit contains quartzites and quartz-feldspar gneisses; these are overlain by mica gneisses and the mica gneisses by amphibolites, which form the top bed. The mica gneiss member is thin and presumably discontinuous. It also contains narrow layers and beds of amphibolites and quartz-feldspar gneisses. Magnetite- and amphibole-banded quartzites with a maximum thickness of a few metres occur locally between the quartzites and amphibolites, which is where the bulk of the calc-silicate gneisses probably also occur. In the Apukasjärvi and Vätsäri schist zones the amphibolites are locally overlain by graphite- and/or pyrite-rich black schists.

Folding

The structure of the Vätsäri synclinorium is complicated. Its amphibolitic core has been compressed into an almost vertical zone between dome-shaped anticlines (anticlinoriums) composed of rocks of the granite gneiss complex and the acid gneisses of the Vätsäri zone. West of Surnujärvi, the axial plane of this syncline trends approximately N—S. At the southern end of this lake the syncline forks to the west and the southeast. The western fork gradually bends southwestwards, which is the general trend of the schist zone in the Vätsäri area. The trend of the axial plane (B-axis) of the synclines varies because the synclines are bounded by dome-shaped anticlines.

The axis of the Apukasjärvi synclinorium trends NW in the southeastern part of the synclinorium and N in its central and northern parts. The dip of foliation is approximately 20—50° WSW at the eastern edge of the southern part of the synclinorium, and roughly 20—70° ENE at the western edge. Hence, in cross-section the synclinorium is an almost symmetric, open sylinder in this area. The amphibolites and mica gneisses in the core of the synclinorium are folded, often intensively so. The folds are shallow with almost vertical axial planes. Around Apukasjärvi, the fold axis tilts gently, sometimes northwestwards and sometimes southeastwards at an angle of approximately 5° to 20°. This is the B-axis of folding in the middle part of the Apukasjärvi schist zone. In the northern parts of the schist zone the fold axes plunge to N. The amplitudes of the folds are several metres or more. The mica gneisses and amphibolites also exhibit tight minor folding. The fold axis of the latter conforms locally to that of the forementioned B-axis, but in the northern part of the Apukasjärvi schist zone it is usually parallel to the lineation and plunges to SW. The southern part of the schist zone is dominated by lineation trending S 40°E or N 40°W, which is likewise the trend of the sub-horizontal fold axes and the trace of the axial plane of the schist zone in this area. In the northern part of the Apukasjärvi schist zone and at the eastern margin of the southern part, the predominant trend for the lineation is S 30—60°W. From these areas towards the centre of the schist zone, south of Apukasjärvi, the lineations trending S 30—60°W gradually bend southwards (anti-clockwise) and finally join the S 40°E lineation.

The shape, orientation and tectonic structures of the Apukasjärvi synclinorium, e.g. the trend of the fold axes and lineations, are emphasized by structures of anticlinoriums composed of rocks of the granite gneiss complex that were uplifted and deformed simultaneously on both sides of the synclinorium during folding. In other words, the forms of the anticlinoriums and the deformations that took place in them during folding (block movements) are reflected as folds and lineations in the schists that folded and metamorphosed between and on top of the anticlinoriums. In structure, the Apukasjärvi synclinorium is an axial depression similar to but more extensive than the minor synclines or their relicts (Nitsjärvi, Vuoskujärvi, Paudijärvi, Surnuvuono) that delimit the anticlines of the granite gneiss complex.

The Apukasjärvi synclinorium was folded during its earliest stages as a consequence of compressive forces acting towards E or W during the Prekarelian period. Later, during the Karelian orogeny, the direction of compression changed to roughly NE or SW. There is no conclusive evidence in the Apukasjärvi area for structures that developed during the deformation of the granulite complex.

THE GRANULITE COMPLEX AND ITS MARGINAL ZONES

The granulite complex and its marginal zones constitute the central part of the Inari—Utsjoki bedrock. The complex can be divided into three parts:

1) the granulite complex proper
2) the northeastern marginal zone of the granulite complex
3) the southwestern marginal zone of the granulite complex.

These three parts comprise one tectonic unit, even though there are significant differences in their rock types. The reason for this is that the rocks of the granulite complex proper were metamorphosed under the conditions of the granulite facies and the rocks of its marginal zones under those of amphibolite facies.

The granulite complex proper

The rocks of this complex are mostly garnet gneisses that were formed by metamorphism from acid and intermediate supracrustal rocks and also from infracrustal rocks under the conditions of the granulite facies. Furthermore, some pyroxene gneisses are encountered that were derived from amphibolites, hornblende gneisses and basic sills. Infracrustal rocks concordant with the garnet gneisses are gabbros, diorites and quartz diorites, as well as ultrabasic rocks and some garnet-bearing porphyritic granites. The garnet gneisses, pyroxene gneisses and infracrustal rocks are cut by coarse-grained, anatectic dykes formed during the diaphthoretic granulitisation. The postgranulitic scapolite-biotite quartz diorite of Vuoskuljärvi is located on the southwestern slopes of the fell Muotkatunturi. The postorogenic granite of Nattanen and some olivine diabases and quartz syenite porphyry dykes are outside the area of the present study.

On the basis of its characteristic garnet gneisses, the granulite complex proper can be divided in a longitudinal direction into two sub-areas: the central and eastern garnet gneisses, and the western garnet gneisses. The former are mainly garnet-cordierite gneisses and coarse-grained garnet-quartz-feldspar gneisses, whereas the latter are largely fine- and coarse-grained garnet-quartz feldspar gneisses and garnet-biotite gneisses. There is, however, no sharp contact between these two sub-areas; both of them contain rocks characteristic of the other.

Some of the typical rock types in both sub-areas, e.g. fine-grained garnet-quartz-feldspar gneisses and garnet-cordierite gneisses, may occur as fairly extensive and on the whole comparatively homogeneous areas. However, on closer observation, less homogeneous features become apparent, e.g., the fine-grained garnet-quartz-feldspar gneisses contain coarse-grained garnet-quartz-feldspar gneisses as bands, streaks and portions of varying width parallel to the schistosity (bedding). The contacts between the different rock types vary from sharp to diffuse. The garnet-cordietite gneisses and the coarse-grainet garnet-quartz feldspar gneisses bear such a close resemblance

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to one another macroscopically, that in large-scale the eastern part of the granulite complex proper is more homogeneous than the western part. However, in outcrops, the garnet gneisses of the eastern part are very heterogeneous owing to the frequent occurrence of streaks and schlieren and in some places even of veined-gneissose structure. The heterogeneous features are further emphasized by the great variations in the abundances of garnet, cordierite and biotite, and in the size of the garnet and cordierite grains.

Garnet gneisses

The garnet gneisses of the granulite complex proper are fine- and coarse-grained garnet-quartz feldspar gneisses, garnet-cordierite gneisses, garnet-biotite gneisses and garnet-biotite-plagioclase gneisses.

Garnet-cordierite gneisses

Garnet-cordierite gneisses are migmatic, highly foliated, grey, veined-gneissose rocks or weakly foliated, often almost massive, light-coloured gneisses with streaks and schlieren. The varieties grade into each other and hence, cannot be distinguished on a small-scale map (1: 400 000).

The veined gneisses are rectlinear schistose, or crinkled and patched rocks with minor folds. Their light-coloured veins are discontinuous and exhibit distinct boundaries or grade into the dark-coloured streaks and schlieren (Figs. 21 and 22). The width of the veins, streaks and schlieren ranges from a few millimetres to several centimetres.

Megascopically the weakly foliated, almost massive garnet-cordierite gneisses with streaks and schlieren resemble, and often grade into, the coarse-grained garnet-quartz-feldspar gneisses, but differ from them in their cordierite content, meagre though it is.

In texture the garnet-cordierite gneisses are granoblastic, medium- to coarse-grained (Ø = 1—5 mm) rocks. The garnet often occurs as porphyroblasts or clusters of crystals. In some places the crystals of cordierite and potash feldspar are also distinctly coarse. Main minerals are potash feldspar, quartz, plagioclase (An_{25-40}), garnet (n' = 1.785, 1.788, 1.790, 1.792, 1.803 depending on the outcrop), biotite (γ' = 1.635, 1.645, 1.649, 1.654) and cordierite (distortion index δ = 0.26—0.29, γ' = 1.548, 1.549, 1.552, 1.553, 1.554). The abundance of cordierite, garnet and biotite is highly variable, so much so that cordierite is often no more than a minor constituent characteristic of the rock. Of the feldspars, hair-perthitic potash feldspar usually occurs in greater abundance than plagioclase. In some varieties, however, potash feldspar only appears as antiperthite. Sillimanite is a common minor constituent, but sometimes it occurs in such abundance that the term sillimanite-garnet-cordierite-gneiss would be justified. Accessories are opaques (ilmenite, graphite, pyrrhotite, pyrite), rutile, monazite, spinel and zircon. A few grains of andalusite have

Fig. 21. Folded migmatic garnet-cordierite-gneiss. Dark streaks are mainly biotite, cordierite and garnet. Light veins are quartz, plagioclase and potash feldspar. Dark, roundish dots on a light background are garnet (Ø = 1—3 cm). Inari, Myösäjärvi. Photo K. Meriläinen.

Fig. 22. Carnet-cordierite gneiss. Cordierite and garnet occur predominantly in dark biotite-rich streaks and schlieren. Inari, Törmänen. Photo E. Halme.

Fig. 23. Amphibolite relicts in garnet-cordierite gneiss. Inarijärvi, Karlassaaret. Photo K. Meriläinen.

been encountered as relicts in the garnet-cordierite gneiss on the eastern shore of the lake Paadar. Sporadically distributed thoroughout the garnet-cordierite-gneisses, and even abundantly at some locations in the Inarijärvi area, are elongated or roundish relicts of different rock types, e.g. quartz-feldspar gneisses, mica gneisses, hornblende gneisses, pyroxene gneisses and amphibolites (Fig. 23).

The mineral composition of the garnet-cordierite gneisses corresponds to that of rocks metamorphosed from aluminium-rich sands and shales, e.g. mica schists, mica gneisses and quartz-feldspar gneisses as well as their migmatites with granitic material. However, the rocks that underwent granulitisation, and from which the garnet-cordierite gneisses are derived exhibit inclusions indicating that they probably belonged to two separate gneiss associations. One of them is the gneiss association that characterizes the western part of the granulite complex proper (fine-grained garnet-quartz-feldspar gneisses, garnet-biotite gneisses and garnet-biotite-plagioclase gneisses), that is, the rocks of the sedimentary group. The other is the gneiss association in the northeastern and southwestern marginal zones of the granulite complex (quartz-feldspar gneisses, quartzites, various biotite gneisses, amphibolites and hornblende gneisses), i.e. the rocks of the sedimentary-volcanic group. In addition, some of the garnet-cordierite gneisses are derived from rocks of the granite gneiss complex, as can be deduced from the large-scale tectonic structures of the rocks and the outcrop observations.

Table 11
Chemical composition of garnet-cordierite gneisses.

	Weight per cent						Norms				
	1	2	3	4	5		1	2	3	4	5
SiO_2	57.36	70.24	71.82	71.03	73.06	Q ..	24.10	40.69	37.55	30.36	34.04
TiO_2	0.95	0.84	0.28	0.11	0.26	or .	24.74	20.57	25.85	15.12	9.62
Al_2O_3	22.05	14.38	12.97	16.44	15.36	ab .	8.96	12.00	15.46	34.22	36.84
Fe_2O_3	2.67	1.36	1.47	0.57	0.59	an .	2.28	4.92	4.28	11.59	13.87
FeO .	6.47	4.31	3.58	1.49	1.03	c ..	14.93	6.47	3.65	2.75	1.34
MnO	0.08	0.05	0.06	0.03	0.02						
MgO	4.24	2.24	1.86	0.92	0.69	en .	10.60	5.60	4.65	2.33	1.73
CaO .	0.47	1.08	1.06	2.42	2.86	fs ..	8.23	5.46	4.99	2.13	0.96
Na_2O	1.06	1.42	1.83	4.05	4.36	mt .	3.87	1.97	2.13	0.84	0.86
K_2O	4.18	3.48	4.37	2.56	1.63	il ..	1.81	1.60	0.53	0.21	0.50
P_2O_5	0.08	0.08	0.06	0.07	0.06	ap .	0.02	0.18	0.13	0.17	0.13
CO_2 .	0.00	0.01	0.10	0.00	0.00	cc .	—	0.02	0.23	—	—
H_2O^+	0.50	0.58	0.56	0.40	0.21						
H_2O^-	0.06	0.06	0.04	0.00	0.03	fem.	24.62	14.70	12.37	5.53	4.05
	100.11	100.13	100.06	100.09	100.16						
							Niggli values				
							1	2	3	4	5
Rb_2O	0.017	0.012	0.10	0.007	0.005	al ..	41.85	39.85	37.69	46.26	45.83
SrO .	0.021	0.032	0.038	0.075	0.071	fm .	44.60	37.76	34.19	14.81	11.96
ZrO_2	0.019	0.021	0.020	0.012	0.010	c ..	1.63	5.46	5.60	12.39	15.55
BaO .	0.14	0.10	0.20	0.15	0.04	alk .	11.92	16.93	22.52	26.54	26.66
Cu ..	0.001	< 0.001	0.006	< 0.001	< 0.001	si ..	185.06	330.89	354.67	339.68	370.06
Ni ..	0.008	0.007	0.007	< 0.001	< 0.001	ti ..	2.30	2.97	1.04	0.40	1.00
V ...	0.026	0.013	0.007	< 0.001	0.004	p ..	0.01	0.16	0.12	0.14	0.12
Cr ..	0.019	< 0.001	0.006	< 0.001	< 0.001	h ..	5.38	9.11	9.21	6.38	3.56
						co_2	—	—	0.68	—	—
						k ..	0.72	0.62	0.61	0.29	0.20
						mg .	0.46	0.42	0.40	0.45	0.44
						qz ..	+37.58	+163.17	+164.59	+133.52	+163.42

1. Inari, Törmänen, airfield, A 268. Anal. P. Ojanperä 1968.
2. Inari, Karttamojärvi, F 23/1968. Anal. P. Ojanperä 1968.
3. Inari, Viekkala, A 276. Anal. P. Ojanperä. 1968.
4. Inari, Myösäjärvi, A 269 b. Anal. P. Ojanperä 1968.
5. Inari, Myösäjärvi, A 269 c. Anal. P. Ojanperä 1968.

The chemical compositions of the garnet-cordierite gneisses correspond to those of mica schists and kinzigites (Table 11) in South Finland (see Simonen 1953). Nevertheless, the only sample analysed from Northern Lapland which is indisputably of sedimentary origin comes from the garnet-cordierite gneiss at Törmänen, the others being migmatites of less definite origin. However, the graphite content of the garnet-cordierite gneisses and the relicts of sedimentary rocks encountered in them often indicate their sedimentary origin.

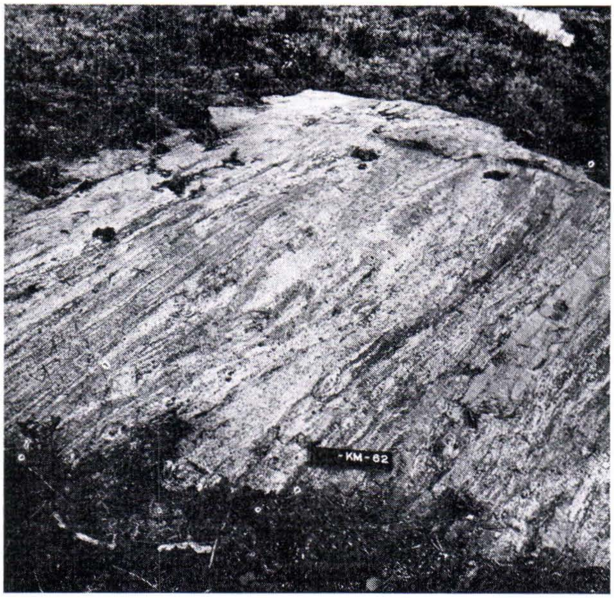

Fig. 24. Coarse-grainet garnet-quartz-feldspar gneiss with pronounced foliation. Inari, Sikovuono. Photo K. Meriläinen.

Coarse-grained garnet-quartz-feldspar gneisses

Coarse-grained garnet-quartz-feldspar gneisses are encountered throughout the granulite complex proper, but are most abundant in its central and eastern parts (inner arch). Some of them are distinctly or intensely foliated (Fig. 24), whereas others are massive and megascopically suggestive of garnetiferous migmatite granites (Fig. 25). Like granites, they are either grey in colour as a result of abundant quartz and feldspars, or brownish grey owing to weathering. However, the garnet content of these rocks is too high for granites.

Foliated varieties are met with mainly in the western and central parts of the granulite complex proper. They are often heterogeneous gneisses with dark schlieren and streaks. Veined gneisses are more rarely encountered. A characteristic feature is the presence of small streaks composed of garnet and biotite and sometimes of sillimanite (Figs. 25 and 26).

The foliated varieties often exhibit small bodies, bands, schlieren or lens-like relicts of fine-grained garnet-quartz-feldspar gneiss, similar to those in the garnet-cordierite gneisses. Pyroxene gneiss is occasionally interbedded with the foliated coarse-grained garnet-quartz-feldspar gneiss.

Almost massive, coarse-grained garnet-quartz-feldspar gneiss varieties are encountered mainly in the eastern parts of the granulite complex, especially at Inarijärvi and to the southeast and northwest of this lake. It is often a matter of opinion as

Fig. 25. Coarse-grained garnet-quartz-feldspar gneiss resembling migmatic granite. Dark schlieren are sillimanite-bearing and rich in garnet and biotite. Petrologically they are analogous to the garnet-sillimanite-biotite gneisses in the northeastern marginal zone of the granulite complex. Inarijärvi, Nanguvuono. Photo K. Meriläinen.

Fig. 26. Coarse-grained garnet-quartz-feldspar gneiss. Dark streaks consist of garnet with some biotite. Inari, Raappisoaivi. Photo E. Halme.

Table 12
Mineralogical composition of coarse-grained garnet-quartz-feldspar gneisses.

	1	2	3	4
Quartz	37.7	36.2	29.2	66.5
K-feldspar	22.8	25.6	21.0	18.4
Plagioclase	19.5	18.5	24.3	7.3
Biotite	+	+	1.0	+
Sericite	5.5	1.0	+	+
Garnet	14.3	16.6	13.0	6.8
Sillimanite	—	—	+	—
Accessories	0.2	2.1	1.5	1.0
An	nd	35	45	nd

1. Inari, Morgamjärvi, 164/KM/57.
2. Inari, Joukaisvaara, 11/KM/56.
3. Inari, Menesjoki, 128 a/KM/56.
4. Inari, Kaitamojärvi, 134/AT/56.

to whether or not these varieties should be distinguished from the garnet-bearing migmatic granites and the light-coloured, slightly foliated garnet-cordierite gneisses. The differences between them are largely due to their distinct mineral composition and structures; this is also typical of some other migmatite areas, e.g. that of South Finland (see Härme 1958, 1959, 1965).

The coarse-grained garnet-quartz-feldspar gneisses are granoblastic in texture and medium- to coarse-grained (Ø = 1—5 mm) rocks. Main minerals are quartz, potash feldspar (triclinicity Δ = 0.0—0.4), plagioclase (An_{25-45}) and garnet (n' = 1.782, 1.783, 1.784, 1.787, 1.789, 1.790, 1.797). The potash feldspar is hair-perthitic orthoclase, and the garnet is pyrope-rich almandine (pyrope c. 30—35 %, grossularite 1 % and andradite 5 %). Furthermore, biotite and frequently sillimanite also occur. Accessories are rutile, monazite, graphite and zircon. Sericite, chlorite and secondary biotite (Table 12) are alteration products, and sometimes andalusite occurs as relicts (Joukaisvaara).

In chemical composition the coarse-grained garnet-quartz-feldspar gneisses (Table 13) correspond to the kinzigites and mica schists of South Finland derived mainly from greywackes, mixtures of sand and shale (see Simonen 1953). The similarity between some of these and the biotite-muscovite-plagioclase gneiss of Kivilompolo, Vätsäri, is obvious (see Table 6). Although the coarse-grained garnet-quartz-feldspar gneisses correspond in chemical composition to various greywackes and shales, some of them at least are indisputably granulitised migmatites. Before the granulitisation these migmatites were infra- and supracrustal rocks typical either of the granite gneiss complex or the northeastern marginal zone of the granulite complex. There are good examples of the tuffaceous origin of the coarse-grained garnet-quartz-feldspar gneisses in the southwestern marginal zone of the complex, where the hornblende gneisses altered to garnet-quartz-feldspar gneisses during granulitisation.

Table 13
Chemical composition of coarse-grained garnet-quartz-feldspar-gneisses.

	Weight per cent				Norms		
	1	2	3		1	2	3
SiO_2	71.94	68.04	67.34	Q	38.58	36.56	35.81
TiO_2	0.05	0.55	0.69	or	24.27	16.25	17.15
Al_2O_3	14.40	16.42	14.85	ab	16.99	16.68	14.79
Fe_2O_3	0.71	1.01	2.38	an	4.01	7.82	8.09
FeO	2.99	4.49	4.90	c	5.18	7.33	5.87
MnO	0.09	0.08	0.12				
MgO	1.31	2.07	2.67	en	3.26	5.15	6.65
CaO	1.17	1.67	1.70	fs	5.00	6.65	6.12
Na_2O	2.01	1.97	1.75	mt	1.02	1.46	3.45
K_2O	4.11	2.75	2.90	il	0.09	1.05	1.30
P_2O_5	0.07	0.08	0.06	ap	0.17	0.18	0.13
CO_2	0.22	0.00	0.00	cc	0.50	—	—
H_2O^+	0.62	0.50	0.56				
H_2O^-	0.09	0.12	0.11	fem	10.04	14.49	17.65
	99.78	99.75	100.03				

	Mode				Niggli values		
	1	2	3		1	2	3
Quartz	37.7	36.2	29.2	al	43.8	42.4	36.3
Potash feldspar	22.8	25.6	21.0	fm	26.1	33.6	41.4
Plagioclase	19.5	18.5	24.3	c	6.5	7.9	7.6
Biotite	—	+	1.0	alk	23.6	16.1	14.7
Sericite	5.5	1.0	+				
Garnet	13.7	16.6	12.5	si	371.5	298.5	279.6
Alter. products	0.6	+	0.5	ti	0.19	1.8	2.1
Sillimanite	—	—	+	p	0.16	0.15	0.1
Accessories	0.2	2.1	1.5	h	12.2	9.0	9.3
	100.0	100.0	100.0	co_2	1.6	—	—
An	nd	35	45	k	0.57	0.48	0.52
				mg	0.39	0.40	0.40
				qz	+177.1	+134.1	+120.8

1. Inari, Morgamjärvi, 164/KM/56. Anal. A. Heikkinen 1957.
2. Inari, Joukaisvaara, 11/KM/56. Anal. A. Heikkinen 1957.
3. Inari, Menesjoki, 128 a/KM/56. Anal. P. Ojanperä 1957.

However, these alterations require intergranular movement, and wherever this movement was lacking the hornblende gneisses have usually altered to hypersthene gneisses (Table 19).

Fine-grained garnet-quartz-feldspar gneisses

Fine-grained garnet-quartz-feldspar gneiss is the dominant rock type in the western part of the granulite complex, e.g. on the fells of Marestatunturit, Viipustunturit and Hammastunturit and at many localities in Saariselkä and even on the fells of Pais-

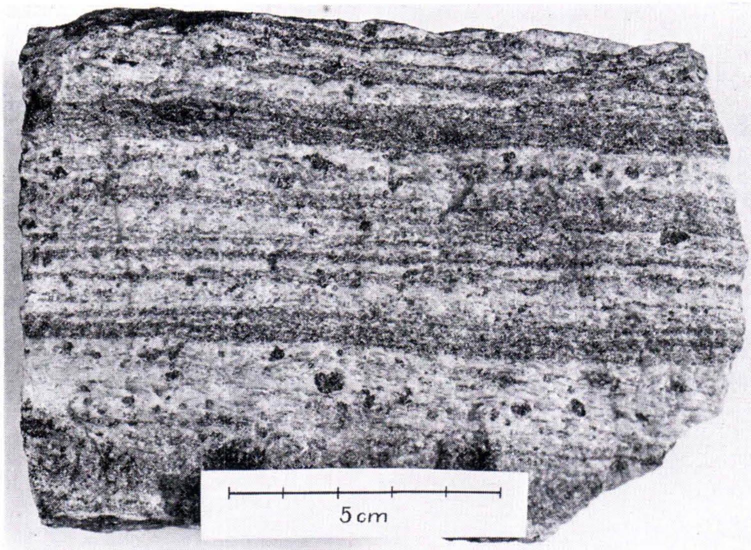

Fig. 27. Fine-grained garnet-quartz-feldspar gneiss. Garnets are limited almost entirely to light-coloured quartz-feldspar-bearing layers. Utsjoki, Rittatshobma near Inarijoki. Photo E. Halme.

tunturit and Muotkatunturit. It is generally easy to distinguish this rock from the other main rock in the area, garnet-biotite gneiss, by its greater resistance to erosion, lighter colour and lower garnet content. However, transitional varieties exist between these two. In some places, the fine-grained garnet-quartz-feldspar gneisses also contain schlieren, bands, small bodies and even fairly extensive areas of coarse-grained garnet-quartz-feldspar gneisses, as in the tributaries of the river Menesjoki. However, on the whole, these coarse-grained varieties are more foliated than the varieties in the eastern and central parts of the complex.

The weathered surface of the fine-grained garnet-quartz-feldspar gneisses is grey or greyish-white. The fresh fracture surface is lighter in colour than the weathered surface and usually distinctly banded (Fig. 27). The banded character of the rock is emphasized by the fact that the dark bands are richer in biotite and often have darker quartz than do the light ones. Garnet occurs mainly in the light-coloured bands, where it was formed from biotite during the metamorphic differentiation of the rock. Other characteristics of the fine-grained garnet-quartz-feldspar gneisses are their small grain size (Ø = 0.2—1 mm), abundant quartz and feldspar, but low or meagre garnet and biotite content. Furthermore, the rock is distinctly foliated, with rectangular cleavage (Fig. 28). In habit the fine-grained garnet-quartz-feldspar gneisses are suggestive of the acid granulites of Saxony.

The texture of the fine-grained garnet-quartz-feldspar gneisses is granoblastic or blastoclastic (Fig. 29). Main minerals are plagioclase (An_{15-40}, usually An_{25-35}),

Fig. 28. Gently dipping fine-grained garnet-quartz-feldspar gneiss with rectangular cleavage. Inari, Paltsavaara. Photo K. Meriläinen.

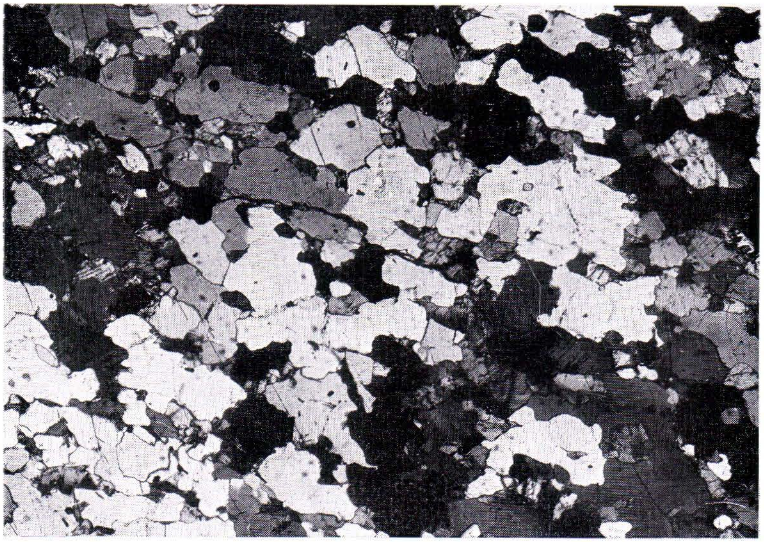

Fig. 29. Blastoclastic texture in fine-grained garnet-quartz-feldspar gneiss. During the granulitisation of the rock two or more quartz crystals have joined to form one. Even so, traces of the original texture can often still be discerned as embayed margins of large crystals or as fine dust-like groundmass demarking the crystals. Utsjoki, Buornavaara. Magn 20 x. Photo E. Halme.

Table 14
Mineralogical composition of fine-grained garnet-quartz-feldspar gneisses.

	1	2	3	4	5	6	7	8
Quartz	87.3	72.8	63.7	52.2	52.0	60.3	60.2	50.6
K-feldspar	3.4	1.0	—	18.3	23.9	18.4	5.5	18.1
Plagioclase	3.6	22.1	26.5	19.5	12.0	12.8	26.1	18.3
Biotite	—	1.2	0.4	6.7	4.4	1.8	1.8	3.5
Sericite	—	—	5.1	—	—	—	—	—
Garnet	3.6	2.6	4.1	3.1	6.6	5.3	6.0	8.3
Sillimanite	—	—	—	—	0.6	0.9	—	0.6
Accessories	1.1	0.3	0.2	0.2	0.5	0.5	0.4	0.6
An	25	30	42	35	35	nd	35	25

1. Inari, Avdshikasoaivi, 144 b/PV/56.
2. Inari, Roavvioaivi, 154/KM/56.
3. Inari, Kolshanoaivi, 35/KM/56.
4. Inari, Vestojoki, 3 a/KM/56.
5. Inari, Sallajokkaoaivi, 115 c/KM/56.
6. Inari, Ladnjoaivi, 41/KM/56.
7. Inari, Pohj. Kynsileikkaamapää, 73 b/PV/56.
8. Inari, Pohj. Kynsileikkaamapää, 74/PV/56.

potash feldspar and garnet, with quartz averaging more than half of the minerals. The amounts of plagioclase and potash feldspar vary and, on the whole, the varieties that are richest in quartz are also frequently richest in plagioclase. The garnet content also varies, but it is always markedly lower than in the garnet-biotite gneisses. In composition the garnet is pyrope-rich almandine: c. 35—45 % pyrope, 55—60 % almandine, 2—5 % andradite, 1—2 % grossularite and 1—2 % spessartite (n' = 1.782, 1.783, 1.785, 1.786, 1.787, 1.788, 1.788, see p. 42). Biotite also occurs in addition to the garnet as does some sillimanite, but there are seldom more than a few percent of biotite. Accessories are graphite, opaques, apatite, monazite, rutile and zircon. Graphite is sometimes so abundant that it is a significant minor constituent of the rock. The mineral compositions of the fine-grained garnet-quartz-feldspar gneisses are given in Table 14.

The chemical composition of the fine-grained garnet-quartz-feldspar gneisses corresponds to that of greywackes, subgreywackes and intermediate tuffaceous sediments (Table 15). Some of the varieties richest in quartz and at the same time poorest in garnet are derived from relatively pure quartz sandstones. Well-defined fine-grained garnet-quartz-feldspar gneisses of tuffaceous origin occur in the southwestern marginal zone of the complex. In this zone hornblende gneisses (tuffaceous sediments) were altered during granulitisation into hypersthene-bearing quartz-feldspar gneisses and as result of associated intergranular movements, into fine-grained garnet-quartz-feldspar gneisses. They can hardly be distinguished from the fine-grained garnet-quartz-feldspar gneisses derived from greywackes and subgreywackes. The former, however, form a distinct group of rocks of sedimentary

Table 15
Chemical composition of fine-grained garnet-quartz-feldspar gneisses.

	Weight per cent				Norms		
	1	2	3		1	2	3
SiO_2	78.38	78.52	82.25	Q	52.50	52.26	60.60
TiO_2	0.53	0.47	0.40	or	15.03	15.64	5.57
Al_2O_3	10.38	9.74	9.08	ab	15.16	13.69	17.41
Fe_2O_3	0.87	0.63	0.28	an	5.37	5.06	7.82
FeO	2.84	3.19	2.01	c	2.71	2.36	1.81
MnO	0.04	0.07	0.03				
MgO	1.16	1.61	0.94	en	2.89	4.01	2.34
CaO	1.18	1.13	1.66	fs	3.70	4.70	2.86
Na_2O	1.79	1.62	2.06	mt	1.25	0.90	0.39
K_2O	2.54	2.65	0.94	il	1.00	0.89	0.76
P_2O_5	0.08	0.09	0.07	ap	0.18	0.21	0.16
CO_2	0.00	0.00	0.00				
H_2O^+	0.23	0.42	0.20	fem	9.02	10.71	6.51
H_2O^-	0.08	0.12	0.10				
	100.10	100.26	100.02				

	Mode				Niggli values		
	1	2	3		1	2	3
Quartz	50.6	52.2	72.8	al	39.4	36.3	41.1
Potash feldspar	18.1	18.3	1.0	fm	30.8	35.4	25.4
Plagioclase	18.3	19.5	22.1	c	8.1	7.7	13.6
Biotite	3.5	6.7	1.2	alk	21.7	20.6	19.9
Garnet	8.3	3.1	2.6				
Sillimanite	0.6	—	—	si	504.8	497.0	630.8
Accessories	0.6	0.2	0.3	ti	2.6	2.2	2.3
	100.0	100.0	100.0	p	0.22	0.24	0.23
				h	6.7	11.4	7.6
An	25	35	30				
				k	0.48	0.52	0.23
				mg	0.36	0.43	0.42
				qz	+318.0	+314.5	+451.2

1. Inari, Pohj. Kynsileikkaamapää, 74/PV/56. Anal. P. Ojanperä, 1957.
2. Inari, Vestojoki, 3 a/KM/56. Anal. P. Ojanperä, 1957.
3. Inari, Roavvioaivi, 154/KM/56. Anal. P. Ojanperä, 1957.

origin together with the shale-derived garnet-biotite and garnet-biotite-plagioclase gneisses of the granulite complex proper. The amount of volcanic component of these rocks is uncertain.

Carbonate-bearing intercalations are encountered in the fine-grained garnet-quartz-feldspar gneisses on the fells of Marestatunturit, e.g. at Raappisoaivi (Fig. 30). The texture of these intercalations is blastoclastic. Main minerals are quartz, carbonate, clinozoisite and tremolite. In addition, garnet, chlorite, talc and scapolite are encountered. Accessories are titanite, apatite and zircon. Approximately 20 to 40

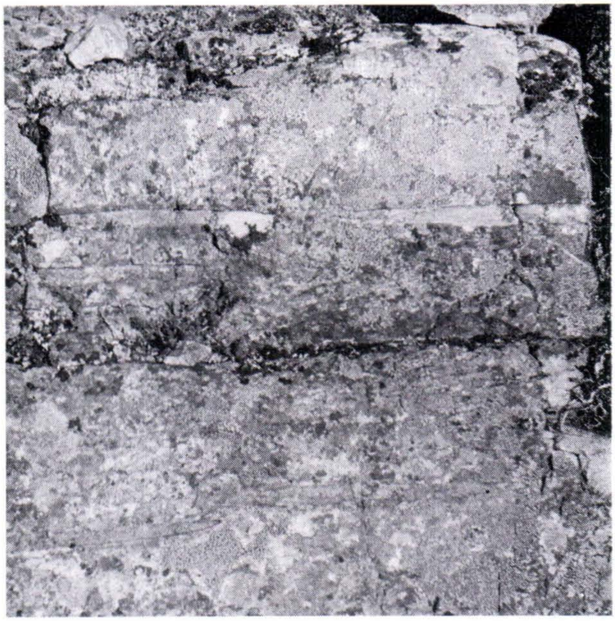

Fig. 30. Carbonate-bearing intercalations in fine-grained garnet-quartz-feldspar gneiss. Inari, Raappisoaivi. Photo K. Meriläinen.

percent of the minerals in the rock are carbonate and about 50 to 60 percent quartz. The carbonate-bearing or -rich beds and bands in the fine-grained garnet-quartz-feldspar gneisses suggest that minor calcareous sandstones were also formed during the deposition of the sedimentary group in the granulite complex. It seems that the carbonates are of organic origin as is also the graphite.

Garnet-biotite gneisses

There are several varieties of garnet-biotite gneisses, which differ from each another on the basis of their garnet and biotite contents. They are more readily weathered, richer in garnet and darker in colour than the fine-grained garnet-quartz feldspar gneisses, and hence, usually easy to distinguish from them. There are, however, transitional types of all degrees between these two.

The most typical garnet-biotite gneisses are interbedded (some decimetres to several metres thick) with the fine-grained garnet-quartz-feldspar gneisses, in which case the fine-grained garnet-quartz-feldspar gneiss is the predominant rock type. Less commonly, the garnet-biotite gneiss predominates, and then the fine-grained garnet-quartz feldspar gneiss occurs as irregular alternating narrow bands in the garnet biotite gneiss.

Fig. 31. Garnet-rich garnet-biotite gneiss. Diameter of garnets and garnet clusters ranges from 2 to 5 cm. Inari, Fällipesoaivit. Photo K. Meriläinen.

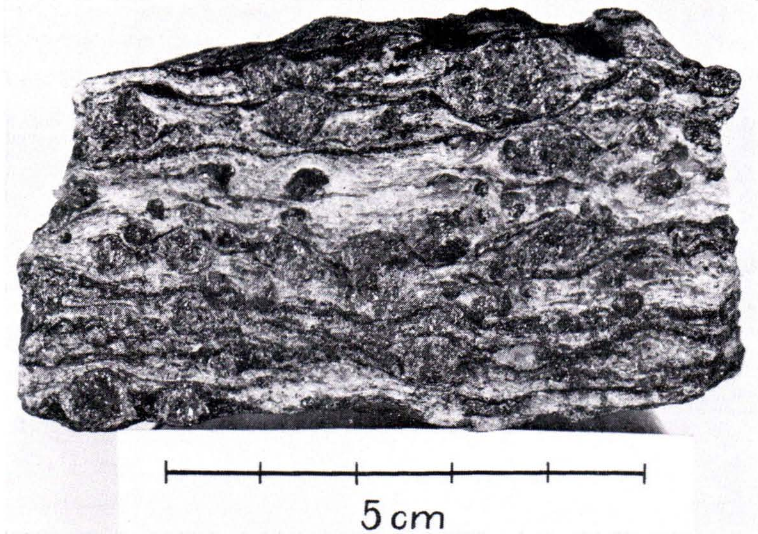

Fig. 32. Typical garnet-biotite gneiss. Diameter of garnets ranges from 3 to 10 mm. Inari, Fällipesoaivit. Photo E. Halme.

The colour of the weathered surface of the garnet-biotite gneisses is often a characteristic grey-brown interspersed with violet. The fresh fracture surface is either grey with crystals of red-brown garnet or yellow-brown as a consequence of weathering and abundant garnet. Most of the garnet-biotite gneisses are easy to identify on the basis of their biotite content. However, in some cases biotite has been almost wholly replaced by garnet under the conditions of the granulite facies. Single garnet crystals and garnet aggregates often form large augen shaped structures, usually 0.5—1 cm in diameter, rarely as much as 2—3 cm (Figs 31 and 32).

The texture of the garnet-biotite gneiss is granoblastic. The space between the large garnet porphyroblasts ($n' = 1.785$) is composed of fine-grained (Ø = 0.5—2 mm) potash feldspar, quartz and plagioclase (An_{15-30}). There are usually only a few percent of biotite ($\gamma' = 1.637$), but still quite enough to colour the fresh fracture surface grey. Also often encountered are sillimanite and the accessories apatite, opaques, graphite, rutile and zircon.

Table 16
Chemical composition of garnet-biotite-gneiss.
Inari, Raappisoaivi, 147/KM/56. Anal. P. Ojanperä 1957.

	Weight per cent	Norms	
SiO_2	53.42	Q	13.64
TiO_2	0.90	or	30.45
Al_2O_3	26.29	ab	14.53
Fe_2O_3	1.63	an	2.06
FeO	6.50	c	17.14
MnO	0.05		
MgO	3.35		
CaO	0.55	en	8.34
Na_2O	1.72	fs	9.19
K_2O	5.15	mt	2.36
P_2O_5	0.11	il	1.71
CO_2	0.00	ap	0.27
H_2O^+	0.51	cc	—
H_2O^-	0.14	fem	21.87
	100.34		

Niggli values	
al	47.4
fm	35.7
c	1.8
alk	15.1
si	163.2
ti	2.1
p	0.14
h	6.6
co_2	—
k	0.66
mg	0.43
qz	+2.8

The chemical and mineral compositions of the garnet-biotite gneisses indicate that they derive from argillaceous sediments (Table 16). They have high Al_2O_3 and K_2O contents but low CaO like normal argillaceous sediments. The pyrite and pyrrhotite disseminations and graphite content suggest that sapropelic sediments were also formed during the deposition of the shales.

Garnet-biotite-plagioclase gneisses

Garnet-biotite-plagioclase gneisses occur locally as beds a few decimetres thick in the garnet-biotite gneisses and in the fine-grained garnet-quartz-feldspar gneisses. Sometimes the beds are several metres wide, but they may also be visible only as bands a few centimetres wide on the weathered surface of the rock. In the garnet gneisses in the eastern part of the granulite complex proper they have often been observed merely as relicts. Transitional varieties from garnet-biotite-plagioclase gneisses to garnet-biotite-gneisses and pyroxene gneisses also occur.

The garnet-biotite-plagioclase gneisses are dark brown or grey-brown, fine-grained (Ø = 0.2—1 mm) and biotite-rich rocks. The garnet porphyroblasts and aggregates are distinctly smaller than those in the garnet-biotite gneisses (Ø = 1—3 mm).

The texture of the garnet-biotite-plagioclase gneisses is granoblastic, and the main minerals are plagioclase (An_{37-57}), quartz, biotite and garnet ($n' = 1.786$, 1.790). Plagioclase accounts for roughly 50 percent and quartz for 25 percent of the minerals. The amount of garnet varies and biotite is always present in abundance. Some varieties also contain hypersthene. A most interesting feature is the almost total absence of potash feldspar. Accessories are apatite, zircon, rutile and opaques (Table 17).

Table 17
Mineralogical composition of garnet-biotite-plagioclase gneisses.

	1	2	3	4	5
Quartz	18.9	22.2	24.6	25.1	30.2
K-feldspar	—	—	—	—	6.1
Plagioclase	40.4	40.6	53.1	51.5	40.9
Biotite	15.6	21.6	16.2	13.4	18.3
Garnet	23.4	14.7	4.2	8.8	2.8
Hypersthene	—	—	1.7	—	—
Accessories	1.7	0.9	0.2	1.2	1.7
An	40	38	50	40	36

1. Inari, Jänispää, 119/KM/56.
2. Inari, Kolshanoaivi, 85 a/KM/58.
3. Inari, Tuorisoaivi, 167/KM/56.
4. Inari, Arkkulautavaara, 21/KM/56.
5. Inari, Sallajokkaoaivi, 114/KM/56.

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Table 18
Chemical composition of garnet-biotite-plagioclase gneiss. Inari, Toarisoaivi, 167/KM/56. Anal. P. Ojanperä 1957.

	Weight per cent	Norms	
SiO_2	61.92	Q	21.45
TiO_2	0.44	or	7.90
Al_2O_3	19.12	ab	21.82
Fe_2O_3	0.40	an	30.18
FeO	4.11	c	2.37
MnO	0.06		
MgO	2.89	en	7.20
CaO	6.27	fs	6.59
Na_2O	2.58	mt	0.58
K_2O	1.34	il	0.83
P_2O_5	0.16	ap	0.37
CO_2	0.00	cc	—
H_2O^+	0.57	fem	15.57
H_2O^-	0.10		
	99.96		

	Mode	Niggli values	
Quartz	24.6	al	38.3
Potash feldspar	—	fm	27.5
Plagioclase	53.1	c	22.8
Biotite	16.2	alk	11.4
Garnet	4.2		
Hypersthene	1.7	si	210.4
Accessories	0.2	ti	1.1
	100.0	p	0.22
		h	7.6
An	50	CO_2	—
		k	0.25
		mg	0.53
		qz	+64.8

Since the chemical composition of the garnet-biotite-plagioclase gneisses is markedly higher in CaO than is that of the garnet-biotite gneisses (Table 18), the former are presumably derived from calcareous shales and greywackes. During regional metamorphism the carbonates disintegrated, with the consequence that CO_2 was expelled from the rock and the CaO became incorporated into anorthite-rich plagioclase. The anorthite content of the plagioclase is indeed appreciably higher than that of the plagioclase in other garnet gneisses, e.g. the garnet-biotite varieties.

Pyroxene gneisses

Pyroxene gneisses are rare although sporadically distributed throughout the garnet gneisses of the granulite complex proper. In the western part of the complex they usually occur as beds ranging in thickness from some decimetres to a few metres, but in the eastern part they are often no more than relicts of variable size.

Locally, and specifically at the western margin of the granulite complex proper, the pyroxene gneisses are interbedded with fine- and coarse-grained garnet-quartz-feldspar gneisses. These pyroxene gneisses are metamorphosed amphibolites and hornblende gneisses similar to those found in the southwestern marginal zone of the granulite complex. A few zones, some tens of metres wide at the most, in which the pyroxene gneisses are interbedded with garnet gneisses have been found locally also inside the granulite complex. One exceptional zone, 300—400 m wide, occurs at Joukaisvaara about 6 to 8 km east of the easternmost corner of the Vaskojoki anorthosite. At Vollivaara, between Ivalo and Nellimö, pyroxene gneisses have been encountered that are often hornblende-bearing. Their mineral composition differs mainly in the relative abundances of hypersthene and plagioclase (An_{60-70}). They are identical to the pyroxene gneisses encountered from the banks of the river Tenojoki, north of Karigasniemi, in the southwestern marginal zone of the granulite complex (p. 81).

The pyroxene gneisses are fine-grained (Ø = 0.5—1 mm) dark brown rocks, but at the marginal zones of the granulite complex proper they are also lighter, brown-grey in colour.

The texture of the pyroxene gneisses is granoblastic. Main minerals are plagioclase (An_{50-80}), hypersthene ($\gamma' = 1.716$, $\alpha' = 1.702$, $2V\alpha = 50°$), quartz and often also biotite. Sometimes, and particularly at the margins of the granulite complex proper, the pyroxene gneisses also contain diopside ($c\Lambda\gamma = 39—40°$, $2V\gamma = 48°$) and potash feldspar. The accessories, apatite and opaques, are found in far greater abundance in the pyroxene gneisses than in the other gneisses of the granulite complex proper. Alteration products are hornblende and talc. Garnet is not encountered in the most common pyroxene gneisses (Table 19). The biotite-rich varieties are transitional

Table 19
Mineralogical composition of pyroxene gneisses.

	1	2	3	4	5	6
Quartz	8.9	8.0	8.8	19.9	18.1	20.6
K-feldspar	3.0	—	—	4.0	—	—
Plagioclase	51.5	57.7	74.7	62.1	55.2	48.2
Biotite	1.6	7.9	—	+	6.4	11.4
Hornblende	—	—	1.7	—	—	—
Hypersthene	35.0	24.9	9.4	10.6	17.6	17.6
Diopside	—	—	3.9	—	—	—
Accessories	+	1.5	1.5	3.4	2.7	2.2
An	60	70	40	nd	nd	50

1. Inari, Jäkäläpää, 146/KM/56.
2. Inari, Kynsileikkaamapää, 93/KM/56.
3. Inari, Ladnjoaivi, 44 a/KM/56.
4. Utsjoki, Paktivaara, 121/HN/59.
5. Inari, Verkkojärvi, 254/PV/58.
6. Utsjoki, Paaddosoaivi, 115/HN/59.

types to biotite-plagioclase-gneisses; when rich in hornblende they grade into hornblende gneisses.

The pyroxene gneisses are derived from amphibolites and hornblende gneisses, some of which were originally basic volcanic rocks, sills or diabases, some others metamorphosed calcareous sediments rich in iron and magnesium.

Infracrustal rocks

The infracrustal rocks of the granulite complex proper are mainly quartz diorites concordant with the garnet gneisses. In addition, gabbros, diorites, some ultrabasic rocks and garnetiferous porphyritic potash granites are also found. There are three varieties of quartz diorite: hypersthene quartz diorite, garnet-biotite quartz diorite and the scapolite-biotite quartz diorite of Vuoskuljärvi. The garnet-biotite quartz diorites and garnetiferous porphyritic potash granites can be distinguished from the other infracrustal rocks of the granulite complex proper in that they are always garnet-bearing and that locally they grade into coarse-grained garnet-quartz-feldspar gneisses. On the other hand, the hypersthene quartz diorites are seldom garnetiferous. Observations indicate that the infracrustal rocks (with the exception of the Nattanen and Juvoaivi granites) are concordant with the garnet gneisses. The main reason for this is that granulitisation or diaphthoretic metamorphism took place after the emplacement of these infracrustal rocks and hence, the coherent orientation of the garnet gneisses and infracrustal rocks does not necessarily reflect the synkinematic character of the infracrustal rocks.

Ultrabasic rocks

Ultrabasic infracrustal rocks occur as small bodies or lenses. In some tectonised zones they are schistose and even mylonitic, elsewhere massive or only slightly foliated.

Table 20
Mineralogical composition of ultrabasic infracrustal rocks.

	1	2	3
Olivine	0.8	—	—
Hypersthene	22.5	31.1	37.9
Augite	49.0	8.8	11.8
Hornblende	23.4	58.0	29.0
Talc	—	—	5.4
Biotite	3.2	—	3.2
Plagioclase	0.6	—	10.9
Accessories	0.5	2.1	1.8
An	nd	—	55

1. Inari, Pastepelltshokka, 160 a/AT/57.
2. Inari, Siveloaivadsh, 251/PV/58.
3. Inari, Etusolmujärvet, 6 a/PV/56.

The ultrabasic rocks are dark brown or black in colour. They are locally cut by thin quartz-feldspar veins that are often garnetiferous.

The texture of the ultrabasic rocks is hypidiomorphic, granoblastic, locally nematoblastic or mylonitic. In mineral composition they are hypersthenites, hypersthene-augite, hypersthene-hornblende or hypersthene-augite-hornblende rocks. Furthermore, they often contain some olivine, plagioclase and biotite as well as opaques and apatite as accessories. In the tectonised zones the following alteration products occur: tremolite, cummingtonite, serpentine, chlorite, talc, biotite, epidote, sericite and quartz. Table 20 gives the mineral compositions of the ultrabasic rocks as determined by point counter.

Gabbros

Gabbros are small, discrete intrusions or portions in the quartz diorites. They are brown grey in colour. Their plagioclase is also brownish or yellow brown as it usually is in basic, hypersthene-bearing rocks in charnockite areas. They exhibit weakly or highly foliated structure with a medium grain size (Ø = 1—3 mm).

The texture of the gabbros is hypidiomorphic or hypidiomorphic-granular and sometimes even distinctly cataclastic. The main minerals are plagioclase (An_{50-70}), hypersthene and hornblende. The abundance of hornblende and hypersthene is variable. The hornblende is dark brown in colour and pleochroic: γ' = dark brown > α' = yellow brown. Augite and sometimes biotite are also present. Accessories are apatite and opaques. Alteration products are biotite, colourless or light-coloured hornblende, sericite and serpentine. The colour index is 30—65. The mineral compositions of some gabbros are given in Table 21.

Table 21
Mineralogical composition of gabbros.

	1	2	3	4
Plagioclase	49.4	35.0	47.9	65.9
Hornblende	23.0	40.9	21.2	10.4
Tremolite	—	—	—	+
Hypersthene	27.2	21.8	29.7	15.0
Augite	0.4	2.3	+	7.4
Biotite	—	+	+	—
Accessories	+	+	1.2	1.3
An	65	60	60	50
Color index	50.6	65.0	52.1	34.1

1. Inari, Ladnjoaivi, 43 c/KM/56.
2. Inari, Kolshanoaivi, 36/KM/56.
3. Inari, Härkäpuro, 166/KM/56.
4. Inari, Kettujoki, 96/KM/60.

Table 22
Mineralogical composition of diorites.

	1	2	3	4
Quartz	0.8	—	1.4	2.1
K-feldspar	6.6	+	3.7	6.8
Plagioclase	67.4	63.0	81.9	58.1
Hypersthene	4.4	21.8	6.5	11.6
Augite	5.8	—	1.4	9.4
Hornblende	—	—	0.3	—
Biotite	9.7	+	2.5	3.5
Scapolite	—	12.5	—	—
Accessories	5.3	2.7	2.3	8.5
An	43	60	50	nd
Color index	25.2	24.5	13.0	33.0

1. Inari, Rääpisjärvi, 8/KM/56.
2. Utsjoki, Karnasrattaoaivi, 41 a/AH/60.
3. Inari, Sotajoki, A 241.
4. Inari, Pailovaara, A 225.

Diorites

Diorites occur as portions in the quartz diorites and as independent intrusions. In structure they are weakly foliated, and in colour greenish or brownish grey.

The texture of the diorites is hypidiomorphic or hypidiomorphic-granular. Main minerals are plagioclase (An_{43-60}) and hypersthene (Table 22). In addition a few percent of augite, biotite and potash feldspar are present as well as minor quartz and occasional hornblende. Marialitic scapolite is abundant in one of the diorites. Accessories are opaques and apatite. Apatite is clearly more abundant than it is in the other plutonic rocks of the granulite complex proper, which also applies to the apatite in the diorites in the southwestern marginal zone of the granulite complex. The colour index is less than 30. Some of the diorites are plagioclase-rich leucodiorites or anorthositic diorites (colour index < 15). The anorthositic diorites in the southwestern marginal zone of the granulite complex are similar but hornblende-bearing (see Table 37).

Quartz diorites

Quartz diorites form rock sequences, some kilometres in length, which are usually composed of several discrete intrusions. In some localites the quartz diorites also contain gabbro and diorite portions and a few of them are intruded by thin garnet-bearing quartz-feldspar dykes. The quartz diorites are brown or greenish grey (hypersthene-bearing) or light grey (hypersthene-deficient) depending on their mineral composition.

Table 23
Mineralogical composition of quartz diorites.

	1	2	3	4	5
Quartz	9.7	13.3	14.5	16.9	21.2
K-feldspar	4.4	4.8	—	1.2	+
Plagioclase	71.1	73.7	70.5	64.3	60.0
Hypersthene	10.5	3.5	9.4	11.9	15.6
Biotite	0.5	4.1	3.2	1.1	2.1
Hornblende	—	—	—	3.1	—
Accessories	3.2	0.6	2.4	1.5	1.1
An	45	45	48	38	42
Color index	14.2	8.2	15.0	17.6	18.8

1. Utsjoki, Karnasrattaoaivi, 41b/AH/60.
2. Inari, Ahvenjoki, 100/KM/56.
3. Inari, Vaskojoki, near Heikkilä, 70/PV/56.
4. Inari, Ylempi Akujärvi, 133/KM/57.
5. Inari, Lammaspää, 177/KM/56.

In mineral composition the quartz diorites are: 1) hypersthene quartz diorites, 2) garnet-biotite quartz diorites and 3) scapolite-biotite quartz diorites. The first group may also contain garnet, whereas the other two scarcely ever have any hypersthene. Garnet-biotite quartz diorite is present only in the central and eastern parts of the granulite complex proper, that is, in those areas where the garnet-cordierite gneisses and coarse-grained garnet-quartz-feldspar gneisses predominate.

The *hypersthene quartz diorites* are weakly foliated and sometimes also schistose. Their texture is hypidiomorphic or hypidiomorphic-granular. Main minerals are plagioclase (60—70 % An_{40-50}), quartz (10—20 %) and hypersthene (Table 23). The hypersthene is distinctly pleochroic: $\omega' =$ reddish $> \gamma' =$ blue-grey, $2V\alpha = 53, 56, 60, 62°$. In addition, some biotite and occasionally hornblende and/or garnet are present. Accessories are opaques, apatite, zircon and potash feldspar. The potash feldspar generally occurs only as antiperthite. The colour index is approximately 10 to 20.

The average chemical composition of the hypersthene quartz diorites of the granulite complex proper is slightly more basic than that of the quartz diorites of the charnockite province described by A. Simonen (1960 a) from South Finland. This is revealed in the analyses by the fact that the quartz diorites of the granulite complex proper (Table 24) are somewhat more improverished in SiO_2 but markedly more enriched in MgO than are the quartz diorites of the charnockite province. The quartz gabbros in the southwestern marginal zone of the granulite complex have higher CaO, FeO + Fe_2O_3 and MgO contents and a lower SiO_2 content (Table 36) than do the quartz diorites of the granulite complex proper. However, in their mineral composition it is often only the higher anorthite content of the plagioclase that indicates quartz-gabbroic chemical composition.

Table 24
Chemical composition of hypersthene quartz diorites.

	Weight per cent 1	Weight per cent 2		Norms 1	Norms 2
SiO_2	60.20	61.27	Q	15.62	13.60
TiO_2	0.67	0.75	or	7.62	10.35
Al_2O_3	18.05	16.59	ab	29.53	34.51
Fe_2O_3	1.41	1.48	an	26.93	21.78
FeO	4.71	3.96	c	1.04	—
MnO	0.08	0.08			
MgO	3.22	3.28	en (Di)	—	0.78
CaO	5.62	5.55	fs (Di)	—	0.47
Na_2O	3.49	4.08	wo (Di)	—	1.32
K_2O	1.29	1.75	en	8.02	7.38
P_2O_5	0.15	0.44	fs	6.51	4.47
CO_2	0.01	0.00	mt	2.03	2.15
H_2O^+	0.90	0.44	il	1.27	1.42
H_2O^-	0.12	0.09	ap	0.34	1.00
	99.9	99.76	cc	0.02	—
			fem	18.19	18.99

	Mode 1	Mode 2		Niggli values 1	Niggli values 2
Quartz	21.2	16.9	al	34.6	32.4
Potash feldspar	+	1.2	fm	32.1	31.1
Plagioclase	60.0	64.3	c	19.6	19.7
Hypersthene	15.6	11.9	alk	13.7	16.8
Hornblende	—	3.1			
Biotite	2.1	1.1	si	195.6	203.0
Accessories	1.1	1.5	ti	1.6	1.9
			p	0.2	0.6
An	42	38	h	11.1	5.8
			co_2	0.04	—
Color index	18.8	17.6	k	0.20	0.22
			mg	0.49	0.52
			qz	+41.1	+35.8

1. Inari, Lammaspää, 177/KM/56. Anal. P. Ojanperä 1958.
2. Inari, Ylempi Akujärvi, 133/KM/57. Anal. P. Ojanperä 1958.

The *garnet-biotite quartz diorites* are grey, medium-grained (Ø = 2—4 mm) rocks, which are occasionally almost massive although they often show gneissose structure.

The texture of the garnet-biotite quartz diorites is hypidiomorphic or granular. The major minerals are quartz, plagioclase (An_{28-40}), biotite and garnet. Plagioclase contains antiperthite and occasional myrmekite. Biotite exhibits pronounced pleochroism, γ' = reddish brown > α' = yellowish brown. Garnet, which is pyrope-bearing almandine (n' = 1.797), occurs as irregular aggregates, nests or porphyroblasts. The environment of the grains or grain clusters is frequently almost free from biotite, suggesting that the garnet was formed at the expense of biotite (Fig. 33). Quartz is more abundant than it is in the hypersthene quartz diorites. Minor amounts

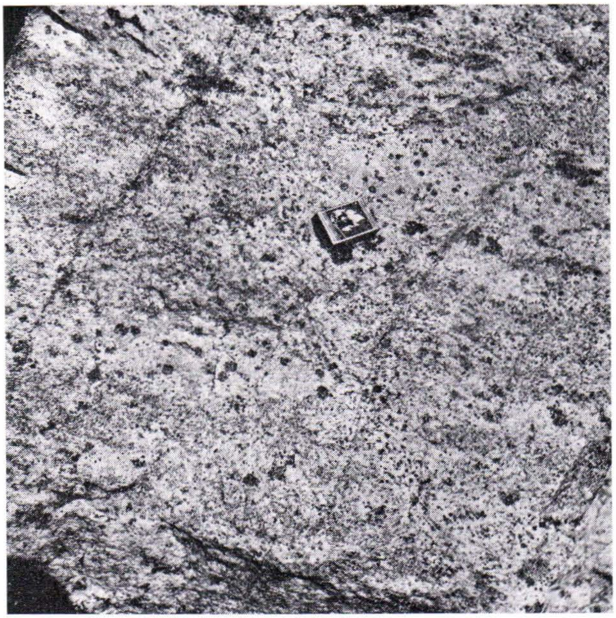

Fig. 33. Garnet-biotite quartz diorite. The garnets often occur as accumulations in an almost biotite-free environment, suggesting that garnet was formed at the expense of biotite contemporaneously with some potash feldspar. Inarijärvi, Lusmasaari. Photo K. Meriläinen.

of cordierite are encountered locally. Opaques, apatite and potash feldspar are the accessories, of which the latter usually occurs only as antiperthite. The colour index is 5—12 (Table 25).

Table 25
Mineralogical composition of garnet-biotite quartz diorites.

	1	2	3	4	5
Quartz	29.5	32.8	38.7	39.8	45.8
K-feldspar	—	0.9	+	5.4	2.6
Plagioclase	59.3	55.5	56.5	45.8	42.7
Biotite	3.8	9.1	3.0	8.7	6.6
Muscovite	0.2	—	—	+	—
Garnet	5.8	1.0	+	+	2.2
Accessories	1.4	0.7	1.8	0.3	0.1
An	40	33	30	28	32
Color index	11.2	10.8	4.8	9.0	8.9

1. Inari, Kivioja, 205/PV/56.
2. Inari, Joensuunselkä, 138/PV/57.
3. Inari, Joensuunselkä, 126/PV/57.
4. Inari, Letsemäjärvi, 131/PV/58.
5. Inari, Myösäjärvi, A 269.

Table 26
Chemical composition of garnet-biotite quartz diorite.
Inari, Kivioja, 205/PV/56. Anal. P. Ojanperä 1958.

	Weight per cent	Norms	
SiO_2	66.98	Q	29.89
TiO_2	0.71	or	6.96
Al_2O_3	16.39	ab	26.22
Fe_2O_3	0.04	an	19.22
FeO	4.44	c	2.97
MnO	0.05		
MgO	2.05	en	5.10
CaO	4.01	fs	7.03
Na_2O	3.10	mt	0.06
K_2O	1.18	il	1.35
P_2O_5	0.12	ap	0.27
CO_2	0.00		
H_2O^+	0.60	fem	13.81
H_2O^-	0.08		
	99.78		

	Mode	Niggli values	
Quartz	29.5	al	39.3
Plagioclase	59.3	fm	27.9
Biotite	3.8	c	17.5
Muscovite	0.2	alk	15.3
Garnet	5.8		
Accessories	1.4	si	272.9
	100.0	ti	2.2
		p	0.2
An	40	h	9.2
		k	0.20
Color index	11.2	mg	0.45
		qz	+111.7

The chemical composition of the garnet-biotite quartz diorites (Table 26) corresponds closely to that of the quartz diorites in the charnockite and trondhjemite province of Southern Finland (Simonen 1960 a), except, however, that the average *fm* content is higher and the average *alk* content lower in the former. In the light of the analytical data available, the infracrustal rocks of the granulite complex proper in particular appear on the whole to be richer in *fm* and poorer in *alk* than do the correponding rocks in the charnockite province of Southern Finland. The infracrustal rocks of the charnockite province are products of a lower grade granulite facies. This is manifested by the fact that, besides hypersthene, the quartz diorites of the charnockite province almost invariably contain diopside and/or hornblende, whereas the hypersthene quartz diorites of the granulite complex proper are almost totally devoid of these minerals. Furthermore, the quartz diorites of the charnockite province contain conspicuously more biotite (3 to 5 times more) than do the corresponding rocks of the granulite complex. Thus, the infracrustal rocks of the granulite complex proper constitute a province of infracrustal rocks characteristic of that complex.

The *scapolite-biotite quartz diorite* at Vuoskuljärvi, north of Vaskojoki, is associated with an extensive and well-defined aeromagnetic anomaly in which a magnetite-bearing diorite predominates (Table 22, anal. 1). The quartz diorite at Vuoskuljärvi is also magnetite-bearing but its relation to the country rock has not been established. The scapolite-biotite quartz diorite is grey or reddish grey in colour and even-grained to distinctly porphyritic. The porphyritic variety (Ø = 0.5—2 cm) abounds and the rock is only slightly foliated whereas the even-grained varieties are practically lacking in foliation.

The texture of the scapolite-biotite quartz diorite is hypidiomorphic or hypidiomorphic-granular. The main contituents are plagioclase (An_{30-40}), biotite, quartz and scapolite. Plagioclase exhibits faint zonal structure and in some places it contains antiperthite and sericite. Biotite is pleochroic with γ' = brown > α' = yellowish brown; a minor part of it is recrystallised. The marialitic scapolite is straw yellow and is most abundant in the porphyritic varieties where it occupies the interstices between the other minerals, notably the grains of the plagioclase with fractured margins. Small amounts of chlorite and sericite occur as alteration products, and magnetite, antiperthitic potash feldspar, apatite and zircon as accessories.

Garnetiferous porphyritic potash granites

Along the local roads of the villages of Koppelo and Veskoniemi in Ivalo and on the eastern shore of the lake Kokkojärvi there are fairly extensive areas occupied by an almost massive, garnetiferous porphyritic potash granite, which is closely associated with coarse-grained garnet-quartz-feldspar gneisses. These potash granites are grey or brownish grey in colour and conspicuously plutonic in character. Porphyritic potash feldspar grains abound in the medium-grained (Ø = 2—5 mm) matrix composed of biotite, garnet (almandine 65 %, pyrope 25—30 %, andradite 5 %, spessartite 2 % and grossularite 1 %, n' = 1.797), plagioclase (An_{30-35}) and quartz. The grains of potash feldspar are clear and include crystals of biotite, quartz and plagioclase but never garnet. This indicates that garnet crystallised after potash feldspar, i.e. the rock was already porphyritic when underwent granulitisation. Plagioclase has altered to sericite giving rise to random cloudiness. In places, garnet has altered into cordierite, which was later partially chloritised. At the same time biotite has altered into an intense brownish-red or almost colourless variant. In the outcrops, cordierite has been observed to replace garnet. Cordierite has also crystallised along cracks and farther in the rock. The growth of cordierite probably took place simultaneously with the anatectic veins and garnet-gneisses in the environment. As massive rocks, however, the garnetiferous porphyritic potash granites were more resistant to later metamorphic alterations than were the garnet gneisses.

Anatectic dykes

In the eastern part of the granulite complex proper in and around Inarijärvi, dykes abound that are either coarse-grained, pegmatitic (Ø = 2—5 cm) and heterogeneous or even- and medium-grained (Ø = 2—5 mm) and homogeneous. These dykes are conformable with their country rocks or cross cut them and grade into or even brecciate the surrounding garnet gneisses. The mineral compositions of these dykes vary considerably. Some of the coarse-grained varieties are rich in plagioclase (An_{30-50}), whereas some others contain abundant potash feldspar and quartz. Moreover, most of the dykes also have garnet, cordierite, biotite and locally sillimanite. Zircon, monazite, fluorite, opaques and sometimes also andalusite, kyanite or tourmaline are encountered as accessories. The medium-grained varieties are grey rocks devoid of biotite. They are composed of c. 30 % potash feldspar, 30 % plagioclase (An_{25-35}) and 30 % quartz, in addition to which there are garnet, sillimanite and often also biotite as minor constituents. These dykes are anatectic and owe their mineral composition and structure to the local conditions of crystallisation during the diaphthoretic stage of granulitisation.

The northeastern marginal zone of the granulite complex

The northeastern marginal zone of the granulite complex is from 2 to 10 km wide and lies between the granulite complex proper and the granite gneiss complex. However, it can be clearly traced only at and around Inarijärvi. Farther north it is overlain by extensive swamps and Quarternary deposits and hence, it outcrops in only a few places.

The rocks in the northeastern marginal zone of the granulite complex are composed mainly of quartzites, quartz-feldspar gneisses, mica gneisses and hornblende gneisses. In addition, amphibolites and infracrustal quartz diorites occur concordantly with the supracrustal rocks. The supracrustal rocks are often cut by granite veins or veinlets but they are seldom veined gneisses. These rocks are also penetrated and sometimes brecciated by granitic pegmatites, diabases and a basic dyke at Lusmasaari. The diabases, when discernible, often display concordant contacts with the supracrustal rocks.

The marginal zone differs from the granite-gneiss complex in its abundant supracrustal rocks, mica gneisses and hornblende gneisses in particular, but also in quartzites. The marginal rocks can be distinguished from those of the granulite complex proper in that the marginal rocks were metamorphosed mainly under the conditions of the amphibolite fecies. The boundary between the granulite complex proper and its northeastern marginal zone is often tectonic. However, the supracrustal rocks of the marginal zone include the coarse-grained garnet-quartz-feldspar gneisses and garnet-cordierite gneisses characteristic of the eastern part of the granulite complex proper as portions and zones that locally may attain considerable width. The boundary with the granite gneiss complex is ill-defined. The quartzites indicate that it is probably north of the straits of Kaikunuora and Lusmanuora.

Supracrustal rocks

The supractustal rocks in the northeastern marginal zone of the granulite complex are composed of quartzites, quartz-feldspar gneisses, mica gneisses, amphibolites and hornblende gneisses. The mica gneisses and hornblende gneisses are often garnetiferous. Where garnet is abundant in the mica gneisses, they resemble the biotite-rich garnet-biotite gneisses and garnet-biotite-plagioclase gneisses of the granulite complex proper. The rocks of the marginal zone were metamorphosed mainly under the conditions of the amphibolite facies but locally under those of the granulite facies.

Quartzites

Quartzites are encountered at several localities on the southern shores of the islands Kaamassaari and Lusmasaari, on the nearby islands, at the northern end of the bay Nanguvuono and west of the lake Sarmijärvi. The quartzites occur as layers a few metres to a hundred metres thick in quartz-feldspar gneisses. They are also encountered as thin alternating intercalations in the other supracrustal rocks.

The quartzites are pale grey, fine- or medium-grained (Ø = 0.2—2 mm) rocks with pronounced foliation (Fig. 34). In some exposures graded bedding has been observed, suggesting that the top of the beds is to the south.

Fig. 34. Orthoquartzite displaying cross-bedding. Inarijärvi, Lusmasaari. Photo K. Meriläinen.

Table 27
Mineralogical composition of quartzites and quartz-feldspar gneisses.

	1	2	3	4	5	6	7	8
Quartz	70.1	65.0	49.9	38.2	31.3	27.4	27.0	23.9
K-feldspar	+	22.1	13.2	21.1	21.2	4.8	3.3	+
Plagioclase	15.7	7.4	27.3	31.1	42.1	61.4	58.4	64.2
Biotite	+	3.3	9.5	4.0	2.6	5.0	10.7	1.0
Chlorite	—	+	—	—	2.6	—	—	5.0
Sericite	+	1.9	—	—	0.2	1.4	—	—
Hornblende	6.9	—	—	5.3	—	—	—	4.7
Accessories	7.3	0.3	+	0.3	+	+	0.6	1.2
An	25	24	nd	25	23	nd	27	32

1. Quartzite. Inari, Taplasaari, 122/KM/57.
2. Quartzite. Inari, Lusmasaari, 94/KM/57.
3. Quartz-feldspar gneiss. Inari, Skäydevaara, 86/PV/57.
4. Quartz-feldspar gneiss. Inari, Mossaaret, 91/KM/57.
5. Quartz-feldspar gneiss. Inari, Kaamassaari, 128/KM/57.
6. Quartz-feldspar gneiss. Inari, Mossaaret, 93/KM/57.
7. Quartz-feldspar gneiss. Inari, Sieksvuono, 97/KM/57.
8. Quartz-feldspar gneiss. Inari, Korkeloniemi, 96 a/KM/57.

The thickest quartzites are very quartz-rich orthoquartzites. Their texture is granoblastic or blastoclastic. In addition to quartz, they always contain plagioclase, potash feldspar and minor biotite, and hornblende and/or magnetite. Rarely magnetite may account for several percent of the rock. These quartzites resemble certain varieties of magnetite-banded, cherty quartzites, despite the fact that no distinct banded structure has been noted. The quartzites contain opaques, apatite and zircon as accessories as well as sericite, muscovite and epidote as alteration products (Table 27). The thin quartzite bodies are often rich in feldspar and represent transitional types to quartz-feldspar gneisses.

The quartzites are derived from quartz-rich sands that were deposited in the shelf area under variable depositional conditions (interbedded layers of quartzites and mica gneisses) simultaneously with volcanic activity (irregular interbedded layers of quartzites, quartz-feldspar gneisses, amphibolites and hornblende gneisses).

Quartz-feldspar gneisses

Quartz-feldspar gneisses occur as fairly wide areas as well as thin beds and bands alternating randomly with amphibolites, hornblende gneisses, biotite gneisses and sometimes even with quartzites (Fig. 35). In some places they grade into hornblende gneisses and are themselves often hornblende-bearing. The quartz-feldspar gneisses are grey in colour fine- to medium-grained (Ø = 0.2—2 mm) rocks with well-developed foliation. The quartz-feldspar gneisses are often cut by concordant or discordant granite veins or veinlets.

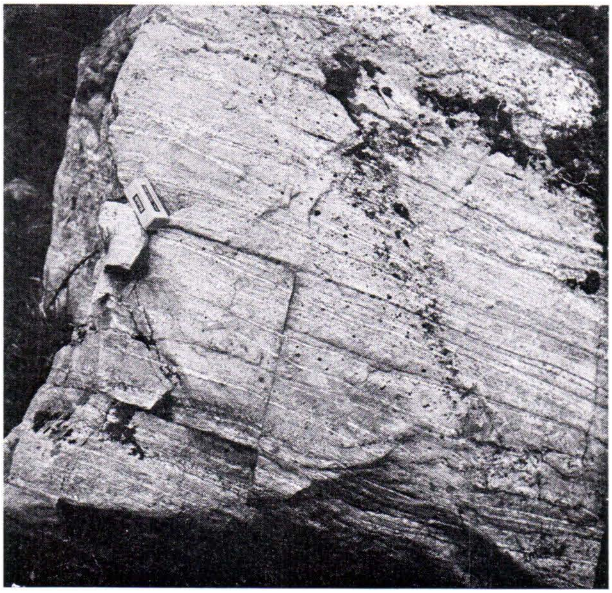

Fig. 35. Fine-grained, quartz-rich quartz-feldspar gneiss. Inari, Skäydevaara. Photo K. Meriläinen.

The texture of the quartz-feldspar gneisses is granoblastic. Main minerals are quartz, plagioclase (An_{20-35}) and potash feldspar with minor biotite, often hornblende and occasionally almandine. Sericite, muscovite and chlorite are alteration products. Accessories are opaques, apatite, titanite and zircon (Table 27).

The quartz-feldspar gneisses were originally arkosic sands and greywackes, with some probable admixed volcanic ash and weathering products from volcanic rocks. This is evident from the occurrence of hornblende in quartz-feldspar gneisses and from the grading of these gneisses into hornblende gneisses.

Mica gneisses

Mica gneisses occur as thick, heterogeneous bodies in which varieties of mica gneiss and quartz-feldspar gneisses alternate randomly as relict layers and beds, locally with relict graded bedding. Occasionally amphibolite intercalations are also found, in which case the mica gneisses contain amphibole. The mica gneisses are dark grey or greyish brown in colour. They are frequently cut by granite veins. In places the mica gneisses are migmatised and show intensive minor folding.

In mineral composition the mica gneisses are garnet-sillimanite-biotite gneisses, garnet-biotite-plagioclase gneisses and biotite gneisses. Their texture is granoblastic.

Fig. 36. Migmatic garnet-biotite-sillimanite gneiss. The rock is rich in garnet; garnet and sillimanite occur in the dark streaks and bands mainly in association with biotite. Inarijärvi, Nanguniemi. Photo K. Meriläinen.

The main minerals of the *garnet-sillimanite-biotite gneisses* are quartz, biotite, plagioclase (An_{25-30}) and potash feldspar with variable amounts of garnet (almandine, $n' = 1.795$), sillimanite and locally cordierite. Accessories are opaques, apatite, monazite, rutile and zircon (Table 28). In mineral composition they resemble the

Table 28
Mineralogical composition of mica gneisses.

	1	2	3	4
Quartz	48.7	27.4	2.6	3.2
K-feldspar	12.1	13.1	—	+
Plagioclase	1.9	17.0	56.8	52.4
Biotite	22.6	23.8	32.2	33.5
Sericite	—	—	1.4	—
Garnet	5.2	14.7	4.1	6.4
Sillimanite	9.3	4.0	—	—
Accessories	0.2	—	2.9	4.5
An	25	30	34	40

1. Garnet-sillimanite-biotite gneiss. Inari, Vihalassaaret, 10 c/KM/59.
2. Garnet-sillimanite-biotite gneiss. Inari, Sarmivuono, 116/Tyni/57.
3. Garnet-biotite-plagioclase gneiss. Inari, Malkosaaret, 156 a/PV/58.
4. Garnet-biotite-plagioclase gneiss. Inari, Siskelvuono, 6 a/Tyni/58.

Fig. 37. Biotite gneiss. Light-coloured veins and spots are composed predominantly of quartz and potash feldspar. Inari, Skäydevaara. Photo K. Meriläinen.

garnet-biotite gneisses of the granulite complex proper, but are conspicuously richer in biotite and often poorer in garnet (Fig. 36). These differences are mainly due to the dissimilar conditions of metamorphism. The chemical composition of the garnet-sillimanite-biotite gneisses corresponds to that of shales as does that of the garnet-biotite gneisses of the granulite complex proper.

Plagioclase (An_{30-40}, even An_{60-70}) and biotite are the dominant minerals in the *garnet-biotite-plagioclase gneisses*. Some quartz and garnet also occur. Accessories are opaques, apatite, potash feldspar and zircon (Table 28). Apatite is markedly more abundant than it is in other supracrustal rocks of the northeastern marginal zone of the granulite complex. In mineral composition the garnet-biotite-plagioclase gneisses are similar to those in the granulite complex proper. The chemical composition corresponds to that of the calcareous shales or greywackes.

The *biotite gneisses* (Fig. 37) are distinctly lighter in colour and richer in quartz and feldspar than are the garnet-biotite-plagioclase gneisses. The most light-coloured and most biotite-deficient varieties (c. 10 % biotite) can thus be considered as transitional types to quartz-feldspar gneisses. Quartz, plagioclase (An_{20-30}), potash feldspar and biotite are the main constituents; there are minor amounts of garnet ($n' = 1.749$) and occasionally also cordierite or hornblende. Some biotite gneisses correspond to the fine-grained garnet-quartz-feldspar gneisses derived from greywackes in the granulite complex proper.

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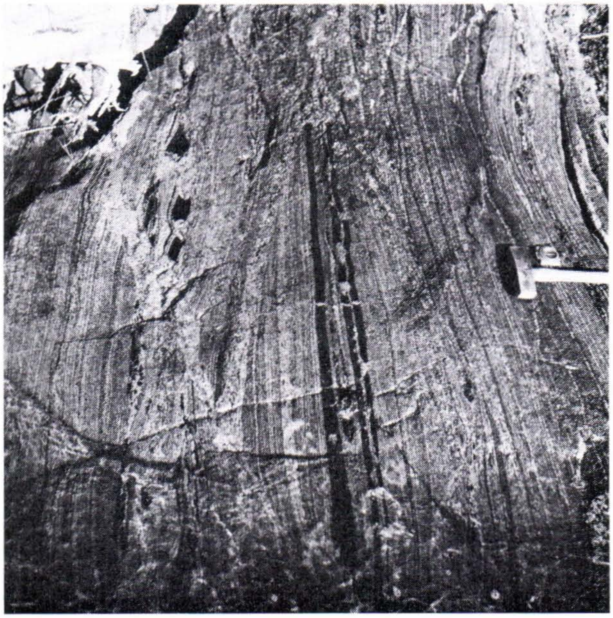

Fig. 38. Hornblende gneiss. Dark bands are amphibolite that locally forms boudinages due to tectonisation of rock. Amphibolite displays more intense weathering than hornblende gneiss. Inarijärvi, Lusmanuora. Photo K. Meriälinen.

Hornblende gneisses

Hornblende gneisses occur in markedly greater abundance than do amphibolites. On the shores of the straits Lusmanuora and Kaikunuora they locally occupy areas up to several metres in width (Fig. 38). In general, however, they are layers from only a few centimetres to some tens of centimetres wide that alternate randomly with other supracrustal rocks.

The hornblende gneisses show distinct foliation and are fine- to medium-grained (Ø = 0.2—3 mm) rocks. The colour varies from dark green to greyish green depending on the abundance of hornblende. The texture of the hornblende gneisses is granoblastic. Main minerals are plagioclase (An_{30-55}), quartz, hornblende and often biotite. Locally there are also small amounts of epidote, cummingtonite, garnet or chlorite. Opaques, titanite, apatite and zircon are the accessories (see Table 7).

Abundant epidote, diopside or even scapolite occur locally in the narrow hornblende gneiss bands. These are calc-silicate gneisses similar to those found in the amphibolites and hornblende gneisses of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones.

Almost massive long and narrow pyrrhotite zones up to two metres thick are sometimes associated with the hornblende gneisses although pyrrhotite usually occurs as dissemination. In addition to pyrrhotite there is some pyrite and occasional sphalerite and graphite. The graphite may even be quite abundant (see Lahtinen 1972).

Amphibolites

In general the amphibolites occur as beds from a few decimetres to some metres thick in quartz-feldspar gneisses and mica gneisses. In some localities they grade into hornblende gneiss with which they alternate randomly as bands and beds. In mineral composition the amphibolites are mainly hornblende-plagioclase rocks, although locally abundant diopside amphibolites are encountered as are also a few cummingtonite amphibolites.

The amphibolites are well foliated and fine- to medium-grained (Ø = 0.5—2 mm), dark green rocks. In texture, they are grano- or nematoblastic. The major minerals are hornblende and plagioclase (An_{40-55}) with minor biotite, epidote, cummingtonite, garnet and quartz as well as local concentrations of diopside. Opaques, titanite and apatite are the accessories.

The thickest amphibolite beds are distinctly banded and metamorphosed basic volcanic rocks. The other, homogeneous varieties, are metamorphosed diabase dykes identical with those cutting the rocks of the granite gneiss complex.

Infracrustal rocks

The infracrustal rocks in the northeastern marginal zone of the granulite complex are quartz diorites exhibiting concordant boundaries with the supracrustal rocks. Among them, however, are granodiorites that cannot be distinguished macroscopically from the quartz diorites. Gabbro or diorite are present as marginal varieties of one quartz diorite body. Veins of granite and coarse pegmatitic granite cut the quartz diorite at some localites.

Quartz diorites

Quartz diorites are grey or dark grey rocks, which exhibit a moderate to distinct foliation with cataclastic structure. The grain size varies from place to place (Ø = 0.2—5 mm). Amphibolite xenoliths have been encountered as long bands or oblong inclusions. The texture of the quartz diorites is hypidiomorphic or hypidiomorphic-granular. Main minerals are plagioclase (An_{30-40}), hornblende and quartz with minor biotite, and rare augite, hypersthene, garnet or potash feldspar. Opaques, apatite, titanite and zircon (Table 29) are accessories.

The chemical composition of the Kutujärvi quartz diorite (Table 30) is close to that of the hypersthene-bearing quartz diorites in the granulite complex proper, but the Kutujärvi variety is somewhat richer in silica. The chemical composition also resembles that of the quartz diorites in the trondhjemite or granodiorite province in South Finland (see Simonen 1960 a).

Table 29
Mineralogical composition of quartz diorites.

	1	2	3	4
Quartz	15.7	28.3	39.8	41.6
K-feldspar	3.2	—	3.9	—
Plagioclase	58.3	52.7	40.0	45.0
Augite	1.4	—	—	—
Hypersthene	—	1.1	—	—
Hornblende	13.1	14.8	3.4	5.4
Biotite	8.3	2.5	10.0	4.0
Epidote	—	—	2.5	+
Garnet	—	—	—	2.7
Accessories	+	0.6	0.4	1.3
An	30	38	28	nd
Color index	22.8	19.0	16.3	13.4

1. Inari, Kenttäsaaret, 98/KM/57, A 39.
2. Inari, Nellimö, Kutumajärvi, 121 a/PV/57, chem.anal. in Table 30.
3. Utsjoki, Päärikvaara, 141/PV/60.
4. Inari, Syysjärvi, 77/RL/61, A 117.

Table 30
Chemical composition of quartz diorite.
Inari, Nellimö, Kutumajärvi, 121 a/PV/57. Anal. P. Ojanperä 1958.

	Weight per cent	Norms	
SiO	64.62	Q	25.14
TiO_2	0.39	or	4.01
Al_2O_3	14.15	ab	26.90
Fe_2O_3	2.22	an	22.34
FeO	4.70	en } Di	1.48
MnO	0.11	fs } Di	1.29
MgO	2.93	wo } Di	2.86
CaO	6.07	en	5.81
Na_2O	3.18	fs	5.05
K_2O	0.68	mt	3.22
P_2O_5	0.11	il	0.74
CO_2	0.04	ap	0.27
H_2O^+	0.44	cc	0.09
H_2O^-	0.06		
	99.70	fem	20.81

	Mode	Niggli values	
Quartz	28.3	al	29.3
Plagioclase	52.7	fm	35.4
Hypersthene	1.1	c	22.9
Hornblende	14.8	alk	12.4
Biotite	2.5		
Chlorite	+	si	227.4
Accessories	0.6	ti	1.0
	100.0	p	0.17
		h	5.8
An	38	co_2	0.19
Color index	19.0	k	0.12
		mg	0.43
		qz	+77.8

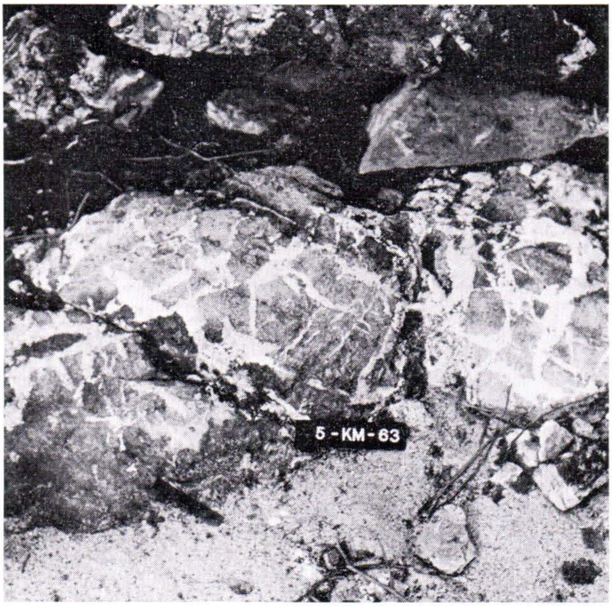

Fig. 39. Basic dyke brecciated by scapolite veinlets. Inarijärvi, Lusmasaari. Photo K. Meriläinen.

The Lusmasaari basic dyke

The supracrustal rocks on the southern shore of the island Lusmasaari are cut by a basic dyke 10 to 15 m wide that runs at low angles to the general trend of their foliation. The same rock is also exposed on a small islet near Lusmasaari.

The bulk of the dyke is composed of coarse-grained (Ø = 2—10 cm), greenish grey diopside as the major mineral and dark green amphibole. Diopside and amphibole occur as areas that are parallel to the dyke and have sharp contacts with each other. Amphibole exhibits a serrated structure towards diopside just as the core quartz in some granitic pegmatites does towards the marginal feldspar. Coarse-grained mica (phlogopite) is occasionally intergrown with diopside and amphibole. Carbonate rock occurs as accumulations 30 to 200 cm wide that contain chlorite pseudomorphs after chondrodite. Scapolite (marialite) is also encountered as occasional aggregates or single grains between the diopside crystals. The southern edge of the dyke is composed of dark green gabbro with zoned plagioclase (An_{30-45}), diopside and dark, brownish green hornblende. Accessories are opaques, apatite and zeolites (in the gabbro of the marginal zone).

On the southern shores of the islands Lusmasaari and Kaamassaari, narrow diopside-, amphibole- and scpolite-bearing veins cut, penetrate and brecciate the supracrustal country rocks (Fig. 39). These veins were probably formed simultaneously with the basic dyke at Lusmasaari.

The southwestern marginal zone of the granulite complex

The southwestern marginal zone is a belt, 5 to 10 km wide, between the granulite complex proper and the West Inari schist zone. At several localities it is separated from the granulite complex proper by fracture and fault zones. In other places the rocks of the marginal zone grade into those of the granulite complex proper for a short distance, and the rocks of similar origin and composition differ from each other only in their mineral compositions, which reflect the variations in the conditions of metamorphism. The boundary between the southwestern marginal zone and the arkose gneisses in the West Inari schist zone is poorly exposed owing to the overlying swamp and Quarternary deposits. In the description of rock types, the western boundary of the southwestern marginal zone has been considered to coincide with the eastern boundary of the arkose gneiss zone.

The southwestern marginal zone of the granulite complex is composed of supracrustal rocks (quartz-feldspar gneisses, biotite gneisses, hornblende gneisses and amphibolites) and infracrustal rocks (ultrabasic rocks, gabbros, diorites, quartz diorites and potash granites). The infracrustal rocks exhibit concordant contacts with the supracrustal rocks. Both rock types are cut by concordant and discordant granitic veins that in some places are coarsely pegmatitic.

Near the granulite complex proper the quartz-feldspar gneisses, amphibolites and hornblende gneisses as well as some biotite gneisses form a group of interbedded banded rocks known as the sedimentary-volcanic group. In many places the rocks of this group were metamorphosed under the conditions of the granulite facies but have still preserved their primary banded structure. The supracrustal rocks in the northeastern marginal zone of the granulite complex and the Apukasjärvi, Vätsäri and Kuorboaivi schist zones also sometimes occur as a similar but less well-defined sedimentary-volcanic group.

Supracrustal rocks

The supracrustal rocks in the southwestern marginal zone of the granulite complex consist of quartz-feldspar gneisses, biotite gneisses, amphibolites and hornblende gneisses. They often contain garnet, and the hornblende gneisses may have hypersthene in addition to garnet. The supracrustal rocks were metamorphosed under the conditions of the amphibolite facies although locally granulite facies conditions also prevailed.

Quartz-feldspar gneisses

Quartz-feldspar gneisses occur in the amphibolites and hornblende gneisses adjacent to the granulite complex proper as layers and bands ranging from a few millimetres to several metres in thickness (sedimentary-volcanic group). In places the quartz-feldspar gneisses predominate over amphibolite, so that in the head-

Table 31
Mineralogical composition of quartz-feldspar gneisses.

	1	2	3	4	5	6	7
Quartz	32.8	32.9	39.8	44.9	46.0	49.8	51.0
K-feldspar	34.9	15.8	—	—	—	—	—
Plagioclase	29.0	47.5	51.8	43.9	49.9	46.5	44.5
Biotite	2.3	+	—	—	—	—	+
Hornblende	—	—	1.2	9.5	—	2.9	—
Hypersthene	—	2.2	3.3	—	—	—	+
Garnet	1.0	—	0.5	0.4	—	—	1.6
Accessories	+	1.6	3.4	1.3	4.1	0.4	2.9
An	25	25	45	nd	30	23	34

1. Inari, Koierivaara, 78 a/PV/57.
2. Inari, Appisjoki, 47/KM/57.
3. Inari, Vaskojoki, 68/KM/58.
4. Inari, Vaijoki, 109/KM/56.
5. Inari, Kolshanoaivi, 77/KM/58.
6. Inari, Appisjoki, 39/KM/57.
7. Inari, Saddehjavritshobma, 61/KM/58.

waters of the river Vaijoki and between Repojoki and Kuttura, for instance, they attain a width of several tens of metres.

The quartz-feldspar gneisses are grey, fine-grained (Ø = 0.2—1 mm) and distinctly foliated rocks. Their texture is granoblastic or blastoclastic. Plagioclase (An_{25-45}) and quartz are the predominant minerals, in addition to which there are often either one or several of the following: hornblende, hypersthene, garnet (almandine, $n' = 1.795$) and biotite. With an increase in the abundance of hornblende and/or hypersthene, the quartz-feldspar gneisses grade into hornblende gneisses and hypersthene gneisses. Potash feldspar is rare or absent. Opaques, titanite, apatite and zircon are the accessories (Table 31).

Except for the paucity of potash feldspar the quartz-feldspar gneisses in the southwestern marginal zone of the granulite complex are similar to the corresponding rocks in the northeastern marginal zone (Table 27).

The quartz-feldspar gneisses were derived from arkose sands and greywackes. They were deposited simultaneously with volcanic activity and, as can be inferred from the abundance of hornblende and the occurrence of amphibolite- and hornblende gneiss bands, they have been intermixed with volcanic ash and perhaps also with weathering products from volcanic rocks. In this respect they resemble the quartz-feldspar gneisses in the northeastern marginal zone of the granulite complex.

Biotite gneisses

Biotite gneisses abound in the structurally complicated synclinorium between Vaskojoki and Repojoki. These rocks contain local amphibolite layers and are often hornblende-bearing. In the area between Vaskojoki and the granulite complex proper,

Table 32
Mineralogical composition of mica gneisses.

	1	2	3
Quartz	33.7	36.7	47.0
K-feldspar	0.5	17.8	+
Plagioclase	45.4	22.0	32.7
Biotite	9.5	9.7	14.8
Muscovite	3.6	—	—
Chlorite	1.2	—	1.3
Hornblende	2.2	—	—
Hypersthene	—	2.0	—
Garnet	1.5	11.2	2.0
Accessories	2.4	0.6	2.2
An	32	nd	32

1. Inari, Puskujärvi, 68/KM/56.
2. Inari, Ruittuavdshi, 104/KM/56.
3. Inari, Puskujoki, 173/KM/60.

biotite gneisses are encountered immediately southeast of the amphibolites and as intercalations in amphibolites and quartz-feldspar gneisses adjacent to the boundary of the granulite complex proper.

The biotite gneisses are grey, moderately foliated and fine-grained (Ø = 0.2—2 mm) rocks with granoblastic texture and cut by granite veins. Main minerals are quartz, plagioclase (An_{32}) and biotite, the latter often as much as to 10 to 15 percent. In addition, the rocks frequently contain garnet (almandine, $n' = 1.796$) and one or more of the following minerals: hornblende, muscovite and hypersthene. Epidote, chlorite and sericite are alteration products, with opaques, graphite, titanite and apatite as accessories (Table 32).

The mineral composition suggests that the bulk of the biotite gneisses were primarily greywackes, although some of the varieties richest in biotite might even have been shales. They were deposited simultaneously with volcanic activity under conditions similar to those prevailing in the northeastern marginal zone of the granulite complex.

Hornblende gneisses

Towards the edge of the granulite complex proper the amphibolites grade into a zone displaying randomly alternating beds and bands of variable thickness composed of amphibolite, hornblende gneiss, quartz-feldspar gneiss and locally biotite gneiss. This zone of varying supracrustal rocks (sedimentary-volcanic group) can be traced for the whole length of the southwestern edges of the granulite complex on Finnish territory. Similar narrow zones have been found locally also inside the granulite complex proper (Fig. 40).

Fig. 40. Mutually interlayered quartz-feldspar gneiss, hornblende gneiss and amphibolite near mouth of river Appisjoki on Ivalojoki. Photo K. Meriläinen.

In their main features, the hornblende gneisses resemble the corresponding rocks in the Apukasjärvi, Vätsäri and Kuorboaivi schist zone and the northeastern marginal zone of the granulite complex. Their colour depends on the abundance of dark minerals (grey, greyish green, green or brown).

The hornblende gneisses are fine- to medium-grained (Ø = 0.2—2 mm) rocks with granoblastic texture. Main minerals are hornblende, plagioclase (An_{30-50}) and quartz, with minor amounts of biotite and hypersthene and/or garnet. In some places diopside and epidote abound, and less frequently scapolite and carbonates, in which case the rock is calc-silicate gneiss. Titanite, apatite, graphite and opaques occur as accessories, the first two being more common than in the other supracrustal rocks of the marginal zone.

Adjacent to and south of the Vaskojoki anorthosite the banded hornblende gneiss-bearing zone, the sedimentary-volcanic group, is well exposed in only a few outcrops. North of Karigasniemi on both sides of the river Tenojoki, this same banded rock type is well preserved, although metamorphosed under the conditions of the granulite facies. The best exposures are visible in fresh road cuts on the Norwegian side of the border. Darker and lighter bands, due to the variation in the pyroxene content, often alternate in the rock. Plagioclase (An_{40-80}) and hypersthene are the predominant minerals in the pyroxene-bearing bands. The rock also contains quartz, and locally potash feldspar, garnet or clinopyroxene and often abundant opaques (magnetite). The amount of hypersthene varies greatly: in some bands it accounts for more than 50 percent of the minerals, whereas in others it hardly exceeds 10 percent. Usually the bands in which hypersthene is scarce are relatively richer in quartz and biotite than are those in which it is abundant. Pyroxene is locally either partially or totally replaced by hornblende. These bands rich in hornblende often contain as much as 20 to 50 percent garnet. Similar pyroxene gneisses have also been encountered in the granulite complex proper at Vollivaara between Ivalo and Nellimö.

The hornblende gneisses with associated hypersthene gneisses were primarily tuffaceous sediments, and the graphite content of the calc-silicate gneisses may indicate an organic origin for the carbonates.

Amphibolites

Amphibolites are found as an almost uninterrupted band up to a few hundred metres wide in the southwestern marginal zone of the granulite complex bordering the Vaskojoki anorthosite. They also abound in the headwaters of the rivers Postijoki and Lemmenjoki. Furthermore, they alternate with quartz-feldspar gneisses, hornblende gneisses and biotite gneisses as bands and beds between the amphibolite zone and the granulite complex proper.

In general, the amphibolites are dark green, fine-grained (Ø = 0.2—1 mm) and slightly banded rocks. In places, however, they are coarser (Ø = 2—3 mm) and more homogeneous resembling foliated gabbros (gabbro-amphibolite). Both varieties show prominent or even intensive foliation. The texture of the amphibolites is grano- or nematoblastic. Their main minerals are hornblende and plagioclase (An_{40-55}), with the hornblende usually predominating. These rocks also frequently contain garnet, hypersthene, diopside or biotite. Some pale bands are rich in diopside or epidote. Opaques, apatite and titanite are the accessories (Table 41).

The amphibolites were probable volcanogeneous rocks that were metamorphosed largely under the conditions of the amphibolite facies. The gabbroic varieties (gabbro-amphibolites) may, however, be amphibolitised sills.

Infracrustal rocks

The infracrustal rocks in the southwestern marginal zone of the granulite complex comprise ultrabasic rocks, gabbros, diorites, quartz diorites and potash granites concordant to the supracrustal rocks. The potash granites excepted, they were probably emplaced simultaneously with the gabbro massifs and ultrabasic rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones.

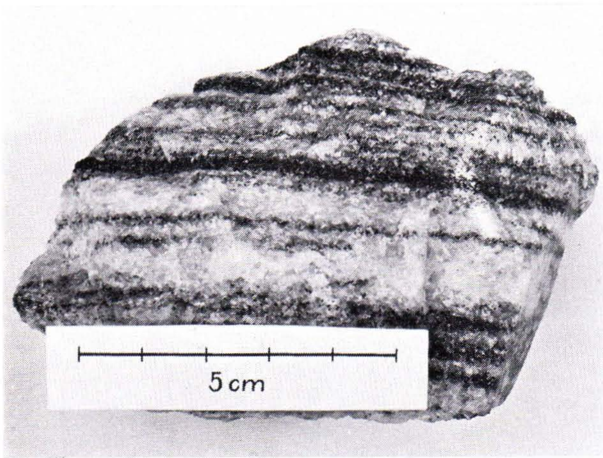

Fig. 41. Gneissose, banded anorthosite. Inari, southwest of Pyhäjärvi. Photo E. Halme.

Ultrabasic rocks

With the exception of the extensive Vaskojoki anorthosite massif, which covers c. 250 km^2, the ultrabasic rocks are small bodies or lenses probably not more than a few hundred metres in length. Their mineral compositions correspond to those of anorthosites, peridotites, hornblendites and serpentinites.

The *peridotites* are massive or slightly foliated rocks with a brown weathering crust. They are composed mainly of olivine and hypersthene. Spinel (green hercynite), fibrous serpentine and opaques (usually magnetite) are also encountered. There may be as much as several percent of magnetite.

The *hornblendites* are dark green hornblende rocks that have been observed at only one site, north of the lake Lemmenjärvi on the banks of the river Lemmenjoki.

In the southwestern marginal zone there are three *anorthosite* occurrences: at Vaskojoki, Karigasniemi and Sallisuo. The major part of the Vaskojoki anorthosite is a white or grey, even-grained (Ø = 2—3 mm) rock that is occasionally porphyritic. It shows slight to moderate foliation, and is often gneissose (Fig. 41) as a result of hornblende-bearing streaks. The hornblende content is most conspicous at the margins. Hornblende gneiss and amphibolite also occur as bands (Fig. 42) and large lenses. The southwestern edge of the massif is gabbroidic and rich in hornblende. On the southern margin some cavities filled with scapolite have been found.

The texture of the Vaskojoki anorthosite is hypidiomorphic with plagioclase as the dominant mineral. Plagioclase is frequently zoned with a core of bytownite (An_{70-80}) or occasionally even anorthite (An_{95}) and a rim of anorthite (An_{70-50}). The abundances of dark minerals in the rock are about 5 to 10 % hornblende

Fig. 42. Amphibolite bands in anorthosite. Inari, Vaskojoki. Photo K. Meriläinen.

(γ = brownish green, > α = yellowish green, c/γ = 14—18°, 2Vα = 70—75 ± 5°), couple per cent augite (c/γ = 42—49°, 2Vγ = 55—60 ± 5°) and minor hypersthene (α = reddish, γ = bluish, 2Vα = 65 + 5°) or garnet (almandine). Apatite opaques, epidote and occasional zircon and titanite are the accessories (Table 33).

Table 33
Mineralogical composition of anorthosites.

	1	2	3
Plagioclase	92.7	84.8	87.2
Hornblende	5.4	13.8	7.3
Augite	1.2	0.9	5.0
Hypersthene	0.7	—	—
Epidote	—	+	0.3
Garnet	—	0.2	—
Accessories	+	0.3	0.2
An	80	80	95
Color index	7.3	15.2	12.8

1. Inari, Kettuoja, 16/KM/56.
2. Inari, Suuri Iivananjärvi, 206/Tyni/58.
3. Inari, Loddipelvaara, 89/KM/58.

Table 34
Chemical composition of anorthosite.
Inari, Siuttavaara, 166/MT/58. Anal. P. Ojanperä 1963.

	Weight per cent	Norms	
SiO_2	50.38	Q	—
TiO_2	0.09	or	1.06
Al_2O_3	30.94	ab	28.56
Fe_2O_3	0.31	an	68.64
FeO	0.32	c	—
MnO	0.01		
MgO	0.14	en } Di	0.35
CaO	13.99	fs } Di	0.18
Na_2O	3.38	wo } Di	0.30
K_2O	0.18	mt	0.44
P_2O_5	0.02	il	0.17
CO_2	0.00	ap	0.03
H_2O^+	0.27		
H_2O^-	0.07	fem	1.44
SrO	0.05		
	100.15		

	Mode	Niggli values	
Plagioclase	97.0	al	48.82
Hornblende	2.0	fm	1.90
Accessories	1.0	c	40.21
	100.0	alk	9.07
An	70	si	135.15
		ti	1.77
Color index	3	p	0.16
		h	2.41
		k	0.03
		mg	0.30
		qz	—1.13

The average chemical composition of the Vaskojoki anorthosite massif is somewhat higher in iron and magnesium than is that of the analysed sample (Table 34), since it contains more hornblende than the latter. Even so, the Vaskojoki anorthosite is distinctly poorer in iron and magnesium and richer in calcium than are some other anorthosites, e.g. those in the Adirondacks, South Norway (see Turner & Verhoogen 1960) or in the Kemi area, North Finland (see Härme 1949). The Vaskojoki anorthosite probable contains more plagioclase than do the above rocks.

Megascopically and in mineral composition the anorthosites at Karigasniemi, Sallisuo and even at Mutajärvi (one of infracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones) are similar to the anorthosite at Vaskojoki. The anorthosite at Karigasniemi is cut by numerous scapolite veins (Ø = 1—30 mm).

Gabbros

The gabbros are medium-grained (2—4 mm), slightly to moderately foliated rocks and dark green or brownish in colour if they contain hypersthene. In places gabbros grade into quartz diorites and sometimes even into diorites. At Sallitunturi, in the headwaters of the river Lemmenjoki, gabbros and quartz diorites alternate in thick layers conformable to the foliation. The gabbros also contain amphibolite as schlieren and bands.

The texture of the gabbros is hypidiomorphic or hypidiomorphic-granular. Megascopically they sometimes appear to be cataclastic, although microscopically the texture is hypidiomorphic-granular. Some of the plagioclase grains are bent, but the groundmass between the large grains is hypidiomorphic. The cataclastic varieties were presumably recrystallised during granulitisation.

On the basis of their mineral composition, the gabbros are quartz gabbros, which can be subdivided even megascopically into various types exhibiting distinct variations in the mutual abundances of quartz, garnet and dark minerals. Plagioclase (An_{40-60}), quartz, hornblende (γ' = dark green > α' = yellowish, $c \Lambda \gamma = 10—14°$, $2V\alpha = 65 \pm 5°$), augite ($c \Lambda \gamma = 40—42°$, $2V\gamma = 54 \pm 5°$) and hypersthene (γ' = red, α' = bluish grey, $2V\alpha = 56 \pm 5°$) are the main minerals. Plagioclase is zoned and hornblende occurs as intergrowths in association with hypersthene. In addition to the above minerals, the quartz gabbros occasionally contain garnet and biotite. The colour index is about 30 to 40 (Table 35). Macroscopically it is often difficult to distinguish between quartz gabbros and quartz diorites because both rock types often contain about 30 percent dark minerals. They differ markedly in chemical composition, because the quartz gabbros have higher Feo + Fe_2O_3, MgO and CaO contents and lower SiO_2 contents than the quartz diorites (Tables 24 and 36).

Table 35
Mineralogical composition of quartz gabbros.

	1	2
Quartz	20.7	21.3
Plagioclase	47.6	41.5
Hypersthene	13.7	1.1
Augite	8.8	0.8
Hornblende	7.9	29.6
Garnet	—	5.0
Accessories	1.3	0.7
An	57	60
Color index	31.7	37.2

1. Inari, Sallitunturi, 85/KM/55.
2. Inari, Miessijoki, 189/KM/60.

Table 36
Chemical composition of quartz gabbro. Inari, Sallitunturi, 85/KM/55.
Anal. P. Ojanperä 1956.

	Weight per cent	Norms	
SiO_2	58.94	Q	18.44
TiO_2	0.56	or	1.50
Al_2O_3	14.68	ab	20.40
Fe_2O_3	2.84	an	28.48
FeO	7.64	c	—
MnO	0.19		
MgO	3.94	en } Di	2.03
CaO	8.02	fs } Di	2.29
Na_2O	2.41	wo } Di	4.37
K_2O	0.25	en	7.78
P_2O_5	0.14	fs	8.81
CO_2	0.00	mt	4.12
H_2O^+	0.38	il	1 06
H_2O^-	0.07	ap	0.33
	100.06	fem	30.79

	Mode	Niggli values	
Quartz	20.7	al	25.2
Plagioclase	47.6	fm	42.5
Hypersthene	13.7	c	25.0
Augite	8.8	alk	7.3
Hornblende	7.9		
Accessories	1.3	si	171.8
	100.0	ti	1.2
		p	0.17
An	57	h	4.4
		k	0.06
Color index	31.7	mg	0.40
		qz	+42.6

Diorites

Diorites occur in association with quartz gabbros and quartz diorites. They are medium-grained (Ø = 2—3 mm), weakly foliated rocks and dark or brownish grey in colour.

According to the mineral composition, the diorites are leuko- or anorthositic diorites. Main minerals are plagioclase and hornblende and there are a few percent of quartz and garnet ($n' = 1.795 \pm 0.003$, almandine-pyrope). Plagioclase is often zoned, the composition varying from oligoclase at the rim to andesine or labradorite in the core. Accessories are opaques and apatite (Table 37); the latter is clearly more abundant in this rock than it is in the quartz diorites. This same relationship has been observed between the diorites and quartz diorites of the granulite complex proper.

Table 37
Mineralogical composition of diorites and quartz diorites.

	1	2	3	4	5
Quartz	1.3	17.3	21.9	24.3	38.4
K-feldspar	—	—	—	—	+
Plagioclase	78.6	55.8	50.9	55.6	51.8
Hornblende	15.5	21.9	21.9	16.1	8.4
Biotite	—	+	1.4	+	—
Garnet	2.6	2.6	3.0	2.2	1.4
Accessories	2.0	2.4	0.9	1.8	+
An	42	40	40	45	40
Color index	20.1	26.9	27.2	20.1	9.8

1. Diorite. Inari, Miessijoki, 29 b/AT/56.
2. Quartz diorite. Inari, Karduvuödi, 115/HN/58.
3. Quartz diorite. Inari, Vaskonkangas, 24/PV/56.
4. Quartz diorite. Inari, Sallitunturi, 83/KM/55.
5. Quartz diorite. Utsjoki, Kaunastaddantatta, 100/PV/59.

Quartz diorites

Quartz diorites are dark or brownish grey, medium-grained (Ø = 2—3 mm) rocks with weak foliation that becomes fairly intensive close to the granulite complex proper. These foliated varieties are difficult to distinguish from the tectonised hornblende gneisses, since they are both garnetiferous.

The texture of the quartz diorites is hypidiomorphic or hypidiomorphic-granular and often also cataclastic. The predominant varieties contain plagioclase (An_{35-45}), hornblende and quartz as main minerals, often also garnet (almandine, $n' = 1.800 \pm 0.002$) and occasionally biotite. Accessories are opaques and apatite. Alteration products are sericite, chlorite, muscovite or epidote (Table 37). Adjacent to the granulite complex proper, the quartz diorites locally contain hypersthene.

The quartz diorites in the southwestern marginal zone of the granulite complex are largely hornblende- or hornblende-garnet-bearing rocks metamorphosed under the conditions of high grade amphibolite facies. Consequently, their mineral composition is distinct from the hypersthene-bearing quartz diorites of the granulite complex proper, which were metamorphosed under the conditions of the granulite facies. There is no such marked difference in mineral composition between the gabbros and more basic infracrustal rocks in the granulite complex proper and those in its southwestern marginal zone, since these all generally contain both hornblende and pyroxene. This suggests that the granulitisation took place under conditions roughly corresponding to the crystallisation temperature of the hypersthene-hornblende gabbros (norites).

Potash granites

Potash granites occur north of Lemmenjärvi in outcrops and large local boulders. They are pinkish, fine- to medium-grained (Ø = 0.5—2 mm), weakly foliated or almost massive rocks with a granoblastic texture. Quartz, potash feldspar and plagioclase (An_{10}) are the predominant constituents. The potash feldspar is cross-hatched, perthitic microcline and occurs in greater abundance than plagioclase. The rocks also contain minor garnet and amphibole with accessories of opaques, titanite and zircon. Potash granites similar to those of Lemmenjärvi occur in the West Inari schist zone on the eastern slope of the Skietshamtunturi fells, in the tectonic window at Kevo and south of Menesjärvi in the granulite complex proper.

Stratigraphy and tectonics of the granulite complex

The primary structures of the sedimentogeneous gneisses in the granulite complex were often destroyed or altered to such an extent when the rocks of the complex were metamorphosed under the conditions of the granulite facies that they are now difficult to interpret. Nevertheless, some large-scale tectonic structures can be established by means of the strike and dip of foliation (bedding) and by the variation exhibited in them.

Foliation and bedding

The foliation in the rocks of the southwestern and northeastern marginal zones of the granulite complex is moderately to well developed, being, however, generally more conspicuous in the former area than in the latter. This is partly because the foliation in the southwestern marginal zone dips more gently and is accentuated by the granulite deformation and partly because the interbedded supracrustal rocks contribute to the impression of distinct foliation. The bedding is commonly parallel to the foliation or conformable with its general trend.

In the area of the granulite complex proper, the foliation is most prominent in the western and southern parts of the complex (Fig. 43), that is, at those sites where the abundance of fine-grained garnet-quartz-feldspar gneisses and garnet-biotite gneisses is greatest. In the areas characterized by coarse-grained garnet-cordierite and garnet-quartz-feldspar gneisses in particular, the foliation is frequently weakly developed and the bedrock, when viewed from a distance, resembles infracrustal rather than supracrustal rocks (Fig. 44). Likewise, the bedding of the rocks has best survived in the western and southern parts of the complex. It is especially marked in those places where the fine-grained garnet-quartz-feldspar gneisses are interbedded with garnet-biotite gneisses. Sometimes the bedding in the former becomes visible owing to the presence of carbonate-bearing bands (Fig. 30). In the garnet-cordierite gneisses the

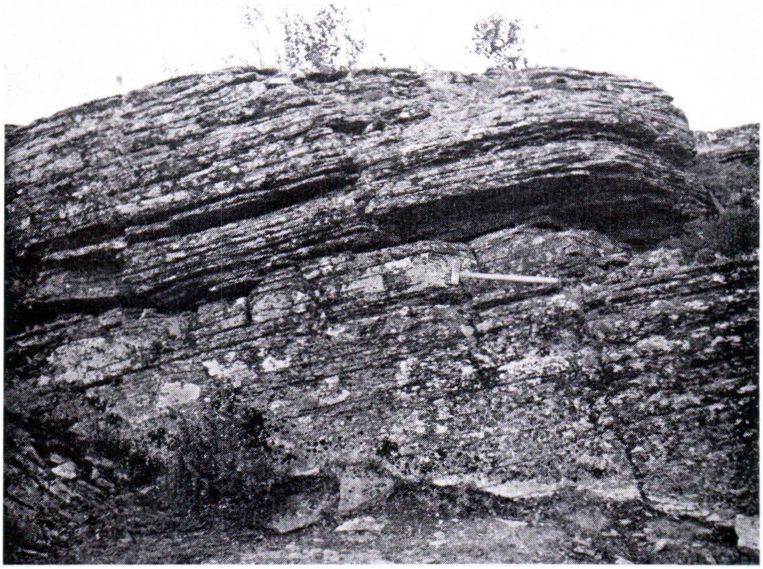

Fig. 43. Highly foliated fine-grained garnet-quartz-feldspar gneiss in western part of granulite complex. Inari, Paltsavaara. Photo K. Meriläinen.

Fig. 44. Weakly foliated coarse-grained garnet-quartz-feldspar gneiss. Inari, Nukkumapää. Photo K. Meriläinen.

bedding is relictic and can be indisputably established only at localities where sedimentogeneous, fine-grained garnet-quartz-feldspar gneisses are more common than usual. The infracrustal rocks in the granulite complex are weakly foliated or gneissose and in the southwestern marginal zone even schistose.

The foliation most often dips E or NE in the area of the granulite complex. At Inarijärvi and southeast of it the foliation, however, usually dips N but also S and SW. A slight variation also exists in the direction of the dip in the headwaters of Kevojoki, east of Karigasniemi. The dip is usually about 10 to 40°, but in extensive areas in the western and inner parts of the complex, the dip is more gentle, i.e. from 0 to 30°. Steep dips (70—90°) are mainly encountered in the eastern and northeastern parts of the granulite complex. On the basis of the variation in the dip, some tectonic macroblocks can be delineated (Figs. 15 and 16).

Stratigraphy

No basal conglomerates have been discovered in the area of the granulite complex to distinguish its supracrustal rocks or rock groups from each other. Consequently, the stratigraphical sequence of the supracrustal rocks has been established on the basis of rock associations, tectonic structures and radiometric datings. The stratigraphy of the rocks is particularly complicated in the northeastern part of the complex, at Inarijärvi and southeast and northwest of it, because intense vertical movements following granulitisation have uplifted the granulite complex proper probably for several kilometres relative to the granite gneiss complex. This can be deduced from the fact that the rocks of the granite gneiss complex were metamorphosed under the conditions of the amphibolite facies whereas those of the granulite complex were metamorphosed mainly under the conditions of the granulite facies.

The supracrustal gneisses in the northeastern marginal zone of the complex are invariably associated with the supracrustal rocks of the Kuorboaivi schist zone at Syysjärvi and are presumably of the same age, i.e. Prekarelian. Further deformation took place during the Karelian orogeny accompanied by the simultaneous intrusion or development of Karelian infracrustal rocks.

The boundary between the northeastern marginal zone of the granulite complex and the granite gneiss complex is emphasized not only by the strong aeromagnetic anomaly but also by the quartzites encountered on the islands of Kaamassaari and Lusmasaari and elsewhere in the northeastern marginal zone of the complex. Despite the fact that these quartzites are seldom more than twenty metres thick they still indicate quite clearly that the quartzites as well as the overlying quartz-feldspar gneisses, hornblende gneisses, amphibolites and various types of mica gneisses form a group of sedimentogeneous and volcanogeneous rocks that are younger than the rocks of the granite gneiss complex. They were presumably deposited on the rocks of the granite gneiss complex discordantly, although they too may be of Prekarelian age. In the northeastern marginal zone of the granulite complex the stratigraphic sequence of these rocks from bottom to top is as follows: quartzites and quartz-feldspar gneisses, amphibolites, hornblende gneisses and amphibolites interbedded with quartz-feldspar gneisses and mica gneisses (the sedimentary-volcanic group), and finally biotite gneisses, which probably occupy a stratigraphic position analogous to that of the fine-grained garnet-quartz-feldspar gneisses (greywackes and sub-greywackes) and garnet-biotite gneisses (argillaceous rocks) of the granulite complex proper.

As indicated previously, the supracrustal rocks characteristic of the northeastern marginal zone are similar to those in the southwestern marginal zone of the granulite complex, whose a stratigraphic sequence from bottom to top is as follows: arkose gneisses (on the western border of the zone) and locally some thin quartzite beds, amphibolites, hornblende gneisses, biotite gneisses and amphibolites interbedded with quartz-feldspar gneisses (the sedimentary-volcanic group). At the top are fine-grained garnet-quartz-feldspar gneisses and garnet-biotite gneisses, the sedimentary group of the granulite complex proper.

Fine-grained garnet-quartz-feldspar gneisses, garnet-biotite gneisses and to a lesser extent also garnet-biotite-plagioclase gneisses form a group of stratigraphically youngest sedimentogeneous gneisses (the sedimentary group) in the western and southern parts of the granulite complex proper. Occasionally, however, they are abundant in the central parts of the complex (the Saariselkä area, Hammastunturit, Nuovakkapää, Palloaivi and some parts of the fells Muotkatunturit and Paistunturi and are even found at its eastern end (Karipää, Rautapää, Kurupää). The eastern and central parts of the complex are largely occupied by coarse-grained garnet-quartz-feldspar gneisses and garnet-cordierite gneisses formed as a result of granulitisation from the gneisses of the sedimentary and sedimentary-volcanic groups of the granulite complex or from the rocks of the granite gneiss complex. Garnet gneisses derived from rocks of the granite gneiss complex occur in the cores of large anticlines and anticlinoriums in particular, in the areas of Paistunturit, Muotkatunturit, Appistunturit and Hammastunturit, as well as at Inarijärvi and northwest and southeast of it.

Folding and metamorphism

The oldest infra- and supracrustal rock of the granulite complex were uplifted, or metamorphosed probably together with the rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and the West Inari schist zone under the conditions of the amphibolite facies about 2 500 Ma ago. According to the zircon ages and the Rb-Sr method, the rocks of the granulite complex proper were later uplifted, or folded and metamorphosed under the conditions of the granulite facies about 2 150 Ma ago, and metamorphosed once again diaphthoretically under the conditions of a low-grade granulite facies and a high-grade amphibolite facies 1 900 Ma ago.

During the granulitisation process, the supracrustal rocks of the complex were metamorphosed under the conditions of a high temperature granulite facies into various types of garnet gneisses. The infracrustal rocks (quartz gabbros, diorites, quartz diorites) altered into hypersthene-bearing varieties that locally contain garnet. However, within the marginal zone of the complex, metamorphism took place mainly under the conditions of the amphibolite facies. Hence, the infracrustal rocks frequently contain amphibole and often garnets as well.

Despite the intense metamorphism primary structural features are sometimes preserved in the garnet gneisses. Thus, fine-grained garnet-quartz-feldspar gneisses exhibit relict bedding and clastic (blastoclastic) structure, which indicates that the metamorphism took place under compression without significant shearing. Large platy quartz crystals were recrystallised from several small grains, but even so, garnet gneisses generated by shearing are more characteristic of the granulite complex proper. The fine-grained garnet-quartz-feldspar gneisses are the rocks of the granulite facies that have best avoided diaphthoretic metamorphism, which is why their zircons (c. 2 140 Ma) are clearly older than the zircons of the garnet-cordierite gneisses (2 000—2 040 Ma) that underwent intense diaphthoretic metamorphism.

The studies on the rocks by the whole rock common lead method and on their potash feldspars by the common lead method clarify the processes that took place during granulitisation in the granulite complex proper, in its rocks and rock groups. Thus, the narrow isochron given by the whole rock common lead method and its position in the diagram (Fig. 50) indicate that some uranium has left the system. The increase in radiogenic lead is distinctly smaller than in the other rocks of the isochrons in the diagram. The fact that the potash feldspars from the rocks of the granulite complex fall within a narrow area in the diagram suggests that lead was strongly homogenized also between the rock units.

During the diaphthoretic stage most of the rocks of the granulite complex were remetamorphosed at high pressure and temperature, i.e. under the conditions of low-grade granulite facies and high-grade amphibolite facies. The garnet in the garnet gneisses was locally altered into cordierite at the same time as the biotite was recrystallised. The grains of cordierite and potash feldspar often grew into porphyroblasts. However, it is unlikely that all the garnet-cordierite gneisses were formed during the diaphthoretic deformation. It is worth noting that, during that event in particular, metamorphism was accompanied by shearing but that the final recrystallisation took place only under compression. Otherwise neither the intrusion of the country rocks by the anatectic veins nor the commonly unoriented massive structure of those veins still be visible. This would also seem to be the only explanation for the crystallisation and survival of cordierite under the conditions of the granulite facies.

During the diaphthoretic stage, axial plane foliation developed locally in the fine-grained garnet-quartz-feldspar gneisses as transverse foliation cutting the bedding (Fig. 45). The reoriented quartz grains are seen as lineations on the plane of schistosity. Moreover, garnets and their aggregates have often been reoriented parallel to this younger foliation (see Sahama 1936). The trend of the foliation produced by the diaphthoretic deformation is NW or WNW. The bedding is seen in some places as a

Fig. 45. Fine-grained garnet-quartz-feldspar gneiss with transversal foliation. Notonly the quartz, but also the garnet crystals and clusters often conform to the new foliation. Inari, Maunavaara, about 10 km northeast of Vasko-joki anorthosite. Photo K. Meriläinen.

N or NE trending lineation on this younger plane of foliation, e.g. on Muotka-tunturit. During the diaphthoretic stage anatectic veins cut the garnet gneisses.

Zircon dating indicates that the granulite complex was penetrated by the Vuoskul-järvi postgranulitic scapolite quartz diorite towards the end of or soon after the diaphthoretic stage, i.e. about 1900 Ma ago. This rock is completely ungranulitised and exhibits only slight foliation. Later, about 1 730 Ma ago, the complex was cut by the postorogenic granites of Nattanen and Juvoaivi as well as by dykes of quartz syenite porphyry and olivine diabase, none of which display any obvious signs of deformation.

THE WEST INARI SCHIST ZONE

The West Inari schist zone, which trends northwards between the granulite complex and the Hetta granite massif, is a fork of the schist area of Central and East Lapland. The supracrustal rocks of the West Inari schist zone are composed of quartzites, arkose gneisses, mica gneisses and schists, hornblende gneisses, amphibolites and green schists. The infracrustal rocks comprise ultrabasic rocks, gabbros, quartz diorites and granites.

The supracrustal rocks (of the West Inari schist zone) form three conformable zones with distinct rock types: 1) a zone of arkose gneisses along the eastern border of the schist zone, 2) the Peltotunturi zone with abundant quartzites and green schists along the western border of the schist zone (see Mikkola 1941), and 3) a wide amphibolite zone between zones 1) and 2). The zones grade into one another and locally contain rocks characteristic of the adjacent zone. The transitional zones are composed of quartzites and hornblende gneisses. The supracrustal rocks are frequently cut by granite veins or veinlets mainly parallel to the foliation, the widest of which, the coarse-grained pegmatites, are several metres, even twenty metres wide. Veined gneisses are rare. Granite veins are more sparse in the amphibolites and green schists than they are in the other supracrustal rocks. The amphibolites include a few diabase-like variants, whose relation to the environment, however, has not been established. Petrologically they are analogous to the diabases in the granite gneiss complex.

Supracrustal rocks

The supracrustal rocks are arkose gneisses, quartzites, mica gneisses or schists, green schists, amphibolites and hornblende gneisses. They were metamorphosed mainly under the conditions of the amphibolite facies although occasionally also under those of the epidote-albite-amphibolite and green schist facies, as for example on the Peltotunturi zone.

Arkose gneisses

An arkose gneiss zone 5 to 15 km wide can be traced along the southwestern marginal zone of the granulite complex. South of the river Ivalojoki it bifurcates. One fork following the border of the granulite complex eastwards and north of Korvatunturi into Soviet territory and the other fork running southwards to northwest of the village of Sodankylä.

The arkose gneisses are distinctly foliated, fine- to medium-grained (Ø = 0.5 to 2 mm) rocks, brownish red, reddish grey or greyish brown in colour. Observations made by the present author indicate that the »banded and mylonitic granite gneiss» in the northern parts of Sodankylä (Mikkola 1941) is arkose gneiss.

The texture of the arkose gneisses is frequently grano- or blastoclastic, although some of the less metamorphosed types are clastic and beautifully layered (Fig. 46). Quartz (25 to 35 percent), potash feldspar (20 to 50 percent) and plagioclase (An_{10-30}) are the major minerals. The arkose gneisses most deficient in potash feldspar are the varieties in association with amphibolites, hornblende gneisses and biotite gneisses that are distinguished from the majority of the arkose gneisses, by their grey color. In addition to the above minerals, these rocks often contain a few percent of bluish green hornblende ($c \Lambda \gamma = 7—14°$, $\gamma' =$ blue green $> \alpha' =$ yellowish), diopside or biotite as well as occasional garnet or epidote. Opaques, titanite and apatite are accessories (Table 38).

Fig. 46. Bedded, clastic arkose gneiss on banks of river Repojoki, south of Lemmenjänkä. Inari, Repojoki. Photo K. Meriläinen.

The chemical composition of the arkose gneisses corresponds to that of arkoses, as is manifested in the analytical data by the high abundances of SiO_2 and Na_2O + K_2O, and the low abundances of MgO, FeO and CaO (Table 39). The arkoses were deposited simultaneously with volcanic activity, which is emphasized by the local

Table 38
Mineralogical composition of arkose gneisses.

	1	2	3	4	5	6	7	8
Quartz	37.5	34.6	33.3	33.1	30.7	27.7	27.4	23.5
K-feldspar	19.3	25.2	25.5	40.3	18.1	22.8	40.9	51.6
Plagioclase	32.8	37.0	29.0	23.4	40.6	41.5	22.1	20.3
Biotite	—	1.6	7.5	—	—	7.7	0.4	—
Sericite	1.4	—	—	—	—	—	—	—
Hornblende	—	0.8	—	1.4	7.0	—	8.7	2.8
Epidote	—	0.3	—	—	1.9	—	—	—
Garnet	+	—	1.5	—	—	—	—	—
Accessories	3.4	0.5	3.0	1.3	1.7	0.3	0.5	1.8
An	16	30	nd	nd	28	18	10	nd

1. Inari, Peltotunturi, 28 b/KM/55.
2. Inari, Vaskojärvi, 63 c/KM/56 (chem. anal. in Table 39).
3. Inari, Vaskojärvi, 63 e/KM/56 (chem. anal. in Table 39).
4. Inari, Vaskojärvi, 63 d/KM/56.
5. Inari, Naukusselkä, 57/KM/55.
6. Inari, Repojoki, 79/KM/55.
7. Inari, Verdiselkä, 89/KM/55.
8. Inari, Kotaoja, 26 a/AT/56.

Table 39
Chemical composition of arkose gneisses.

	Weight per cent			Norms	
	1	2		1	2
SiO_2	72.46	76.50	Q	37.80	36.75
TiO_2	0.32	0.12	or	23.38	22.99
Al_2O_3	11.35	12.52	ab	24.97	33.83
Fe_2O_3	1.62	1.00	an	0.83	2.50
FeO	2.94	0.78	c	1.91	0.82
MnO	0.09	0.05			
MgO	0.21	0.20	en	0.52	0.50
CaO	1.85	0.56	fs	3.71	0.49
Na_2O	2.95	4.00	mt	2.34	1.46
K_2O	3.96	3.89	il	0.61	0.22
P_2O_5	0.04	0.05	ap	0.09	0.11
CO_2	1.29	0.00	cc	2.92	—
H_2O^+	0.72	0.28			
H_2O^-	0.18	0.07	fem	10.19	2.78
	99.98	100.02			

	Mode			Niggli values	
	1	2		1	2
Quartz	34.6	33.3	al	36.9	45.9
Potash feldspar	25.2	25.5	fm	22.5	10.0
Plagioclase	37.0	29.0	c	10.9	3.7
Biotite	1.6	7.5	alk	29.7	39.5
Chlorite	+	—			
Hornblende	0.8	—	si	400.0	475.4
Epidote	0.3	—	ti	1.3	0.56
Garnet	—	1.5	p	0.09	0.13
Accessories	0.5	3.0	h	16.2	7.2
			co_2	9.7	—
An	30	—			
			k	0.47	0.39
Color index	3.2	12.0	mg	0.08	0.17
			qz	+181.2	+217.4

1. Inari, Vaskojoki, 63 c/KM/56. Anal. A. Heikkinen 1957.
2. Inari, Vaskojoki, 63 e/KM/56. Anal. A. Heikkinen 1957.

intercalations of amphibolites and hornblende gneisses in the arkose gneisses. Their hornblende content suggests that the volcanic ash or the weathering products from the volcanic rocks were mixed with arkose sand during the deposition (see Table 38, anal. 5 and 7).

With the exception of their colour and mineral composition, the arkose gneisses bear a certain resemblance to the quartz-feldspar gneisses in the marginal zones of the granulite complex (Tables 27 and 31). The arkose gneisses are generally reddish grey or brownish red and rich in potash feldspar, whereas the quartz-feldspar gneisses are grey and rich in plagioclase. This is probably because on the whole the quartz-feldspar gneisses are more closely associated with the volcanites than are the arkose gneisses. The amount of light minerals is almost the same but the average of quartz is slightly higher in the quartz-feldspar gneisses than in the arkose gneisses. On the other hand, mutual comparison of the arkose gneisses and the quartz-feldspar gneisses in the northeastern marginal zone of the granulite complex in particular shows that the arkose gneisses (arkoses) represent weathering products of rock types whose average potash feldspar content is higher than that of the rocks of the granite gneiss complex immediately east and northeast of the granulite complex.

Quartzites

Quartzites occur as wide zones or intercalations in the green schists and mica schists of the Peltotunturi schist zone. They are also encountered locally along the borders of the amphibolite zones as thin intercalations and bands in the quartz-feldspar gneisses, arkose gneisses and hornblende gneisses. The quartzites on the margins of the amphibolite zones probably form almost continuous layers that are always exposed in those places where outcrops abound (e.g. along river beds).

The quartzites exhibit distinct foliation. They are fine-grained (Ø = 0.2—1 mm), white, grey or greyish brown rocks, and often show microbedding (Fig. 47). Their texture is grano- or blastoclastic and occasionally even clastic. In mineral composition the quartzites are ortho- or arkose quartzites.

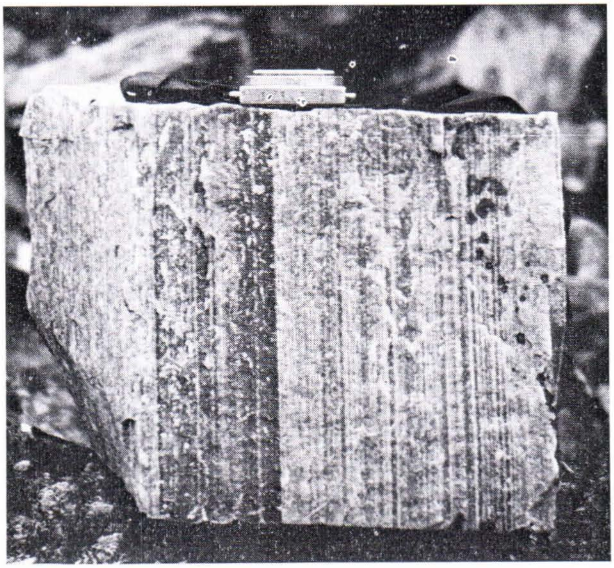

Fig. 47. Fine-grained, blastoclastic, bedded quartzite. Enontekiö, Kortevuoma. Photo K. Meriläinen.

The orthoquartzites are composed predominantly of quartz, with small amounts of plagioclase and potash feldspar. The quartzites in the Peltotunturi schists also contain muscovite and sericite. Opaques, apatite and zircon are the accessories.

Quartz, plagioclase (An_{10-25}) and potash feldspar are the major minerals in the arkose quartzites. Furthermore, the quartzites in the Peltotunturi schists frequently contain muscovite and sericite, and they may pass locally into sericite quartzites and sericite schists. The accessories are carbonate, opaques, apatite, garnet, titanite and, on the borders of the amphibolite zones, often also amphibole and chlorite. The mineral composition of the arkose quartzites locally corresponds to that of the arkose gneisses.

The quartzites are derived from quartz- or feldspar-rich sands, although some of the ones associated with amphibolites and hornblende gneisses may be cherts in origin.

Mica gneisses and mica schists

Mica gneisses and mica schists occur locally in the arkose gneisses as thin layers only slightly richer in mica than are the arkose gneisses themselves. Along the borders of the amphibolite zones and in the Peltotunturi schists thin layers of mica gneisses are interbedded with amphibolites, hornblende gneisses, grey quartz-feldspar gneisses or arkose gneisses, or in the Peltotunturi schists even with green schists and quartzites. On Peltotunturi, mica gneisses have often been replaced by fine-grained and biotite-rich mica schists. The mica schists are also encountered as large inclusions in the eastern part of the Hetta granite.

The mica gneisses are conspicuously foliated rusty rocks, pale or dark grey, sometimes brownish in colour. They are fine- to medium-grained (Ø = 1—2 mm) with granoblastic or nematoblastic texture. Main minerals are plagioclase (An_{10-20}), potash feldspar, quartz and biotite. They often also contain muscovite and occasionally epidote, garnet, carbonate, chlorite or hornblende. Opaques, apatite, titanite, allanite, zircon and sometimes graphite are the accessories (Table 40). In the Peltotunturi mica gneisses, in particular, biotite is partly replaced by muscovite, and in the mica gneisses of the arkose gneiss zone by hornblende. At Peltotunturi garnet-biotite-gneiss has been encountered that resembles the garnet-biotite-gneisses in the granulite complex proper. Marmo has (1960) reported an andalusite-bearing mica gneiss from the eastern part of Peltotunturi.

Mica schists are visibly darker, richer in micas (biotite) and finer-grained than the mica gneisses.

Mica gneisses and schists are largely derived from greywackes. Only the very mica-rich and often garnet-bearing mica gneisses have a composition corresponding to that of micaceous shale. The carbonate-bearing mica gneisses might have been derived from calcareous greywackes and shales, hornblende and/or chlorite-bearing mica gneisses from tuffaceous sedimentary rocks.

Table 40
Mineralogical composition of mica gneisses.

	1	2	3	4	5	6
Quartz	47.1	42.3	39.4	29.3	23.4	10.1
K-feldspar	1.5	7.4	9.2	18.2	—	29.2
Plagioclase	39.8	32.4	34.2	33.4	40.4	29.5
Biotite	8.7	3.8	16.6	12.9	32.1	30.2
Chlorite	—	+	—	—	—	—
Sericite	2.6	8.2	—	—	—	+
Hornblende	—	—	—	—	2.7	—
Epidote	—	—	—	4.6	+	—
Accessories	0.3	5.9	0.6	1.6	1.4	1.0
An	nd	nd	28	nd	33	20

1. Enontekiö, Avisuorajoki, 14/TP/55.
2. Inari, Avisuoratunturi, 35/KM/55.
3. Enontekiö, Peltotunturi, 8 b/RL/55.
4. Inari, Skärrioja, 37 a/KM/55.
5. Inari, Repojoki, 13/KM/61.
6. Enontekiö, Lenkihaka, 22/KM/55.

Hornblende gneisses

Hornblende gneisses interbedded with amphibolites, quartz-feldspar gneisses, arkose gneisses and quartzites, occur along the borders of the amphibolite zones. Some beds and bands, now calc-silicate gneisses, are rich in diopside and/or epidote with occasional carbonates.

The hornblende gneisses are very much the same as those in the marginal zones of the granulite complex and in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones; They are grano- or blastoclastic in texture with plagioclase, quartz and hornblende as major minerals. Furthermore, they often contain biotite, epidote and chlorite, and, especially in the hornblende gneisses in the vicinity of the arkose gneisses, potash feldspar. There is a continuous series of transitional types from arkose gneisses, which frequently contain hornblende, to hornblende gneisses. Hence, it is impossible to draw an exact boundary between the arkose gneisses and the hornblende gneisses (Tables 38 and 7).

The hornblende gneisses are metamorphosed tuffaceous sediments. When the arkose gneiss passes into tuffitic gneiss the relative abundance of plagioclase increases at the expense of potash feldspar in particular. This change in the mineral composition of the deposited material is similar wherever arkositic sandstone deposits derived from granitic bedrock have been overlain and alternately intercalated or mixed with ash and lava of andesitic to basaltic composition. These conditions have also favoured the formation of carbonates, as can be seen from the bands and beds of calc-silicate gneisses following the borders of the amphibolite zones.

Table 41
Mineralogical composition of amphibolites.

	1	2	3	4	5
Diopside	—	3.5	—	2.3	—
Hornblende	62.2	59.8	55.6	52.9	65.4
Plagioclase	36.4	20.0	40.8	43.7	30.7
Epidote	+	+	+	+	+
Chlorite	—	—	+	—	—
Garnet	—	9.7	—	—	—
Accessories	1.4	+	3.6	1.1	3.9
An	nd	40	nd	38	45

1. Inari, Kotaoja, 27/AT/56.
2. Inari, Vaskojoki, Kutusuvanto, 18 b/PV/56.
3. Inari, Kietsimäjoki, 18/RL/55.
4. Inari, Stuorra Poggijävri, 31/PV/56.
5. Utsjoki, Tsharsjoki, 52/FS/59.

Amphibolites

Amphibolites occur not only in the main amphibolite zone of the West Inari schist zone, but also in the Peltotunturi zone and along the edges of the amphibolite zones as intercalations irregularly alternating with other supracrustal rocks. They are also encountered at some localities as beds in arkose gneisses.

The amphibolites show a well-developed foliation. They are banded, fine-grained (Ø = 0.2—1 mm) or medium-grained (Ø = 1—2 mm) rocks, dark or blackish green in colour. Some amphibolites exhibit amygdaloidal structure, the amygdules being filled with ovoidal grains of plagioclase, Ø = 2—3 mm, or with clusters of plagioclase and quartz grains.

The amphibolites are granoblastic in texture with hornblende (c/γ = 17—27°) and plagioclase (An_{25-40}) as main minerals. Plagioclase has frequently been altered into saussurite. In addition to the above minerals, the rocks occasionally contain quartz, garnet and diopside. Opaques, apatite and titanite are the accessories (Table 41).

The majority of the amphibolites are metamorphosed basic (andesitic to basaltic) lavas and tuffaceous rocks. Many amphibolites, especially those that occur as concordant beds in arkose gneisses, are amphibolitised, diabase-like sills or intrusions. Megascopically and in mineral composition they are very similar to the amphibolitised diabases in the granite gneiss complex.

Greenschists

The greenschists, which are mainly restricted to wide zones in the Peltotunturi schists, frequently contain mica schist intercalations and even amphibolite and quartzite beds. They are also encountered in the zones of ultrabasic infracrustal rocks along the margins of the Repojoki amphibolite zone.

The greenschists exhibit conspicuous foliation with signs of strong tectonisation. A fresh surface is greenish or dark green in colour, whereas the weathered surface is often covered with rust. Carbonates and magnetite disseminations are often megascopically visible. Some of the greenschists exhibit amygdaloidal structure, the amygdules being filled with grains of porphyritic plagioclase or clusters of quartz and plagioclase crystals.

The mineral composition of the greenschists varies. The bulk of them are amphibole-chlorite and chlorite schists, which furthermore also contain variable amounts of talc, magnesite, and opaques. The varieties richest in talc and magnesite are amphibole-talc, chlorite-talc, serpentine-talc and talc-magnesite schists. In places the amphibole-chlorite and chlorite schists grade into chlorite-mica schists, with quartz, chlorite and biotite as the predominant constituents. The amphibole in the chlorite-mica and greenschists is commonly colourless or pale green fibrous tremolite. Opaques, titanite and apatite are the accessories.

Greenschists occur regularly in the same areas as peridotites and even in the same bodies with them. Some of the greenschists were presumably formed during the metamorphism of the peridotites, the majority, however, are metamorphosed picritic and tholeitic volcanic rocks. An example of similar, although somewhat less strongly metamorphosed rocks are the greenschists at Kittilä, south of Peltotunturi (see, Mikkola 1941), which have preserved agglomeratic structures and vesicular textures. It is also likely that some of the greenschists are metamorphosed basic sills and tuffaceous sediments.

Infracrustal rocks

The infracrustal rocks in the West Inari schist zone are ultrabasic rocks, gabbros, quartz diorites and granites. They show a concordant boundary with the supracrustal rocks and are locally cut by granite veins. Some of the ultrabasic rocks in the West Inari schist zone have been studied in detail by E. Mikkola and Th. G. Sahama (1936) and V. Marmo (1960).

Ultrabasic rocks

Ultrabasic rocks occur as concordant, oblong or lens-like bodies in the schists of Peltotunturi and along the edges of the Repojoki amphibolite zone. They are often located in fracture zones that appear on maps as ravines, rivers or chains of lakes parallel to the trend of foliation.

In mineral composition the ultrabasic rocks are peridotites, pyroxenites, serpentinites and a diversity of serpentine, chlorite and amphibole rocks, which, in addition to the characteristic minerals, also contain talc and/or magnesite. One intrusive may include several ultrabasic rock types.

Peridotites have a rusty-brown weathering crust; otherwise, they are dark green or brown in colour and massive or foliated. Olivine, hypersthene and serpentine are the predominant minerals with minor amounts of tremolite and chlorite. Opaques, spinel, iddingsite and carbonate are accessories.

Catalysed by the movements, the peridotites have been metamorphosed locally into various kinds of amphibole-chlorite, amphibole-talc-serpentine and chlorite schists, which frequently contain magnesite and occasionally even abundant opaques (magnetite).

Pyroxenites are pale to medium brown, massive or distincly foliated rocks with a hypidiomorphic texture. The interstices between the hypersthene grains often contain small amounts of plagioclase, diopside and tremolite. In some places there are large olivine grains as well as smaller ones that have been totally altered into serpentine. Opaques, apatite and spinel are the accessories.

Serpentinites are dark-green and often clearly foliated rocks with a rusty-brown weathering surface. They are composed chiefly of antigorite and chrysotile although they also contain peridotitic or olivine- and tremolite-bearing bands and accumulations. In these bands the olivine grains form pseudoporphyroblasts that are cut by a network of serpentine, and which accentuate the foliated structure of the rock. The individual olivine grains of the bands show a homoaxial arrangement, which is a clear indication that the serpentine is derived from olivine. Serpentinites, and in places also peridotites, are cut by chrysotile veins that have occasionally developed into asbestos.

Gabbros

Only one gabbro occurrence has been marked on the map, and even that is based on information obtained from old field notebooks. Some amphibolites, which are presumably conformable intrusions or diabase sills, show gabbroic structure.

Quartz diorites

A granite sample taken from the Maunuvaara granite massif (for zircon dating) proved to be quartz diorite. It is a gneissose, medium-grained (Ø = 2—5 mm) rock, grey in colour, which has undergone cataclastic granulation and later recrystallisation. The large, ovoidal plagioclase grains accentuate the gneissose structure of the rock. In addition to the main minerals, plagioclase (An_{30-35}), quartz and biotite, the rock contains some epidote and potash feldspar, with apatite, titanite and muscovite as accessories.

Granites

The granites are grey or pinkish rocks, the pinkish variety being frequently coarse pegmatitic in structure.

Fig. 48. Subhorizontal jointing in Hetta granite. Jointing is conformable with foliation of gneisses in area. Enontekiö, Tsuukisoja. Photo K. Meriläinen.

The grey granite is represented by the Hetta granite (see E. Mikkola 1938, Matisto 1969), which occupies a large and partly migmatic area bordering the Inari schist zone in the west. Granites of this type are also encountered in the Maunuvaara massif along the middle course of the river Repojoki, locally in the Peltotunturi schists, as boulders southwest of Maunuvaara and in an exposure near the mouth of the river Postijoki.

The Hetta granite is a grey or brownish grey, medium-grained (Ø = 1—4 mm) rock with a slightly porphyritic and incipiently foliated or massive structure. At and around Tsuukisvaara the rock exhibits strong, gently sloping and intensive jointing that locally resembles foliation (Fig. 48). This jointing coincides in many places with the gently dipping foliation whose dip seldom attains values as high as 30°. In the vicinity of the river Käkkälöjoki, the granite is occasionally pinkish and contains large, lens-shaped mica schist xenoliths that grade into the granite. This pinkish granite is rich in potash feldspar.

The Hetta granite has a hypidiomorphic or hypidiomorphic-granular texture with plagioclase (An_{20-35}), potash feldspar and quartz as major minerals. It also contains a few percent of biotite as well as rare muscovite and chlorite. Opaques, epidote, allanite, apatite, zircon and titanite are the accessories (Table 42). Hornblende is occasionally found along the western margin of the Hetta granite. Plagioclase is locally zoned with andesitic cores, and consequently, the Hetta granite also passes into granodioritic varieties.

Table 42
Mineralogical composition of granites.

	1	2
Quartz	26.7	29.0
K-feldspar	22.3	25.0
Plagioclase	46.2	38.0
Biotite	2.8	3.8
Chlorite	+	0.6
Muscovite	1.3	2.5
Accessories	0.7	0.6
An	nd	32

1. Enontekiö, Tshuukisvaarri, 8 c/KM/55.
2. Enontekiö, Käkkälöjoki.

The southwestern corner of the Hetta granite south of the river Käkkälöjoki, on the Inari—Utsjoki map sheet, is composed of migmatic granite and biotite gneiss that extend beyond the boundary of the map sheet to the areas of the Enontekiö and Sodankylä map sheets.

The granite area east of Peltotunturi is largely occupied by migmatite in which pegmatitic coarse-grained granite bodies and veins dominate over gneisses (mica gneisses, hornblende gneisses and amphibolites) or vice versa. In addition to potash feldspar, plagioclase and quartz, the granite also contains small amounts of muscovite or biotite.

The granites along the eastern margin of the Repojoki amphibolite zone are pinkish, slightly foliated or almost massive rocks with a fine grain size (Ø = 0.2—1 mm) and granular texture. Potash feldspar, plagioclase (An_{10-20}) and quartz each occupy about one third of the rock volume. Opaques, zircon and biotite as well as garnet and hornblende are the accessories. Aplitic granites similar to these are the pink granites in the southwestern marginal zone of the granulite complex (e.g. Lemmekäspalo), in the granulite complex proper and at Utsjoki in the dome-shaped Kevo window surrounded by granulitic rocks.

Stratigraphy and tectonics

The tectonic structures of the West Inari schist zone are closely associated with those of the granulite complex, and hence their rocks show a similar foliation, gently dipping east- and northeastwards. The stratigraphic sequence of the supracrustal rocks is controlled by tectonic structures.

Foliation and bedding

The schists in the West Inari schist zone, such as sericite quartzites and green schists, are often moderately to distinctly foliated. The foliation is least marked in the arkose gneisses north of Sänkivaara, where recrystallisation was accompanied by homogenisation. The granites at Maunuvaara and Hetta show faint foliation, although the former and the migmatic varieties of the Hetta granite tend to be gneissose and distinctly foliated. The ultrabasic rocks often display distinct foliation, whereas some peridotites and hypersthenites are massive. The foliation often coincides with the bedding, a feature that is most conspicuous in the amphibolites, hornblende gneisses and occasionally in the arkose gneisses and quartzites. Some of the latter even exhibit small-scale graded bedding (Fig. 47).

Stratigraphy

The stratigraphic sequence of the supracrustal rocks in the West Inari schist zone has been determined chiefly on the basis of the tectonic structures in this zone. The sequence of the members from oldest to youngest is: amphibolites, arkose gneisses and quartzites, mica gneisses and mica schists. The youngest members are quartzites, amphibolites, greenstones and green schists. The beds of mica gneisses and schists tend to be thin and probably also incoherent. The supracrustal rocks between the large quartzite and amphibolite zones are composed chiefly of random intercalations of amphibolites, hornblende gneisses, quartz-feldspar gneisses and arkose gneisses with some local layers of quartzite and calc-silicate gneiss.

The supracrustal rocks in the West Inari schist zone are probably Prekarelian. This has been established by the fact that a 2 m thick albite rock (albite diabase) cross-cutting the quartzite at Karasjoki, some 5 km west of the granulite complex, has a zircon date of about 2 700 Ma.

Folding

The foliation and bedding in the supracrustal rocks of the West Inari schist zone almost invariably dip gently 10 to 40° to the east or northeast. From the eastern margin to the central parts of the schist zone the strike roughly conforms to the border of the granulite complex. There are some significant exceptions to this general trend, though, and in some places the strike is E—W. Both the strike and the dip of schistosity and bedding as well as the lineation suggest that plates of arkose gneiss were thrust over the quartzites and amphibolites on its western border. However, the lack of observations on the facing of the beds has made it impossible to conclude whether the folding was isoclinal over the whole area of the schist zone, or what more probable, was it restricted to certain narrow synclinal zones. This latter possibility implies that the stratigraphic sequence of the schists (e.g. arkose gneisses) remained unchanged and that strong folding took place only in some narrow zones when the plates tilted and were thrust over each other along the thrust faults dipping in the same direction. Ultrabasic rocks often occur in these thrust zones. The West Inari schists were probably originally folded into gentle synclines and anticlines simultaneously with the oldest Prekarelian folding of the granulite complex (amphibolite facies). The general trend of the foliation of this deformation phase is roughly N or NE. When the rocks of the granulite complex were deformed and metamorphosed during the Karelian orogeny, a new lineament trending NW was imprinted into the West Inari schists. This lineament developed largely as a consequence of the thrust of the granulite complex towards the southwest and south and also because of the uplift of the Pokka area (granites and granitic gneisses, E. Mikkola 1941) south of Repojoki contemporaneously with the folding of the schists in the Kittilä—Sodankylä area.

RADIOMETRIC AGE DETERMINATIONS

The chronostratigraphical deductions are based on 138 U,Th-Pb analyses of zircon, monazite or titanite, 68 common lead ages of whole rock or potash feldspar and 76 Rb-Sr whole rock or mineral ages. The localities of all the rocks and minerals dated by the U,Th-Pb and Rb-Sr method are shown on the map in Fig. 49. Analytical data and further discussion of geochronology will be given in another context. The isotope analyses were done at the Geological Survey of Finland by Olavi Kouvo and Matti Sakko (U,Th-Pb and common lead ages and Rb-Sr ages on Vainospää and Nattanen granites) and by Brian Gulson (Rb-Sr analyses on samples from granulite and from the granite gneiss complex).

The granite gneiss complex

Four age groups have been established for the infracrustal rocks in the granite gneiss complex (1, 2) and the Kuorboaivi (3) and the Apukasjärvi and Vätsäri (4) schist zones (age in Ma):

	Common lead		Rb-Sr		U,Th-Pb	
	whole rock	feldspar	whole rock	minerals	zircon	titanite
1	2 865	1 900	—	—	2 730	~1 900
2	2 533	1 900	2 430	1 850	2 480	2 000—1 900
3	2 093/2 020 (WR + KF)		—	—	1 940	—
4	1 735 (WR + KF)		1 755	—	1 760	1 760

The decay constants used for age calculations (except those referred from other publications) are:

λ_{238} U = $0.155125 \times 10^{-9}a^{-1}$
λ_{235} U = $0.984850 \times 10^{-9}a^{-1}$
λ_{232} U = $0.049475 \times 10^{-9}a^{-1}$
λ_{87} Rb = $1.43 \times 10^{-11}a^{-1}$

The last two age groups are the infracrustal rocks in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and they will be discussed in the next chapter.

The 2 865 Ma whole rock common lead group includes only two infracrustal rocks of the granite gneiss complex (Fig. 50). They represent the oldest bedrock in

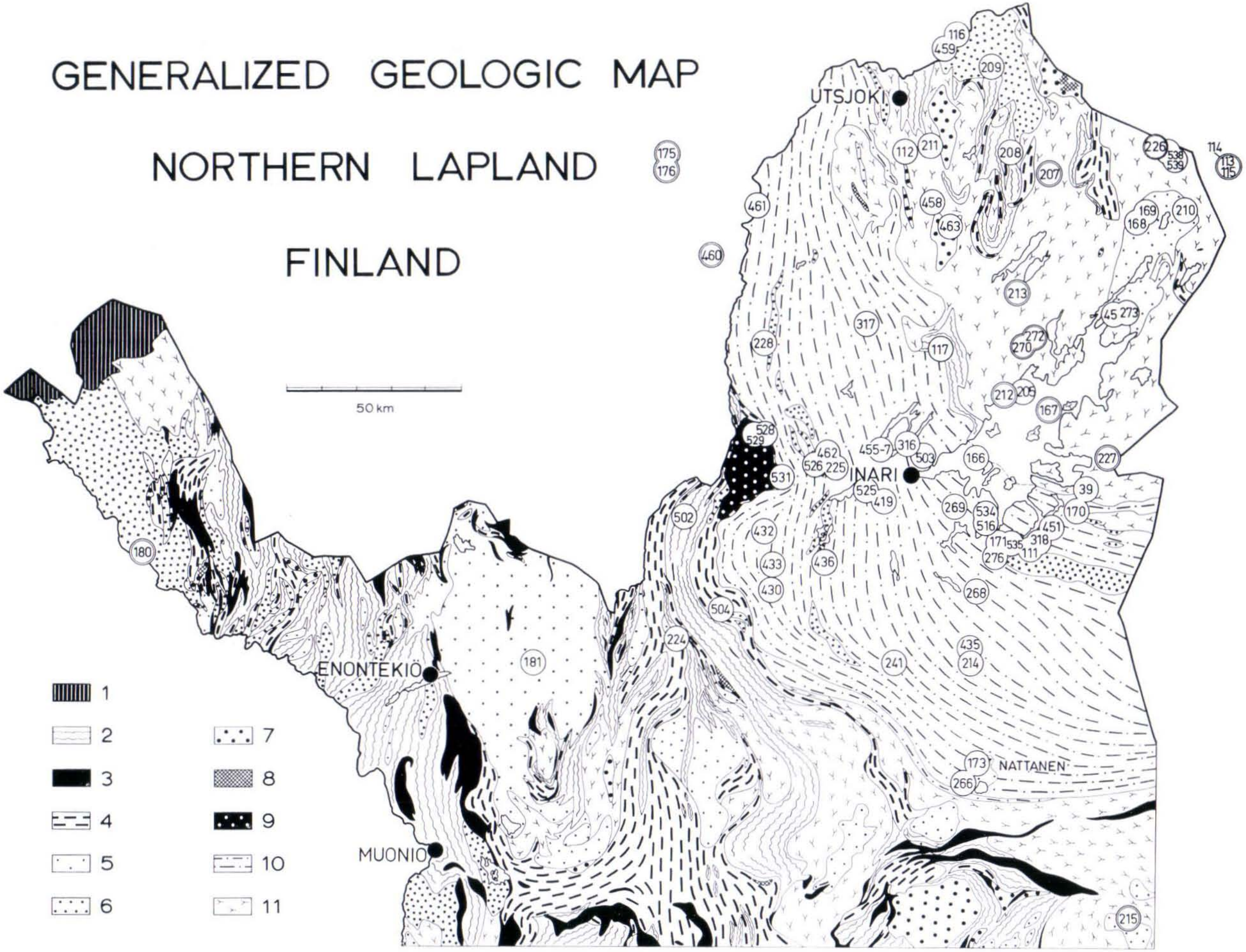

Fig. 49. Generalised geological map of northern Lapland. Simplified from the general geological maps of Finland on a scale 1: 400 000 (Mikkola 1936, 1936, 1937); Matisto 1959; Meriläinen 1965). 1) Paleozoic rocks, 2) gneisses and schists of different kinds (mica gneisses and schists, sillimanite gneisses, leptitic schists, jasper quartzites etc.), 3) quartzites, 4) amphibolites and greenstones, 5) granites, 6) quartz diorites and granodiorites, 7) gabbros and diorites, 8) ultrabasic rocks, 9) Vaskojoki anorthosite, 10) granulite complex proper, 11) granite gneiss complex (Karelian basement).

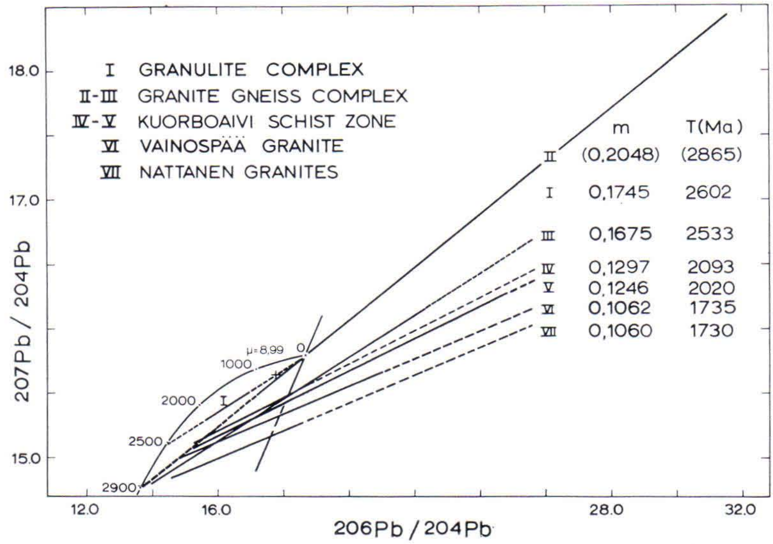

Fig. 50. Summary diagram of $^{207}Pb/204Pb$ versus $^{206}Pb/^{204}$ Pb for whole rock lead and least radiogenic K-feldspar lead isotope analyses from major rock units of the Inari—Utsjoki area. Solid lines have been drawn through the data points; the dashed lines are extrapolations of these. The isochrons are defined by: I, 22 data-points; II, (= zircon ages of 2 730 Ma), 2 points only; III, 13 points; IV (trondhjemites and granodiorites), 7 points; V (= varieties of gabbros (3 points); and the Vaskojoki anorthosite (7 points for which alone m = $0.1\,312_7$, T = 2 115 Ma); VI, 6 points; and VII, 8 points.

the area. The corresponding zircon age group is about 2 730 Ma. The infracrustal rocks examined (Fig. 51: 167-Kuorpasaari, 227-Suovavaara) are in anticlines (antiforms) that developed during the folding of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones. The anticlines are dome-shaped and bordered in places by minor synclines of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones (axial depressions). In the immediate vicinity of the main parts of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones the anticlines contain somewhat younger infracrustal rocks, especially porphyroblastic potash granites. The zircon age group 2 730 Ma also includes one cobble in conglomerate (175-Skoganvarre, Norway) and one basement gneiss (176-Skoganvarre, Norway) north of Karasjok.

Most of the infracrustal rocks of the granite gneiss complex belong to the 2 500 Ma whole rock common lead age group. The corresponding zircon age group is also about 2 500 Ma and contains several quartz diorites and granodiorites (Fig, 51: 115-Neiden, 212-Akulahti, 213-Kittilompolo, 270-Partakko) as well as porphyroblastic potash granites (113-Neiden, 207-Roavvi Tievja, 226-Pirivaara). In addition, this group also includes one migmatic granite (272-Turvejärvi) near the quartz diorite of Partakko and one porphyroblastic potash granite (215-Kairijoki) about 35 to 40 km south of the granulite complex and some 50 km north of the village of Savukoski. The

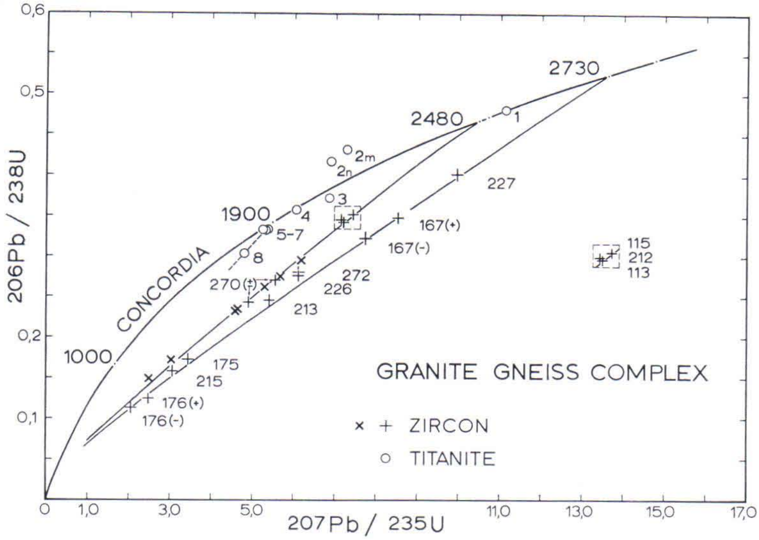

Fig. 51. Summary plot of the zircon and titanite U-Pb analyses showing the 2 730 Ma and 2 450 Ma zircon chords and 1 900 Ma titanite age group (1, A215-Kairijoki; 2, A167-Kuorpasaari: m, magnetic fraction; n, non-magnetic fraction; 3, A226-Pirivaara; 4, A207-Roavvi Tievja; 5, A212-Akulahti; 6, A272-Turvejärvi; 7, A115-Neiden; 8, A270-Partakko). Zircon and titanite belong to the same samples. +, +200 mesh; —, —200 mesh. Data for sample A207-Roavvi Tievja (×) are also shown in Fig. 52.

zircon age of the potash granite of Kairijoki is very discordant and hence it may also belong to the zircon age group of 2 730 Ma. It is noteworthy that the titanite age of this granite is from 2 500 to 2 600 Ma, which indicates that the Kairijoki granite has survived the metamorphisms of Karelian orogeny.

The quartz diorites and granodiorites of 2 500 Ma zircon ages are weakly foliated and cannot be distinguished macro- or microscopically from the petrologically analogous infracrustal rocks of the 2 730 Ma zircon age group. On the other hand, the porphyroblastic potash granites, in which the potash feldspar porphyroblasts have been developed metasomatically in some places, form a distinct group. At Pirivaara (226), for instance, the quartz diorites or granodiorite grades into potash granite together with the development and gradual increase in the number of potash feldspar porphyroblasts in it. These potash granites are Prekarelian, latekinematic infracrustal rocks, which, depending on their conditions of crystallisation, also metasomatically granitised their environment. Their minimum age is probably the same as that of the zircon fractions in the porphyroblastic potash granite of Roavvi Tievja (207), that is, 2 480 Ma (Fig. 52). The Pirivaara granite is clearly a little older than that of Roavvi Tievja (Fig. 51). It should also be pointed out that on the basis of the Rb-Sr whole rock method the rocks of the 2 730 Ma and 2 500 Ma zircon age group show a scatter about a 2 500 Ma reference isochron (see Gulson 1969).

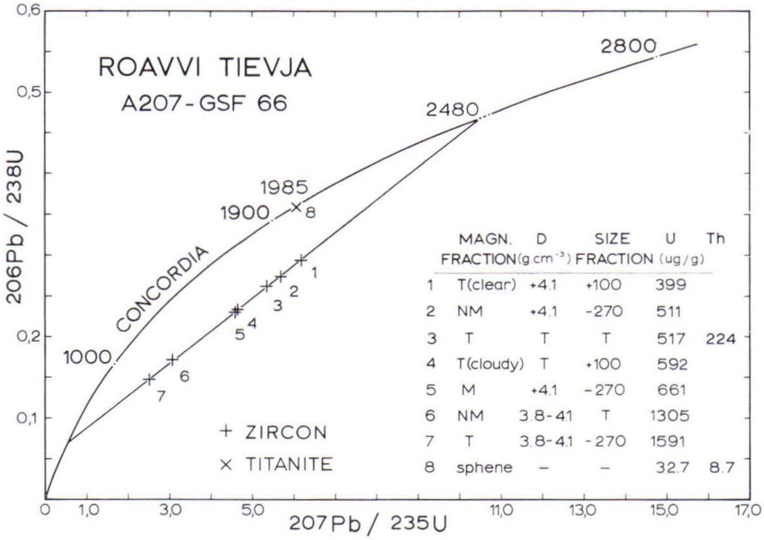

Fig. 52. Concordia plot showing the data-points of the U-Pb analyses of different zircon fractions from the Roavvi Tievja porphyroblastic potash granite.

The rocks of the 2 865 Ma whole rock common lead age group (= 2 730 Ma zircon age group) are possibly only relicts that were best preserved during the Karelian metamorphisms. On the other hand, the Rb-Sr and common lead whole rock ages and zircon ages (about 2 500 Ma) reveal either that the bedrock was rejuvenated:

1) during the Karelian epoch analogously to the mantled domes in the Kuopio and Outokumpu area in eastern Finland (Kouvo 1958, Wetherill et al. 1962, Kouvo 1964; Kouvo and Tilton 1966) or

2) during the Prekarelian epoch when the dome-shaped structures and porphyroblastic potash granites in the granite gneiss complex were developed.

The age of 2 500 Ma may reflect the metamorphism or uplift that took place during the development of the porphyroblastic potash granites. However, the Rb-Sr mineral ages together with the titanite ages and common lead potash feldspar secondary isochron ages suggest that the rocks of the granite gneiss complex were strongly remetamorphosed also during the Karelian epoch about 1 900 Ma ago (Figs. 50 and 51). Furthermore, the least radiogenic lead measured to date in the Precambrian basement complex (granite gneiss complex) was extracted from potash feldspars of a porphyroblastic potash granite in Pirivaara and of two other granites about 10 km southeast of Pirivaara.

The supracrustal rocks of the Björnevann formation (Northeast Norway) are Prekarelian. This can be inferred from the magnetite-banded iron ore characteristic of this formation, which, according to Viggo H. Wiik (1966), occurs as relicts in granodiorite whose zircon, common lead and Rb-Sr whole rock ages are about 2 500 Ma (Fig. 50 and 51; 113-Neiden, 115-Neiden).

The Apukasjärvi, Vätsäri and Kuorboaivi schist zones

The Apukasjärvi and Vätsäri schist zones are comparable with the Björnevann formation as suggested by the radiometric ages and magnetite-banded quartzites. A direct indication of the age of the supracrustal rocks in the Apukasjärvi and Vätsäri schist zones is provided by the mica gneiss at their eastern margin, which has altered into augen gneiss owing to the formation of locally abundant potash feldspar porphyroblasts. Similar augen gneisses are found in the environment of the porphyroblastic potash granite of Pirivaara whose zircon age is about 2 500 Ma. Observations on outcrops indicate that the potash feldspar porphyroblasts in mica gneisses grow simultaneously with the emplacement of the Pirivaara granite. The supracrustal rocks of the Apukasjärvi and Vätsäri schist zones are thus older than 2 500 Ma and therefore Prekarelian in age. The supracrustal rocks of the Kuorboaivi schist zone are similar to the former except that the magnetite-banded quartzites are either absent or have not been revealed owing to the scarcity of outcrops.

The infracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones form two distinct age groups:

	Common lead		Rb-Sr		U,Th-Pb	
	whole rock	feldspar	whole rock	minerals	zircon	titanite
1	2 093/2 020 (WR + KF)		—	—	1 940	—
2	1 735 (WR + KF)		1 755	—	1 760	1 760

The 2 093/2 020 Ma whole rock common lead isochrons (Fig. 50) include rocks classified as early Karelian and Karelian synkinematic infracrustal rocks on the basis of field observations. Of the latter, the quartz diorites and granodiorites (Fig. 53: 116-Sirma, 208-a little hill about 4 km SSE of Akshunjunni, 209-Keinodakoaivi, 458-Mieraslompolo, 459-Vetsikko, 463-Kuktsvaara and trondhjemitic granites 112-Keniskoski, 211-Nuottalvaara) that concordantly intrude the supracrustal rocks of the Kuorboaivi schist zone have been assigned ages of at least 1 940 Ma by the zircon method. Detailed examination showed that the zircon of the Kuktsvaara quartz diorite (463) in the large gabbro massif of Petsikkovaara is about 1 950 Ma (Fig. 54). This may imply that the anorthosites, serpentinites, peridotites, gabbros and quartz diorites associated with them are truly early Karelian. They were intruded into rupture zones between tectonic blocks in the granite gneiss complex and regenerated with some (Prekarelian) trondhjemites and oligoclase granites (Fig. 53, samples 112, 211) during the main and late Karelian metamorphism as were the rocks in the mantled domes.

The postkinematic granites of Vainospää and Päkkevaara constitute the 1 735 Ma whole rock common lead isochron (Fig. 50). Dating by the Rb-Sr whole rock method assigns them the same age as their zircons and titanites (Fig. 53, samples 168, 169, 210). The Vainospää granite (including Päkkevaara) developed in an anticlinorium block of a weathering mountain range uplifted relative to its environment. Its development is presumably associated with the geological history of the nearby Petsamo (Petšhenga) formation.

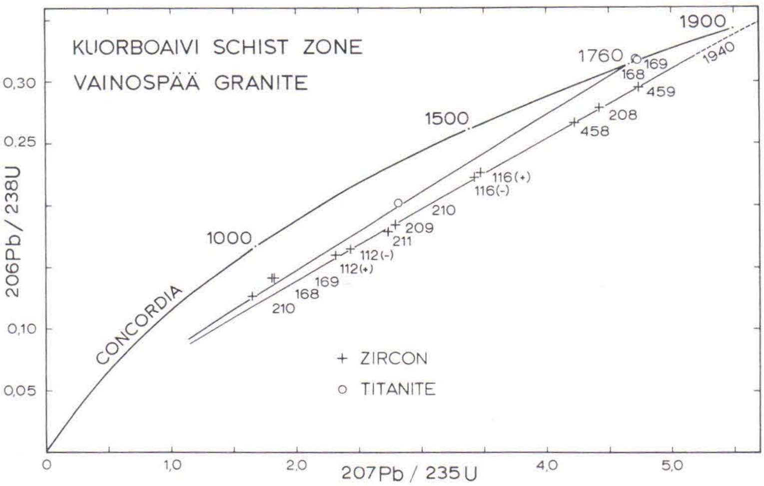

Fig. 53. Concordia diagram for U-Pb analyses of zircons and titanites from Vainospää granite and from the infracrustal rocks in Kuorboaivi schist zone. +, +200 mesh; —, —200 mesh. Data for sample A463-Kuktshvaara are shown in Fig. 54.

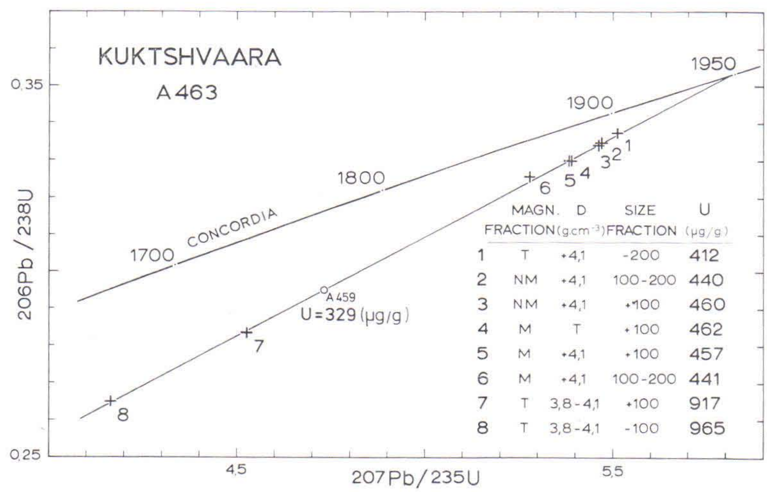

Fig. 54. Concordia diagram for zircon fractions from Kuktshvaara quartz diorite (Petsikkovaara gabbro massif). Chord also passes through A459 zircon from Vetsikko granodiorite. Upper intersection is 1 950 Ma. M, magnetic; NM, nonmagnetic; T, total.

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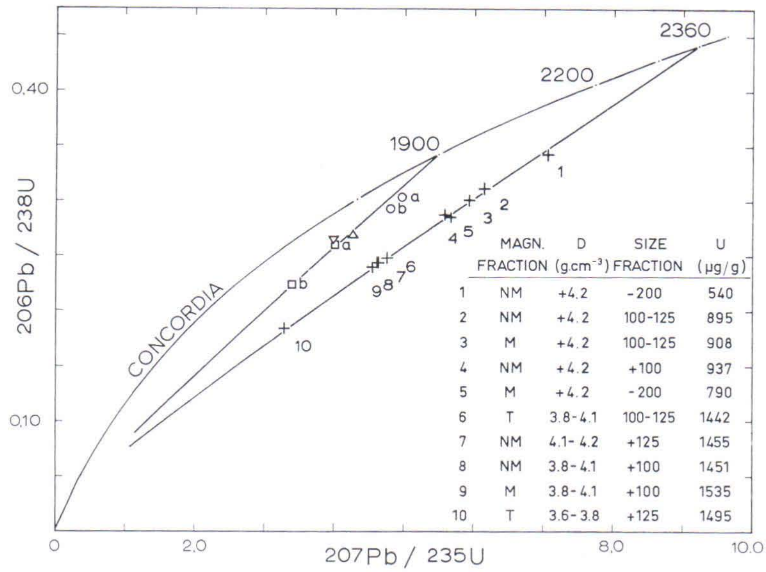

Fig. 55. Concordia diagram for zircons: +, fractions from A504-Lemmekäspalo granite; o, A269-Myösäjärvi granodiorite (older generation: a, subhedral; b, euhedral); □, A502-Kartojärvi pegmatite (a, heavy fraction, $3.8 < d < 4.1$; b, light fraction, $3.6 < d < 3.8$); △, A224-Maunuvaara quartz diorite; and ▽, A184-Hetta granite.

The granulite complex

The rocks of the granulite complex were derived mainly from various Prekarelian supracrustal and infracrustal rocks. Whole rock common lead investigations indicate that they might have been metamorphosed or uplifted about 2 500 Ma ago together with the rocks of the granite gneiss complex and the Apukasjärvi, Vätsäri, Kuorboaivi and West Inari schist zones presumably under the conditions of the amphibolite facies (Fig. 50). Some zircon ages also suggest that the oldest rocks of the granulite complex are Prekarelian: e.g. the zircons of a potash granite occurring concordantly with the supracrustal rocks of the southwestern marginal zone of the granulite complex are c. 2 360 Ma old (Fig. 55: 504-Lemmekäspalo) and the older zircon phase of the garnet-biotite quartz diorite of Myösäjärvi (Figs. 55 and 59: 269-Myösäjärvi) is c. 1 980 Ma old.

Even during the mapping of the granulite complex it was assumed that the rocks of the sedimentary group (fine-grained garnet-quartz-feldspar gneisses, garnet-biotite gneisses and garnet-biotite-plagioclase gneisses) are probably Karelian in origin. This opinion was based on the well-preserved structures they exhibit and on their chemical compositions, especially those of the fine-grained garnet-quartz-feldspar gneisses, which differ markedly from other supracrustal rocks of the area in this respect. The garnet gneisses of the sedimentary group, however, constitute only a

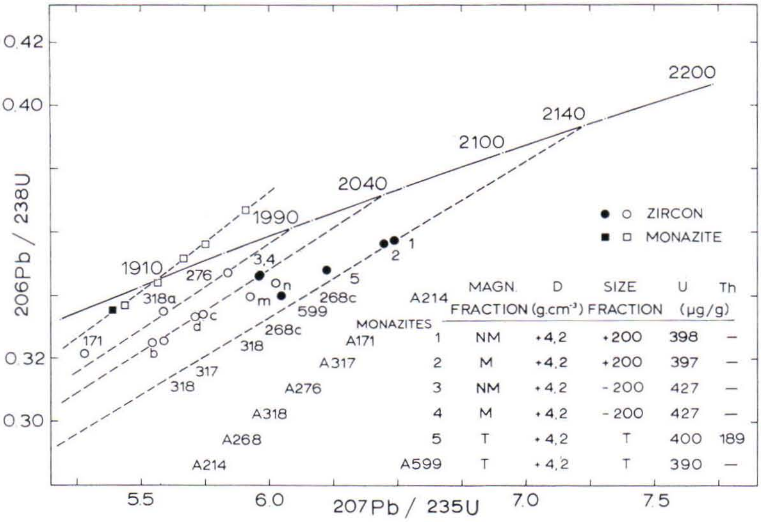

Fig. 56. Concordia diagram for U-Pb ratios of zircons and monazites from garnet-cordierite gneisses (open) and fine-grained garnet-quartz-feldspar gneisses (full circles and squares). m, magnetic fraction; n, nonmagnetic fraction. A318-Könkäänjärvi: a, dark, short prisms; b, long, light coloured prisms; c, total fraction 100—150 mesh; d, total fraction —150 mesh.

small part of the whole area of the granulite complex, the bulk being garnet-cordierite-gneisses and coarse-grained garnet-quartz-feldspar gneisses evidently of Prekarelian source.

Rb-Sr data for all the garnet gneisses (34 samples) indicate an age of about 2 015 Ma. The subdivision of the samples into 1) garnet-cordierite gneisses and 2) fine-grained garnet-quartz-feldspar gneisses is supported by the isotope data, and the ages obtained are (1) 2 200 Ma and (2) 1 900 Ma (Gulson 1969; 2 155 Ma and 1 836 Ma if $\lambda = 1.43 \times 10^{-11}a^{-1}$ used). The granulitisation or the uplift of the granulite complex probably took place c. 2 150 Ma ago and the diaphthoretic metamorphism c. 1 900 Ma ago. The fine-grained garnet-quartz-feldspar gneisses as well as the other garnet gneisses of the sedimentary group are the rocks that were best preserved during the diaphthoretic metamorphism. Consequently the c. 2 140 Ma old zircons (Fig. 56: 214-Paukkula, 599-Roavvioaivi) that recrystallised during the granulitisation have also been preserved in the fine-grained garnet-quartz-feldspar gneisses. The zircons in the garnet-cordierite gneiss of Törmänen (268 c) are of about the same age, but in contrast to the typical garnet-cordierite gneisses, this variety also exhibits the relict banding characteristic of fine-grained garnet-quartz-feldspar gneisses. Nevertheless, the zircons of the garnet-cordierite gneisses are usually approximately 2 000 to 2 040 Ma old (Fig. 56: 276-Viekkala, 317-Kiellajoki, 318-Könkäänjärvi. The sample from Könkäänjärvi contains some different varieties of zircons.) The same age group also includes the older zircon phase in the garnet-biotite quartz diorite of Myösäjärvi

(Figs. 55 and 59, sample 269), and the zircons of the garnetiferous porphyritic potash granite of Koppelo (Fig. 56, sample 171). The zircon age group of 2 000 to 2 040 Ma does not indicate any definite deformation phase of the granulite complex because its zircons are diaphthoretically altered.

Diaphthoretic metamorphism took place under the conditions of low-grade granulite facies and high-grade amphibolite facies without any significant intergranular movements (stress) during the recrystallisation phase. This is demonstrated by the fact that the cordierite and potash feldspar of garnet-cordierite gneisses and coarse-grained garnet-quartz-feldspar gneisses have often crystallised as porphyroblasts or at least as augen-shaped crystals markedly larger than the others. The low triclinicity of potash feldspar ($\Delta = 0.0—0.4$) and the high distortion index of cordierite ($\delta = 0.26—0.39$) also seem to reflect the conditions of crystallisation.

The ages of the monazites (c. 1 900 Ma) in the garnet-cordierite gneisses (Fig. 56: 268 c-Törmänen, 276-Viekkala, 317-Kiellajoki, 318-Könkäänjärvi), in the garnetiferous porphyritic potash granite of Koppelo (171) and in the fine-grained garnet-quartz-feldspar gneiss of Paukkula (214) and especially the ages of the zircons and monazites in the anatectic dykes (Fig. 57: 166-Pääsaaret, 268 e-Törmänen, 316-Korppikuru, 419-Solojärvi), in the dykes crosscutting the garnet-cordierite gneiss of Mutusjärvi (Fig. 58: samples 455, 456 and 457) as well as the youngest zircon fraction in the garnet-biotite quartz diorite of Myösäjärvi (Fig. 59: 269) indicate emphatically that the diaphthoretic metamorphism took place about 1 900 Ma ago. This episode is also limited by the emplacement of the postgranulitic scapolite quartz diorite of Vuoskuljärvi (Fig. 59: 462) c. 1 900 Ma ago (the age of zircon).

The infracrustal rocks (diorites, quartz gabbros, quartz diorites) of the granulite complex proper are mainly Prekarelian, their minimum age being about 2 600 Ma by the whole rock common lead method. The metamorphic age for zircons from the infracrustal rocks, however, is about 1 925 Ma (Fig. 60: 111-Akujärvi, 225-Pailovaara, 228-Karnasrattaoaivi, 241-Sotajoki). It is possible, of course, that during the early stages of the diaphthoretic metamorphism some quartz gabbros, diorites and quartz diorites intruded between tectonic blocks at the same time and in the same way as did the ultrabasic rocks and gabbros in the granite gneiss complex and the Kuorboaivi schist zone, i.e. about 2 050 Ma ago, as suggested by whole rock common lead datings (Fig. 50). Contemporaneously some quartz diorites and granodiorites emplaced into supracrustal rocks of the northeastern marginal zone of the granulite complex or regenerated during its deformation (Fig. 59: 39-Kenttäsaari, 117-Syysjärvi).

After the diaphthoretic phase and the emplacement of the postgranulitic scapolite quartz diorite of Vuoskuljärvi, the complex was intruded by the postorogenic Karelian granites of Nattanen and Juovutunturi (Juvoaivi), quartz-syenite porphyry dykes and olivine diabases. Their undeformed structures and common lead, Rb-Sr, zircon and titanite ages (about 1 730 Ma) show that the granulite complex had become almost perfectly stable before the intrusion of these rocks.

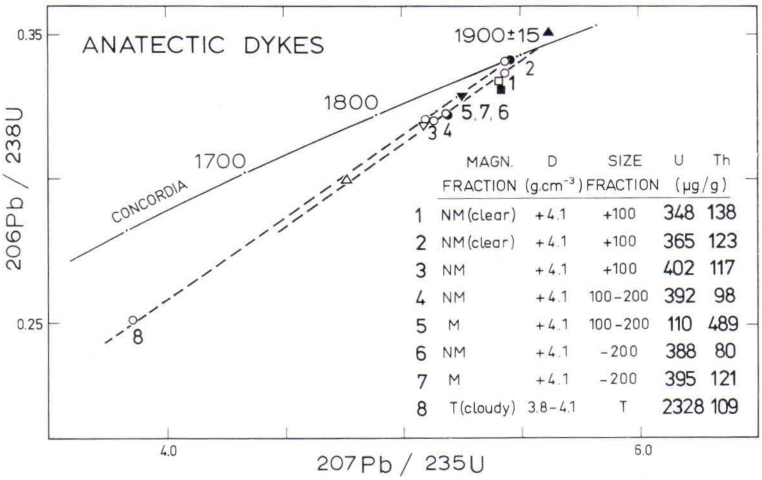

Fig. 57. Concordia diagram for U-Pb ratios of zircons (open) and monazites (full) from anatectic dykes. A268 e-Törmänen (o), A166-Pääsaaret (□), A316-Korppikuru (△) and A419-Solojärvi (▽).

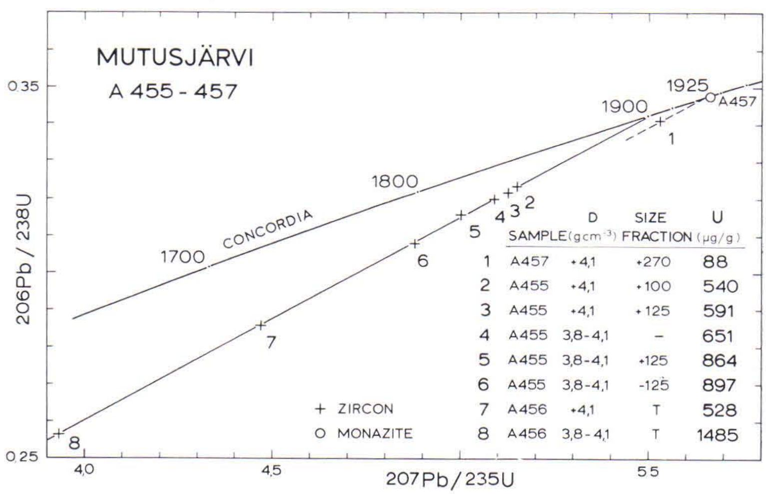

Fig. 58. Ages of zircon fractions from basic dykes (455 and 456) and granite vein (457) cutting Mutusjärvi garnet-cordierite gneisses, and an age of monazite from the granite vein.

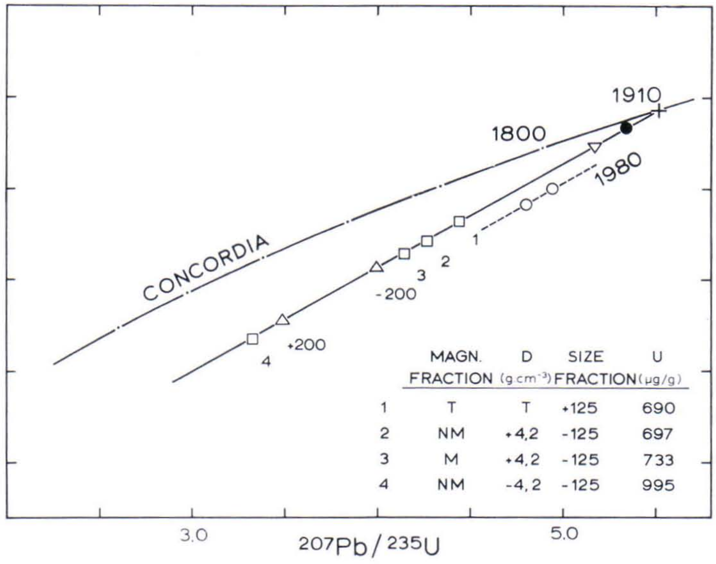

Fig. 59. Concordia diagram for U-Pb ratios of zircons and one monazite (+) from 269-Myösäjärvi garnet-biotite quartz diorite (old generation: open circle, new generation: full circle), 39-Kenttäsaaret quartz diorite (▽), 117-Syysjärvi quartz diorite (△) and 462-Vuoskuljärvi granite (□).

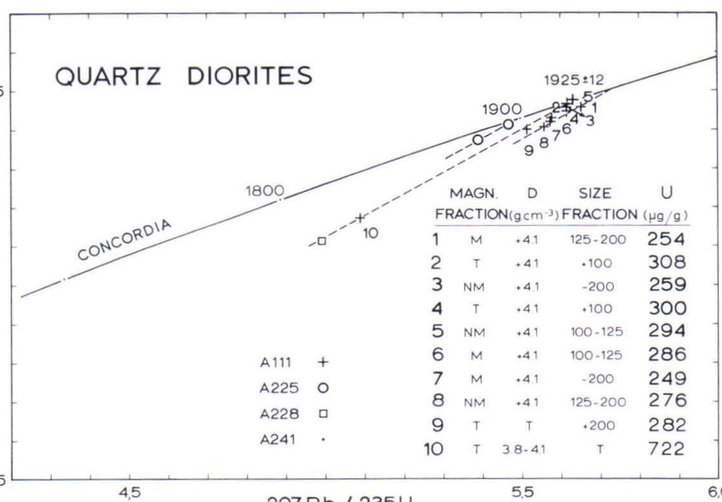

Fig. 60. Concordia plot for zircons from quartz diorites of the granulite complex proper.

The West Inari schist zone

The supracrustal rocks of West Inari schist zone are probably Prekarelian as is indicated by the zircons of the potash granite of Lemmekäspalo (c. 2 360 Ma) and of an albite diabase (c. 2 700 Ma) near Karasjok, Norway.

SUMMARY AND DISCUSSION

The investigation area, which comprises the Inari—Utsjoki area on the general geological map, covers about 24 000 km^2. It consists of four sub-areas:

1) the granite gneiss complex
2) the Apukasjärvi (A), Vätsäri (V) and Kuorboaivi (K) schist zones
3) the granulite complex and
4) the West Inari schist zone

The *granite-gneiss complex* is monotonous, being composed mainly of granite gneisses, quartz diorites, granodiorites and granites, with minor quartz-feldspar gneisses, mica gneisses, hornblende gneisses and amphibolites. The supracrustal rocks, and often the infracrustal rocks as well, are heterogeneous migmatites with streaks and schlieren and frequently exhibiting a characteristic veined gneissose habit. In many localities they are also intensely folded. The supra- and infracrustal rocks are cut by diabases and coarse, pegmatitic granite veins.

The tectonic structures of the granite gneiss complex typically display dome-shaped forms, which are often delimited by zones of steeply dipping foliation. In some places, supracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones occur as minor synclines (axial depressions) between the dome-shaped anticlines or anticlinoriums.

According to the whole rock common lead datings, the age of the oldest infracrustal rocks in the granite gneiss complex is approximately 2 865 Ma. Their zircons give slightly younger age, that is, about 2 730 Ma. These rocks, however, are only relicts preserved in the cores of a few anticlines, most of the infracrustal rocks in the granite gneiss complex having been assigned an age of about 2 500 Ma by the whole rock common lead method and even their zircons are approximately 2 500 Ma old. These ages are further corroborated by the fact that the Rb-Sr whole rock isochron also indicates an age of c. 2 500 Ma. On the basis of these dates obtained by different methods, it is evident that the rocks of the granite gneiss complex were metamorphosed or uplifted some 2 500 Ma ago. On the other hand, the common lead secondary isochron of the potash feldspars, the Rb-Sr mineral isochron, as well as the ages of the titanites all show that the rocks of the granite gneiss complex were intensively remetamorphosed also during the Karelian orogeny about 1 900 Ma ago.

Prekarelian rocks comparable with the granite gneiss complex of the area investigated extend almost continously from the southern margin of the granulite complex to Ladoga in the south (see Mikkola 1941, Enkovaara, Härme and Väyrynen 1953, Matisto 1958, Nykänen 1971, Asa 1971, Laajoki 1972, Silvennoinen 1972). The rocks of these areas resemble each other not only in habit but also petrologically and in their radiometric ages. The infracrustal rocks in Kainuu and Savo-Karelia, however, which have been dated to about 2 800 Ma (zircon), appear to have withstood the influence of the Karelian orogeny better than have those in Inari and Utsjoki. Nevertheless, the zircon ages of the domes in Savo and Karelia (2 300—2 600 Ma) indicate distinct rejuvenation of the bedrock (see Kouvo 1958, Westherill *et al.* 1962, Kouvo and Tilton 1966).

The *Apukasjärvi, Vätsäri and Kuorboaivi schist zones* are synclines or synclinoriums between the dome-shaped anticlines or anticlinoriums of the granite gneiss complex. As a whole they are axial depressions similar to the minor synclines between the dome-shaped anticlines and anticlinoriums of the granite gneiss complex; they differ, however, in their greater areal extent and the more gentle dip of foliation. The dominant supracrustal rocks of the minor synclines are amphibolites and hornblende gneisses, locally also quartzites and calc-silicate gneisses. Besides these, the Apukasjärvi, Vätsäri and Kuorboaivi schist zones alco contain quartz-feldspar gneisses, mica gneisses and locally magnetite-banded, cherty quartzites.

On the basis of their rock associations and syncline or synclinorium structures, the following stratigraphic sequence from oldest to youngest has been established for the supracrustal rocks of the Apukasjärvi and Vätsäri schist zones:

1) quartzites and quartz-feldspar gneisses
2) mica gneisses, or locally quartz-feldspar gneisses, mica gneisses, hornblende gneisses and amphibolites as randomly alternating beds and bands, magnetite-banded quartzites and calc-silicate gneisses
3) amphibolites, with some black schist in their upper part.

The stratigraphic sequence of the supracrustal rocks in the Kuorboaivi schist zone is probably analogous to the above. The Kuorboaivi schist zone, however, is so poorly exposed that information on its rock types is incomplete and magnetite-banded quartzites, for example, have not been encountered.

The supracrustal rocks of the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are veined gneisses or are often cut by granite veins. Most of them, however, have been much better preserved from migmatization than have the corresponding rocks of the granite gneiss complex. The infra- and supracrustal rocks are locally also intruded by diabases.

The supracrustal rocks contain concordant infracrustal rocks (anorthosites, peridotites, hornblendites, gabbros, quartz diorites and granodiorites and granites), which were emplaced or developed during the early Karelian orogeny. In some places, the ultrabasic rosks and gabbros sharply cut the migmatic and veined granite gneisses of the granite gneiss complex.

The schist zones of Apukasjärvi and Vätsäri are comparable with the Björnevann formation some 40 to 60 km to the east. In this formation the stratigraphic sequence for the supracrustal rocks from oldest to youngest is as follows (see Bugge 1960): 1) conglomerates, 2) quartzites and mica schists, 3) quartz-banded iron ore, and 4) biotite-hornblende gneisses (sediments and andesitic effusives).

The most significant difference between the stratigraphic sequences of the supracrustal rocks in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and the Björnevann formation is perhaps the occurrence of conglomerates in the latter. These indicate that the Björnevann formation is younger than the oldest gneiss granites and granite gneisses in the area (granite gneiss complex). J. J. Sederholm (1932) considered them to be of Lapponian age, and thus deposited before the sediments of the Karelian cycle. Since then, however, the Lapponian has also been included in the Karelian formations (see Mikkola 1941, Simonen 1960 b, 1971). In the opinion of Jens A. Bugge (1960), the Björnevann formation dates from the early Karelian.

In the present study the supracrustal rocks of the Björnevann formation and the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are interpreted as Prekarelian owing to the presence, some 20 km west of the Björnevann formation, of quartz-banded iron ores as relicts in the c. 2 500 Ma old granodiorites and granites.

The Björnevann formation and the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are comparable with the schist zones of Kuhmo—Suomussalmi and Ilomantsi, which also contain magnetite-banded quartzites (see Väyrynen 1954, Simonen 1971). According to zircon dating, however, their infracrustal rocks are clearly older than those intruding the schists of the Björnevann formation, i.e. about 2 800 Ma. Of the rocks in Kola and Karelia, USSR, those of Kostamus, Imandra, Himola and Parandova with magnetite-banded iron ores are the closest to the Björnevann formation (see Kratz, Surkin *et al.* 1971).

Zircon ages and field observations indicate that the Apukasjärvi, Vätsäri and Kuorboaivi schist zones were redeformed during the Karelian orogeny when they were subject to intrusions of infracrustal rocks: ultrabasic rocks, gabbros, quartz- and granodiorites and granites. They form two distinct age groups: the older one is about 2 050 Ma by the whole rock common lead method and 1 950 Ma according to the zircons. The younger one is around 1 735 Ma according to the whole rock common lead isochron, the Rb-Sr whole rock isochron and the zircon and titanite ages. In the light of field observations, the first group comprises rocks classified as early and synkinematic infracrustal rocks (anorthosites, peridotites, serpentinites, hornblendites, gabbros, diorites and quartz- and granodiorites). The second group consists of the postkinematic granite massif of Vainospää alone. A noteworthy fact is that, by the zircon method, the synkinematic infracrustal rocks are slightly older than the corresponding rocks in the Svecokarelian area (1 900—1 950, 1 870—1 900 Ma respectively). Some granites of the 1 735 Ma zircon group are found also in South Finland.

Ultrabasic rocks and large gabbro massifs were erupted between the blocks of the granite gneiss complex and at some localities these zones still exhibit remnants of the supracrustal rocks of the Apukasjärvi Vätsäri and Kuorboaivi schist zones. The granite of Vainospää developed in an anticlinorium block that uplifted in a weathering mountain range.

The supracrustal rocks of the *West Inari schist zone* can be divided into three subzones on the basis of their main rock types:

1) arkose-gneisses at the eastern margin of the schist zone,
2) the Peltotunturi zone at the western margin of the schist zone, which borders on the Hetta granite and contains abundant quartzites, green schists and greenstones, and
3) the wide amphibolite zone between zones 1 and 2.

The foliation and bedding of the supracrustal rocks invariably dips gently to the east or northeast (10—40°). From the eastern margin to the central parts of the schist zone the foliation conforms roughly to the westernboundary of the granulite complex. On the basis of the strike and dip of foliation, narrow synclines have been established that often contain ultrabasic infracrustal rocks in addition to amphibolites and green schists. Overthrusting has taken place in these zones along surfaces dipping about 60 to 40° east-northeast.

The stratigraphic sequence of the supracrustal rocks from oldest to youngest is probably as follows:

1) amphibolites, locally quartzites
2) quartzites and arkose gneisses
3) biotite gneisses and schists. This group is often thin and discontinous; it is occasionally replaced by thin and randomly alternating layers or bands of arkose gneiss, quartzite, amphibolite, hornblende gneiss, calc-silicate gneiss and biotite gneiss
4) quartzites } Peltotunturi zone
5) amphibolites and green schists } Peltotunturi zone

The supracrustal rocks in the West Inari schist zone are probably Prekarelian, as is indicated by the quartzite at Karasjoki (Norway), about 5 km west of the granulite complex, which is cut by a 2 m wide albite rock vein (albite diabase) whose zircon age is c. 2 720 Ma. Similarly a Prekarelian zircon age, c. 2 360 Ma, was obtained for the potash granite of Lemmekäspalo, in the southwestern marginal zone of the granulite complex.

The supracrustal rocks in the West Inari schist zone were probably uplifted or metamorphosed 2 500 Ma ago simultaneously with the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and the rocks of the granulite complex. The general strike of the foliation in the West Inari schist zone varies around N-S west and southwest of the granulite complex. Later, during the Karelian orogeny, the rocks of the West Inari schist zone were redeformed and a NW-trending lineament developed that is quite conspicuous in places. At the same time conformable ultrabasic infracrustal rocks, serpentinites, pyroxenites, peridotites as well as occasional granodiorites and quartz diorites and granites were emplaced into the fractures between the tectonic blocks. This episode is indicated by the zircons of the Maunuvaara quartz diorite, about 1 910 Ma, which belong to the same age group as the granodirites and quartz diorites of the Kuorboaivi schist zone. The zircon ages also show that still later the granite massif of Hetta (1 832 Ma) was emplaced on the western border of the West Inari schist zone.

On geologic maps the wide zone of amphibolites, which are included in the supracrustal rocks of the West Inari schist zone, lies in direct connection with the greenstone area of Central Lapland. The zircon ages suggest that the dominant amphibolite zone in the West Inari schist zone is Prekarelian, whereas the albite diabases (Meriläinen 1961, Paakkola 1971) as well as the greenstones of Central Lapland are early Karelian as is indicated by the zircons of albite diabases, which are about 2 160 Ma old (Matti Sakko 1971). It is especially interesting that the main volcanic activity of the Karelian orogeny, as shown by the ages of the albite diabases, was synchronous with the granulitisation or uplift of the granulite complex.

On the basis of the rock types, the *granulite complex* can be divided into three parts:

1) the granulite complex proper (i.e. the granulite complex on the geologic map),
2) the northeastern marginal zone of the granulite complex,
3) the southwestern marginal zone of the granulite complex.

The rocks of the granulite complex proper clearly differ from those in its marginal zones. This is partly due to the fact that the rocks of the granulite complex proper underwent metamorphism mainly under the conditions of the granulite facies, whereas the rocks of its marginal zones were metamorphosed under the conditions of the amphibolite facies, but also partly because of the dissimilarity between the metamorphosed supracrustal rocks.

The subareas of the granulite complex form a tectonic entity whose rocks display foliation or relict bedding dipping gently (10—40°) east and northeastwards. The dip grows steeper and in some places even vertical in the northeastern marginal zone of the complex, in the eastern parts of the granulite complex proper and in some narrow zones. The strike and dip of schistosity reveal tectonic macroblocks that have occasionally preserved their dome-shaped features. In the northeastern marginal zone the dip of schistosity gradually turns towards the west or southwest, with the result that (the area of) the northeastern marginal zone and its environment make up the core of an extensive synclinorium (synform) that was formed during the granulitisation and later uplift of the granulite complex.

The stratigraphic sequence from oldest to youngest of the supracrustal rocks in the northeastern marginal zone of the granulite complex was established on the basis of tectonic structures and rock associations and is as follows:

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1) quartzites and quartz-feldspar gneisses
2) interbedded quartz-feldspar gneisses, biotite gneisses, hornblende gneisses and amphibolites (sedimentary-volcanic group)
3) biotite gneisses whose chemical composition corresponds to that of average shales and greywackes.

North of Syysjärvi the supracrustal rocks characteristic of the northeastern marginal zone join almost without a break to similar rocks of the Kuorboaivi schist zone. Thus, it may be presumed that the supracrustal rocks in the northeastern marginal zone of the granulite complex and in the Apukasjärvi, Vätsäri and Kuorboaivi schist zones are of the same age, i.e. Prekarelian. The quartzites in the northeastern marginal zone of the granulite complex show that the supracrustal rocks in the marginal zone were evidently deposited discordantly on the rocks of the granite gneiss complex. If true this same discordance seems to be even more pronounced in the conglomerate underlying the Björnevann formation northeast of the investigation area.

The stratigraphic sequence from oldest to youngest of the supracrustal rocks overlying the arkose gneisses in the southwestern marginal zone is probably as follows:

1) amphibolites
2) quartz-feldspar gneisses, biotite gneisses, hornblende gneisses and amphibolites (sedimentary-volcanic group) with random intercalations.

These are overlain by the fine-grained garnet-quartz-feldspar gneisses, garnet-biotite gneisses and garnet-biotite-plagioclase gneisses (sedimentary group) of the granulite complex proper. The sedimentary-volcanic groups in the southwest and northeast marginal zones are presumably deposits that correspond stratigraphically with each other.

The rocks of the sedimentary group in the granulite complex proper occupy large areas in the western and southern parts of the complex, and are also locally abundant in its central and eastern parts. The bulk of the garnet gneisses of the complex, however, are coarse-grained garnet-quartz-feldspar gneisses and garnet-cordierite gneisses. On the basis of the garnet gneisses, the granulite complex proper can be divided roughly into two subareas: the eastern half with coarse-grained garnet-quartz-feldspar gneisses and garnet-cordierite gneisses, and the western half with fine-grained garnet-quartz-feldspar gneisses, garnet-biotite gneisses and garnet-biotite-plagioclase gneisses (sedimentary group).

The chemical composition of the fine-grained garnet-quartz-feldspar gneisses corresponds to that of average greywackes and subgreywackes. Macroscopically they are very similar to the granulites in Saxony, but, they never contain kyanite and are somewhat more coarse-grained than the Saxonian granulites. The average pyrope content of the garnet in the fine-grained garnet-quartz-feldspar gneisses is distinctly higher than is that of the pale Saxonian granulites. Banded structure is due to relict bedding. Quartz is platy as is common with the quartz-feldspar rocks of the granulite facies.

The chemical compositions of the garnet-biotite gneisses and garnet-biotite plagioclase gneisses are close to those of average shales. They are rich in garnet and often in biotite as well. The garnet-biotite gneisses with large garnet crystals resemble the khondalites in India.

The coarse-grained garnet-quartz-feldspar gneisses and garnet-cordierite gneisses, which are conspicuously more coarse-grained than the fine-grained garnet-quartz-feldspar gneisses, exhibit schlieren or veined gneiss structures and weak to distinct foliation. Their chemical composition corresponds to that of mica schists and kinzigites, although some of them at least are indisputably granulitised acid and intermediate rocks of the granite gneiss complex. The coarse-grained garnet-quartz-feldspar gneisses and garnet-cordierite gneisses were obviously formed by metamorphism from the rocks of the sedimentary group, sedimentary-volcanic group and granite gneiss complex. Consequently, it is seldom possible to propose an indisputable origin for the various coarse-grained garnet gneisses. In some places in the eastern part of the complex coarse-grained garnet-quartz feldspar gneisses are massive and resemble the garnetiferous migmatic granites.

According to whole rock common lead dating the rocks of the granulite complex were uplifted or metamorphosed about 2 500 Ma ago under the conditions of the amphibolite facies.

The zircon, Rb-Sr whole rock and Rb-Sr mineral ages suggest that the granulitisation or the uplift of the granulite complex took place about 2 150 Ma ago. Soon after that, the diaphthoretic phase began, possibly accompanied by faulting and block movements. Whole rock common lead dating indicates that, early Karelian infracrustal rocks were simultaneously emplaced, about 2 050 Ma ago, into the fractures opened in the granulite complex, the Apukasjärvi, Vätsäri and Kuorboaivi schist zones and the West Inari schist zone.

According to the zircon and monazite ages, the diaphthoretic phase ended about 1 900 Ma ago. This episode is also delimited by the emplacement of the Vuoskuljärvi post-granulitic scapolite quartz diorite c. 1 910 Ma ago.

After the diaphthoretic phase the granulite complex was stabilised to such an extent that hardly any signs of movement are recognisable in the Nattanen and Juovutunturi (Juvoaivi) granites, the quartz syenite porphyry veins or in the olivine diabase veins that crosscut the garnet gneisses. Stabilisation is further indicated by their constant age 1 730 Ma obtained by different methods (whole rock common lead, zircon, titanite and Rb-Sr ages).

The granulite complex extends from Finland into the territories of Norway and the USSR. Soviet researchers have discussed the history of the rocks of the granulite complex in numerous studies. A. I. Tugarinov, E. V. Bibikova and G. L. Goroshchenko (1968) suggest that the granulitisation took place 1 950 $\pm$ 50 ago.

According to them, the zircon ages of granulitised rocks always indicate the date of granulitisation irrespective of the origin of the rocks.

E. V. Bibikova, A. I. Tugarinov, T. V. Gracheva and M. V. Konstantinova (1973) have advanced the opinion that the high temperature zircons are relatively stable in retrograde (diaphthoretic) metamorphism. In the rocks of the granulite facies that have undergone diaphthoretic metamorphism the older zircons may retain as relicts the age of the granulitisation. According to the same authors, the granulites in Lapland were formed 1 930 $\pm$ 60 Ma ago.

The present study shows, however, that the zircons of the garnet gneisses and especially of the fine-grained garnet-quartz-feldspar gneisses were crystallised during granulitisation, i.e. about 2 150 Ma ago or the granulite complex uplifted at this time. The zircons of the diaphthoretically metamorphosed garnet-cordierite gneisses are younger and indicate an age of about 2 000 to 2 040 Ma which, however, is not the age of any episode. The monazites in the garnet-cordierite gneisses as well as the zircons in the anatectic veins give an age of c. 1 900 Ma, which denotes the age of diaphthoretic metamorphism. The metamorphism of the whole granulite complex at high pressure and temperature (granulitisation or uplift and diaphthoreses) lasted for some 250 Ma at least.

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