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ON THE STRATIGRAPHICAL AND STRUCTURAL GEOLOGY OF THE KEMI AREA, NORTHERN FINLAND

BY

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WITH 29 FIGURES IN TEXT, 4 TABLES AND ONE MAP

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PREFACE.

The present investigation was begun on the initiative of my chief, the state geologist, Dr. Ahti Simonen. The field work for this study has been undertaken in the summers 1946—48, during which time I carried out lithologic mapping in the southern part of Kemi—Rovaniemi schist area. The laboratory work has been done during the winters 1947—49. In the spring 1948 I held a lecture at the meeting of the Geological Society of Finland, when the principal questions of this study were presented. In the summer 1948 I was able to take part in the Swedish-Finnish geological excursion along the frontier north of Haparanda—Tornio. For this excursion I beg to express my best thanks, especially to Dr. Olof Ödman of Sweden. The results of this excursion have been published by Olof Ödman, M. Härme, A. Mikkola and Ahti Simonen (1949).

In 1943 I was able to study the Karelian formations in East Karelia under the guidance of my esteemed teacher, Professor Pentti Eskola. He has also advised me during the work and criticized the manuscript of this study. For all this I wish to present my sincere thanks.

To Professor Aarne Laitakari, Director of the Geological Survey of Finland, I am very grateful for his kind permission to have this study published by the Geological Survey.

My chief, Dr. Ahti Simonen, has shown great interest in the progress of my work and has encouraged it by valuable instructions. For all this I am especially indebted.

Mr. O. Kouvo, Mr. R. Vanhala and Mr. O. Näykki have assisted me in the field work. For their valuable labours my special thanks are due.

Further, I desire to present my best thanks to Dr. L. Lokka, Mr. P. Ojanperä, M. A., Mr. H. B. Wiik, M. A., Mr. V. Leppänen, M. A., and Mr. M. Tavela for the chemical analyses presented here and to Mrs. Toini Mikkola, M. A., for the optical determinations.

Mrs. A-L. Okko, M. A., has translated the greater part of the present paper into English and Mrs. Lily Björling (*née* Hird) has revised the English of the manuscript. To them I am greatly indebted.

Maunu Härme

Geological Survey of Finland, Helsinki 1949.

INTRODUCTION.

Some discoveries of gold made in the last century gave rise to geological surveying in northern Ostrobothnia. Research was, however, carried along the lines of prospecting, mainly directed to Quaternary sediments. The surveying of pre-Cambrian rocks was started gradually. In the year 1875 Inberg published the first description of the Kemi—Rovaniemi and Kuusamo schist areas with their neighbourhoods. A lithologic map was appended to the paper, but was of general character only.

Systematic geological mapping was started in the Kemi—Rovaniemi area at the end of last century. In the year 1909 the Geological Survey of Finland published the map sheets of Rovaniemi (C6), Tornio (B5) and Ylitornio (B6). Hackman wrote the explanations to the maps (1914). The division of pre-Cambrian sediments into Kalevian and Jatulian formations was used in the maps, this being the basis of division generally accepted at that time (Sederholm 1907). The division was chiefly made according to the degree of metamorphism. The most strongly metamorphosed sediments were referred to the older Kalevian formation, while the better preserved types were interpreted as the younger Jatulian. The Kalevian formation comprised quartzites, dolomites, slates, mica schists, amphibole schists of different kinds, and metabasites. An unconformity was supposed to exist between these formations, and conglomerates occurring in the area were regarded as the basal formations of the Jatulian, which comprised quartzites and metabasites.

The division into formations of different age was not, however, undisputed and in the year 1915 Mäkinen advanced a theory that there was no unconformity between the formations. This is also supported by tectonical observations. There are two different parts of one and the same formation in question, which parts have been affected by different metamorphism. On the other hand, the degree of metamorphism is due only to varying distances of the intersecting »post-Kalevian» granites, which really are post-Jatulian as well.

In 1916 Mäkinen in his study mainly dealt with middle Ostrobothnia, but paid attention also to the southern part of the Kemi—Rovaniemi schist formation. Granodiorite (granite) situated to SE. of the schist area and partly affected by migmatization is considered by Mäkinen as the basement upon which the sediments had been deposited. The basement rock passes through basal breccia over into quarzite at Juokua (about 15 km. NE. of Kemi).

In 1923 Berghell and Hackman published a description of the quartzite at Kallinkangas on the S. border of the Kemi—Rovaniemi schist area. In the clastic quartzite with current-bedding there were found well preserved ripple marks, sun cracks, and raindrop prints, which gave great support to the uniformitarian or actualistic theory.

After Eskola (1921 a) had grouped the Kalevian and Jatulian as well as the Ladogian and Onegian formations into one orogenic »Karelidic» cycle, Väyrynen reported the results of his investigations from the Kainuu area (1928). In the summary of his studies (1933) he explains as a result of his Kainuu investigations that the present sericite schists and quartzites have been deposited on a flat basement of granite. These formations, later cut by metabasites, have probably been of wide distribution. They were denuded to a great degree, before another formation series of quartzites, slates and limestones was deposited on this uneven surface. The latter sediments are of flysch character. These sedimentary formations are also cut by metabasites, and ophitic, basic and ultrabasic intrusions as well as by huge massifs of granites. Väyrynen further states that the Jatulian formations in the Kuusamo and Kemi—Rovaniemi areas have been deposited in the same geosyncline as the Kalevian sediments. These series have been folded together, so that the intrusion of post-Kalevian granites represents the last phase of the Karelidic orogenic cycle. Younger eruptive rocks cutting these granites have not been found.

In the year 1936 Hausen published his study dealing with the whole Kemi—Rovaniemi schist area. He gives the stratigraphy of the sediments as follows: undermost the quartzite-psammite formation, on top of it argillites, marl schists and »green schists» as well as the dolomite formation. According to Hausen, there is here in question a coherent series of weathering and sedimentation, in which sands have first been deposited after which sedimentation of clayey weathering products took place. Calcium (and magnesium) carbonate and other soluble salts are products of weathering in a warm, humid climate. These products have been carried to the sea and have been precipitated as calcareous mud (altered to dolomites) and, when intermingled with clay, as marls. »The setting of the carbonate matter was going on in the area of clayish sedimentation but to some degree already in the area of psammitic aggradation.» »Green schists» of tuffaceous origin are intimately connected with argillites. »The position of »green schists» is not clear.»

Hausen divides the »greenstone rocks» as follows:

— prekinematic rocks: amygdaloid spilitic basaltic lavas with stratified tuffs (the »green schists»).

— synkinematic rocks: uralite diabases and amphibolites (sheared and also recrystallized). Ophiolites.
— postkinematic rocks: uralite-gabbro (also pyroxene-gabbro) of plutonic character (»Kivalo-gabbro»).

In accordance with Hackman's description of the general map, Hausen regards the basic igneous rocks between Kaakamo and Tornio and the granite of Petäjämaa (in Alatornio parish) as older than the sedimentary formation.

Hausen supposes that the thrust causing the folding had a direction towards S. (or SSE.), the southern granite area being a foreland. During the shearing processes masses of basic lavas protruded upwards along the planes of movement. These ophiolites now appear as metabasites or »greenstones».

This study deals with the southern part of the so-called Kemi—Rovaniemi area. The area investigated is bounded on the south by the Gulf of Bothnia, on the west by the River Tornionjoki, on the east it stretches as far as the River Simojoki, and on the north about to the 66th degree of northern latitude (see Fig. 1).

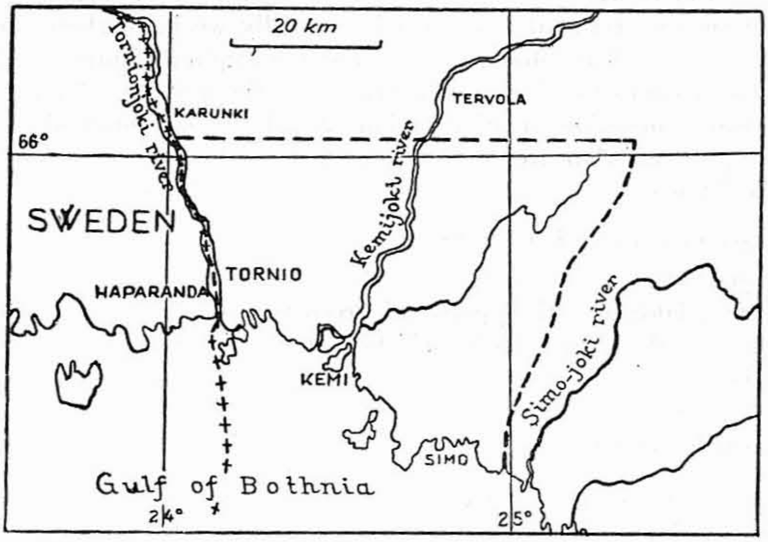

Fig. 1. Location of the area investigated in Northern Finland.

A considerable number of outcrops of pre-Cambrian rocks are met with in the area. In the southeastern and eastern part of the area there is a high ribbon of quartzites, Lautiosaari—Juokua—Kivalo. To the east of it there is a long, coherent zone of basic igneous rocks with outcrops in abundance. The highest points, the hills of Ala-, Keski- and Ylä-Penikka, rise to a height of 170 m. The SE. side of these ridges is built up of granite, the NW. side consisting for the most part of supercrustal formations. The chain of ridges divides the area also morphologically into two different parts, so that the southeastern granite area is widely very flat, whereas in the supercrustal area there are considerable differences in height. The hilly landscape, so characteristic of Lapland, is found even here. — The topographic maps of the area are incomplete, but the author has had at his disposal some aerial photographs, which, of course, have proved very useful. The morphology revealed by them has been of great value in elucidating the geological structure. Geological features near the estuaries of Kemi- and Tornionjoki rivers have been most difficult to explain, as in those localities alluvial sediments due to the uplift of the earth's crust cover wide areas. On the other hand for instance, the Juokua—Kivalo ridge with long, continuous ledges of rocks has been a very important and fertile area for the solving of stratigraphic and tectonic problems.

The Kemi—Rovaniemi area forms a coherent supercrustal formation between extensive granite areas. Its many kinds of rocks generally occur in the Karelian formations and thus it is only natural that in earlier investigations considerable attention has been paid to stratigraphic problems and to age relations between the rocks. Metamorphism in the rocks of the supercrustal formation is generally weak, so there are good possibilities of making observations about the origin and primary lithological characteristics of the rocks. Owing to the scarcity of outcrops, a quite clear conception of all questions could not be obtained.

The pre-Cambrian rocks of the area investigated have been dealt with as follows:

Supercrustal rocks

— quartzites
— amygdaloidal and hypabyssal greenstones
— stratified schists: basic schists partly of tuffaceous origin, and slates
— dolomites
— conglomerates

Infracrustal rocks

— series of differentiation:
    Anorthosite-serpentine series
    »Haparanda-series»
— migmatitic granite

In order to obtain the most coherent view of the subject, the rocks have partly been described according to their age relations. Some strongly metamorphosed rocks have been dealt with in connection with sedimentary rocks, as they have proved to be in close relation to certain sediments both regionally and also because of their distinctly stratified structures. Repetition could not be avoided when discussing the origin of some sediments from the stratigraphical point of view. — The term »metabasite», earlier in common usage, cannot be held suitable, as it includes rock members of different composition and of different degree of metamorphism, and even of varying age. The rocks are treated as groups with types belonging together. Petrographic descriptions have been given only to such an extent as has proved necessary for the elucidation of origin, stratigraphy and age relations of rocks. Instead much attention has been paid to structural features, which will be discussed in a separate chapter. In some questions concerning age relations the author has come to conclusions deviating from the opinions of earlier authors. Therefore, the stratigraphy and the age relations have been dealt with separately.

SUPERCRUSTAL ROCKS.

QUARTZITES.

The quartzites of the area investigated can be divided into the following types:

— stratified, sometimes arkosic sericite quartzites
— »glassy» quartzites, often without stratification
— jaspoid quartzites

The Lautiosaari—Juokua—Kivalo ribbon is underlain by distinctly stratified quartzite in which current bedding is rarely met with. Sericite occurs as cement in varying amounts. In some places the recrystallization is strong and the content of sericite low. Then also the bedding is indistinct, sometimes entirely lacking. Varved texture appears in places showing the base or bottom direction to be SE. Feldspars occur rarely. Carbonate may be found in places as cement in thin lenticular layers. Very large quartz veins are met with, as for instance at Juokua, where one single vein is about 20 metres in thickness.

At Kallinkangas, near the church of Kemi parish, the quartzite is generally cross-bedded, the bottom direction S. Ripple marks, sun cracks, and raindrop prints occur there on the planes of stratification, as described by Berghell and Hackman (1923). Sericite occurs richly in the cement, sometimes forming thin, interstratified pelitic layers. Microcline is found as rounded grains in the quartzite, which indicates that the sediment has been arkosic. There is also carbonate in the cement. The rounded grains of quartz are often small pebbles of vein quartz, or of »glassy» quartzite. Besides, small fragments of sericite schist and limestone (cf. Berghell and Hackman) were found, so that the sediment in some degree resembles conglomerate.

At Laurila, near the electric plant, there is a bed of quartzite, about 20 metres in thickness, showing cross-bedding. The microcline content here is lower than at Kallinkangas, but instead albitic plagioclase occurs in abundance. There are in addition some biotite and a little apatite, zircon as rounded grains, and residues of amphibole. Here, too, the quartzite resembles conglomerate, as at Kallinkangas. This quartzite occurs as inclusion in greenstone. Judging from the mylonitic contacts, it has been pressed therein during tectonic movements. At the canal cutting of Akkunusjoki river (Lautiosaari), mylonitic greenstone material is found in quartzite as intermingled during a strong tectonic crushing. Between Laurila railway station and Kallinkangas long and narrow zones of quartzites are met with in greenstone. They have the same strike and dip as at Kallinkangas, indicating that the greenstone magma has intruded between the quartzite layers. At the Lautiosaari railway cutting and at Vallitunsaari the greenstone contains also layers of quartzite, which may be fragmentary inclusions.

Analyses 1 and 2, Table I, show the composition of two specimens of sericite quartzite, the former taken from Laurila, the latter from Kallinkangas. They show how the alkali ratio varies locally at comparatively small distances.

Glassy quartzite consists almost exclusively of quartz, which is mostly fine-grained. The most important accessory is dark oxide pigment, the colour of the quartzite varying from white to black according to the amount of pigment. The texture is crystalloblastic. Sometimes there are to be found very small idiomorphic crystals of pyrite. Such glassy quartzites are met with *e. g.* at Ahvenjärvi (Alatornio parish) and at Kalkkimaa (SiO_2 = 97.5 per cent, according to Hausen) as well as in the ridge of Kivalo, SW. of Lake Jouttijärvi. They occur as small formations adjoining greenstones, often in the contact between greenstone and basic schists. Stratification is generally lacking. — Extraordinarily thin quartz-microcline veins, only visible microscopically, were found to cut this quartzite at Kalkkimaa.

Only a few occurrences of jaspoid quartzites are found in the area investigated. Black and white striated, dense quartzite resembling the jasper of Kittilä (E. Mikkola 1941) occurs on the south side of Lake Nosanjärvi. In a small area outcrops of this jasper quartzite alternate with outcrops of dolomite. These jasper quartzites are probably not interstratified with the dolomites.

A few veins of dense, red jaspoid quartzite run across the bedding of the dolomite at Kalkkimaa. They are about 2—3 cm. broad and may be compared with other quartz veins occurring in the dolomite.

About 5.5 km. east of Juokua there is a small outcrop of dense, stratified, chocolate brown jaspoid quartzite. It gradually changes through interstratified layers into stratified basic schist, rich in epidote. This jaspoid quartzite contains thin lenticular intercalations with abundant plagioclase and epidote.

GREENSTONES.

Greenstones, characteristic of Karelian formations, are common in the Kemi area, too. To their grain size they range from fine-grained basalt with amygdaloidal texture to fairly coarse-grained diabase. Also gabbroic varieties are found among the greenstones. All these are of ophitic texture and spilitic composition throughout. The chief part of these greenstones belongs to the epidote-amphibolite facies, but varieties of the amphibolite and greenschist facies are also met with. Greenstones of the epidote-amphibolite facies (Eskola 1921 b, 1925) have as chief components the following minerals: plagioclase (An_{4-15}), light green hornblende ($\gamma \wedge c = 10^\circ—20^\circ$), epidote and chlorite. As accessory minerals there are to be found sphene, magnetite, ilmenite, apatite and tourmaline. The amygdules are filled with quartz, carbonate, epidote and biotite. Analyses 1, 2 and 3, Table II, show the chemical composition of three types of greenstones.

In the greenschist facies the albitic plagioclase has remained, while the amphibole has been chloritized and the epidote replaced by carbonate. Types representing the amphibolite facies are in general products of secondary metamorphism. Recrystallization of amphibole starts on the margins of the crystals (see Fig. 2). Epidote begins to disappear and the anorthite content of plagioclase rises to about 30 per cent, being, however, lower in the middle of the grains.

Between Lautiosaari railway station and the highway, an agglomerate (Fig. 3) adjoins these greenstones. The subangular fragments are fine-grained and pale-coloured, containing amygdules of quartz. The matrix has the composition of greenstone and is probably of tuffaceous origin.

The amygdaloidal types of greenstone are extrusive lavas. Besides, there exists another group of greenstones, which is to be considered as hypabyssal diabase. Such is, for example, a belt of greenstones bordering the quartzite belt of Lautiosaari—Juokua—Kivalo on the SE. side. No amygdules are met with there, but the grain size varies within the same limits as in the area of amygdaloidal rocks. About 6 km. to ENE. of Juokua a small coarse-grained dike of greenstone cuts a more fine-grained type. The dike is

Fig. 2. Greenstone, partly amphibolitized. The recrystallization of amphiboles has begun on the margins of amphibole grains. NE. of Ala-Raumo. 20 ×.

Fig. 3. Agglomerate. Subangular fragments of amygdaloidal rock in tuffaceous matrix. Near Lautiosaari railway station.

even-grained up to its contacts. The country rock and the dike are alike as to their composition and facies, so there is reason to suppose that they are of the same origin.

As no essential difference exists between the amygdaloidal rock and the rock without amygdules as regards their mineral composition and character of facies, they are to be considered as belonging to the same intrusion. These greenstones occur, for instance, in the ridge of Kivalo on both sides of the quartzite zone, so that, judging by the bottom direction of the quartzite, the amygdaloidal rocks lie over the quartzite (on the NW. side) and the greenstones without amygdules are situated beneath the quartzite (on the SE. side). Since the greenstones are younger than the quartzites, the type without amygdules represents the hypabyssal part of the extrusive basaltic magma, which forced its way under the bed of quartzite and between the layers. The grain size cannot be regarded as any basis for classification of these greenstones. Thus, for example, west of the ridge of Kivalo in an exposure of amygdaloidal rock, the author noted very great differences in grain size, the exposure being only some dozens of metres in length. This is a common phenomenon in the younger formations, too, when an eruption of thick lava beds has been in question. As the Karelidic greenstones are to be regarded as quite a great formation of wide distribution, such a phenomenon can be possible in them also.

STRATIFIED SCHISTS.

The stratified schists are locally of wide distribution. Their composition varies from considerably basic schists to typical slates. They are all fine-grained and varve structure is a common feature. In many places basic schists gradually pass over into slates, all intermediate stages being met with.

The most basic schists contain albitic plagioclase, pale-coloured amphibole ($\gamma \wedge c =$ about 20°), chlorite, carbonate, quartz, iron ore and sometimes tourmaline. Around the amphibole grains there is often a rim of iron oxide pigment, so that they seem »burned». They are broken, not as a result of tectonical movements, but primarily deposited as such. The carbonate may be, for the most part, of sedimentary origin. The material seems to have undergone only weak decomposition before sedimentation. The varve structure as well as the small variations in composition of different layers show that mechanical sorting caused by water has taken place. The mineral composition and broken forms of minerals prove that the material of the sediment is of tuffaceous origin and also contains products of disintegration.

The slates consist of biotite, quartz, albitic plagioclase and magnetite. Judging by their material, they are products of strong decomposition.

Transition types between the basic schists and slates are often very fine-grained. In general they contain chlorite, albitic plagioclase and residues of amphiboles. The carbonate may occur abundantly in places. In the more slaty types there are no residues of amphiboles, but instead comparatively more chlorite. They contain besides small accumulations of iron oxide pigment or idiomorphic crystals of magnetite. The material of these transitional types has been distinctly affected by partial decomposition.

The stratified schists are generally of a greenish colour. Black slates are met with only in limited areas in the neighbourhood of the Taivalkoski Rapids in the River Kemijoki and in the localities between Kukkola and Hammasjärvi. They are sometimes carbon-bearing (cf. Hackman 1914, Rankama 1948), and *e.g.* near the Taivalkoski Rapids, contain pyrite and pyrrhotite.

Analyses 3, 4, 5, 6, 7, 8 and 9, Table I, show the chemical composition of different stratified schists.

As is apparent from the analyses, these schists are typically poor in potassium, only the slates having a higher potash content. Some slaty types commonly contain porphyroblasts of biotite. Analysis 8, Table I, shows the chemical composition of such a schist. These porphyroblasts are small, about 0.5—1.5 mm. in diameter (Fig. 4). Helicitic structure is distinct. Other mica found in the schists is pale-coloured, while the biotite of these porphyroblasts is dark.

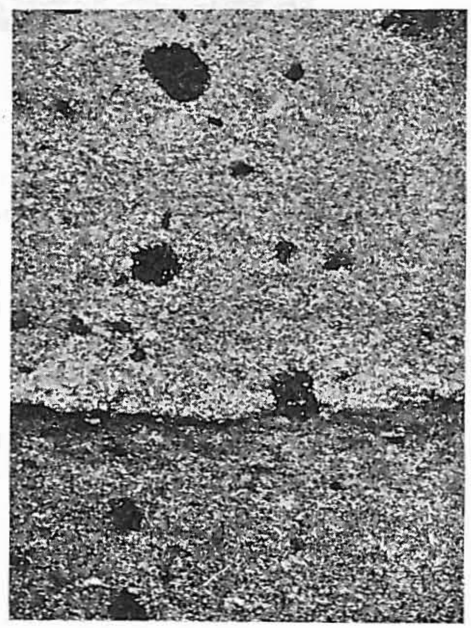

Fig. 4. Porphyroblasts (dark) of biotite in varved slate. NE. of the Taivalkoski Rapids. 20 ×.

In many places at Hammasjärvi and Kukkola there are occurrences of slate with porphyroblasts, about 0.5—2 cm. long, containing quartz and plagioclase (see Fig. 5). In his explanation to the map sheets Hackman has regarded the porphyroblasts as andalusite. Their exact determination is difficult because of the abundance of inclusions, their refractive indices were, however, approximately determined by the immersion method:

$$\alpha' = 1.541 \text{ and } \gamma' = 1.548.$$

Thus andalusite cannot be in question. The crystals are idiomorphic, the section perpendicular to the longitudinal direction is hexagonal and

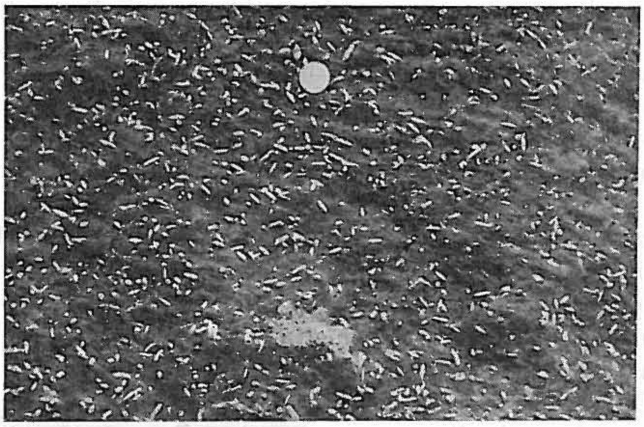

Fig. 5. Porphyroblasts of cordierite in slate. NW. of Hammasjärvi, Alatornio parish.

the extinction in this section is in part sectoral. In all probability the mineral is cordierite. Helicitic structure shows the crystals to be porphyroblasts.

The metamorphism producing these porphyroblasts resulted in a complete recrystallization of the rock and *e.g.* NW. of Hammasjärvi the schist does not split along the planes of stratification. There a basic dike about 10 metres thick and belonging to the Haparanda-series (see p. 32) penetrates these schists.

This porphyroblastic schist is well varved in an exposure about 2 km. S. of Aapajoki railway station. There it is clearly seen that porphyroblasts occur most abundantly in the dark, fine-grained upper parts of the varves (see Fig. 6). Their amount decreases towards the coarser parts and in the bottom of the varves they are in many cases entirely lacking.

Chemical analysis 9, Table I, is made of such porphyroblastic schist and its composition does not essentially differ from that of common slate. The structure of the stratified sediment has not changed and, with exception of the porphyroblasts, no exceptional mineralization seems to have taken place. According to the author's opinion, eventual metasomatism has been fairly weak and elements needed for the production of cordierite have been present already in the primary sedimentogeneous rock. This is more than probable, for the reason that the chemical composition shown by the analyses may well represent such slate where no cordierite has been formed. Judging by the chemical composition, porphyroblasts of cordierite can be produced in connection with recrystallization due to metamorphism in sedimentogeneous rocks of such chemical composition

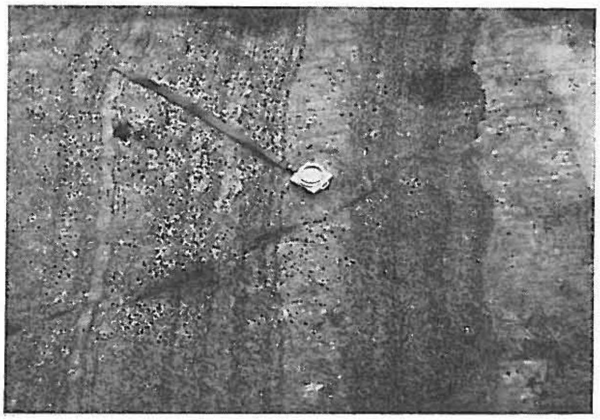

Fig. 6. Porphyroblasts of cordierite in varved slate. In the fine-grained upper parts of varves the porphyroblasts occur in abundance and their amount decreases towards the more coarse-grained bottom parts. By the railway line, ab. 2 km S. of Aapajoki station.

(Eskola 1932 a). Naturally, this does not exclude the possibility that metasomatism could have taken place to some degree also in connection with the production of these porphyroblasts.

On the River Kemijoki, in the neighbourhood of the Taivalkoski Rapids, the slate contains also small garnets (about 1 mm. in diameter), probably almandite ($N_D = 1.796$). Otherwise the mineral composition does not microscopically differ from that of the common slates of the area. These garnets are obviously the result of regional metamorphism (Harker 1928).

The stratified schists are often carbonate-bearing. Basic schists contain interstratified layers of carbonate and they often occur areally in connection with dolomites. On the basis of bottom directions indicated by the varves and of tectonical observations many series of exposures give a cross-section of the stratigraphical succession (see further p. 52).

For the main part, the basic schists represent the greenschist facies, but in connection with them there are to be found such belonging to the

Table I. Chemical composition of sedimentary rocks in the Kemi area.

N:o	1	2	3	4	5	6	7	8	9	10	11
SiO_2	82.46	78.80	47.04	51.76	52.99	54.44	57.87	60.27	61.60	59.88	49.74
TiO_2	0.20	0.24	1.82	1.79	1.43	1.66	0.62	0.90	2.13	0.42	1.50
Al_2O_3	8.04	9.95	14.61	12.98	11.38	10.91	19.38	15.76	17.21	13.97	14.61
Fe_2O_3	2.00	1.36	6.24	5.72	3.52	7.36	2.70	5.20	1.54	2.24	2.89
FeO	0.22	0.94	9.36	7.63	5.76	5.76	6.39	3.82	7.12	5.35	13.54
MnO	—	0.01	0.30	0.22	0.39	0.16	0.28	0.11	0.08	0.16	0.22
MgO	1.17	1.96	9.05	5.82	3.74	1.30	4.92	5.07	1.93	5.14	7.88
CaO	0.18	0.28	3.58	5.43	8.29	6.14	0.38	0.42	0.70	4.29	3.51
Na_2O	0.84	4.10	4.12	4.58	6.15	6.16	1.65	1.50	1.54	6.75	1.45
K_2O	2.84	0.90	0.72	0.58	0.34	0.50	2.32	2.76	3.78	0.62	0.34
P_2O_5	0.30	0.26	0.37	0.12	0.10	0.11	—	0.15	0.15	0.26	0.19
CO_2	—	—	—	0.41	4.24	3.90	—	—	—	—	—
H_2O +	1.26	0.79	2.43	2.67	1.36	1.12	3.33	3.62	2.41	0.83	3.57
H_2O —	0.12	0.07	0.09	0.06	0.06	0.01	—	0.04	0.17	0.08	0.09
	99.63	99.66	99.73	99.77	99.75	99.53	99.84	99.62	100.27	99.99	99.53

1. Quartzite. Kallinkangas. Anal. V. Leppänen.
2. Quartzite. Laurila. Anal. V. Leppänen.
3. Tuffitic schist. Ab. 4 km. NW. of Lake Jouttijärvi. Anal. V. Leppänen.
4. Tuffitic schist. Kalkkimaa. Anal. V. Leppänen.
5. Tuffitic schist. Ab. 3.5 km. SW. of Lake Jouttijärvi. Anal. H. B. Wiik.
6. Tuffitic schist. Ab. 3.5 km. SW. of Lake Jouttijärvi. Anal. H. B. Wiik.
7. Slate. Paakkola. Anal. O. Gustafsson. (Hausen 1936.)
8. Slate. Paakkola. Anal. V. Leppänen.
9. Slate with porphyroblasts of cordierite. Hammasjärvi. Anal. H. B. Wiik.
10. Amphibole-schist. Narkauskoski. Anal. P. Ojanperä. (A. Mikkola 1947.)
11. Amphibolite. E. of Kukkolankoski Rapids. Anal. M. Tavela.

amphibolite facies. On the NW. side of Lake Sompujärvi, but especially SE. of Kukkola railway station, the basic schists are accompanied by banded amphibolitic schists, too. They contain in abundance a needle- and flakelike amphibole, which is actinolite ($\gamma \wedge c = 15—17°$), besides

Fig. 7. Interstratified carbonate layers in amphibolitic schist. Ab. 5 km. ESE. of Kantojärvi, Alatornio parish.

plagioclase, quartz, magnetite and sometimes also epidote or carbonate. Amphibole and epidote are products of recrystallization. Plagioclase is recrystallized, too, its anorthite content sometimes rising to that of andesine.

These amphibolitic schists adjoin such basic schists (occasionally also quartzites), which contain carbonate in abundance as primary sedimentogeneous material. Interstratified carbonate layers occur also in amphibolites (see Fig. 7). It therefore seems that these amphibolites have been primarily similar sediments rich in carbonate, but owing to the influence of younger plutonic intrusions they have been affected by high-temperature metamorphism. A skarn reaction has then taken place between the carbonate and siliceous parts of the sediments whilst the carbon dioxide has escaped. In some carbonate-bearing sediments it could be established that in the immediate vicinity of penetrating dikes a complete skarn reaction has taken place, while at a short distance from the dike it has been only partial, in consequence of which free carbonate has remained. In many cases strong epidotization has taken place in connection with such skarn reaction.

Another type of amphibolite occurs on the SE. side of Kukkola railway station. Bosses ab. 2 cm. in diameter appear on the weathered surface of these rocks (Fig. 8). The helicitic structure shows that these bosses are porphyroblasts. They have secondarily wholly altered into a chlorite-bearing mass (Fig. 9), so that they now appear only as pseudo-


Fig. 8. Bosses of porphyroblasts on the weathering surface of amphibolitic schist. Ab. 2 km. SE. of Kukkola railway station.

morphs, the origin of which cannot be determined accurately. These amphibolites often contain also cummingtonite ($\gamma \wedge c = 17°$) as small needles.

Analysis 11, Table I, shows the chemical composition of such a rock. The present author considers it probable that these pseudomorphous porphyroblasts have originally been of cordierite and this opinion is supported by the analysis. Besides the skarn reaction caused by regional metamorphism this rock has obviously been also affected by metasomatism (see further p. 53).

No distinct line can be drawn between the basic schists and slates, as they grade into each other. As is natural in the case of a stratified sediment, in the transition zone there appear some slaty varves in the basic parts and more basic varves in the slaty parts. The basic schists are, as a rule, poor in potassium, whereas potassium has to be regarded as a typical element of slates. In addition to the main mineral composition, the author regards the potash content as a basis for drawing a line between these two rock types. This division, however, does not give a fully clear conception, as it is possible that the potash content has secondarily increased in these schists, as may be assumed in view of the slates containing porphyroblasts of biotite.

As mentioned above (p. 12), jaspoid quartzite joins on to basic banded schists in the southern end of the ridge of Kivalo. These schists contain plagioclase, amphibole and epidote, further carbonate and magnetite as well as interstratified carbonate layers. About 5 km. north of this locality in the contact zone between the belts of hypabyssal greenstone and anorthosite-serpentine series there is a small occurrence of similar stratified schists in the neighbourhood of a conglomerate. There, they contain epidote, plagioclase, quartz, microcline and biotite. The epidote has been formed by metamorphism. — These two occurrences of basic schists may be connected with the conglomerates of Kivalo (p. 24), but as to their sedimentary character they do not perhaps belong to the other basic schists and amphibolitic schists described above (see further p. 54).

DOLOMITES.

Dolomites are met with most abundantly on the W. side of the River Kemijoki. The biggest occurrences are situated about 3 km. south of Könölä (see map) and at Kalkkimaa, where it has been quarried for farmers. Further, there are numerous occurrences in Hammasjärvi and Kukkola, where it is being quarried for the cellulose industry. Dolomite is also found about 3—4 km. northwest of Koskenkylä railway station, not to mention other smaller occurrences. It is morphologically interesting to note that the exposures of dolomite are often situated higher than the surrounding schist formations. The dolomites of the investigated area are clearly stratified, generally fine-grained. Variations of colour are common, ranging from white to almost black. The same occurrence comprises different types of dolomite in quite irregular order. These dolomites also contain quartz-bearing, even quartzitic interbedded layers with rounded quartz grains. In these layers there occur also microcline, albitic plagioclase and sericite. Thin interstratified layers of glassy quartzite are also found in places. Layers of slate and basic schist are common in the dolomite. Pale-coloured dolomites contain also small lenses of talc. Quartz-carbonate veins, which are often pyrite-bearing, cut layers of dolomite. They are younger than the country rock.

In comparatively few cases of dolomites proper, have reactions taken place between the siliceous matter and carbonates. In such cases there appear needles of either diopside or amphibole as reaction products. Some of these small, local skarn occurrences are found in the western part of the area, as *e. g.* on the River Liakkajoki, by the bridge of Liakka road. They are mainly caused by younger intrusions of the Haparanda-series (see further p. 32).

In two localities at Kalkkimaa the interstratified quartzitic layers are found to contain marks greatly resembling ripple marks on the planes of stratification. As, however, these thin layers occur in comparatively easily deformable dolomite, it is possible that crumpling of this kind could also have been produced by tectonic movements. Hausen (1936) states, however, that the Vitgrund dolomite of the Kalix formation (in Sweden) contains quartzite and sandstone layers with ripple marks on the planes of stratification.

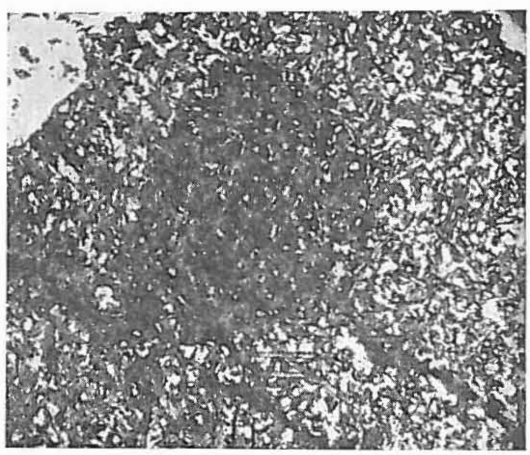

Fig. 9. Pseudomorphic porphyroblast in amphibolitic schist. E. of the Kukkolankoski Rapids. 15 ×.

CONGLOMERATES.

THE TAIVALKOSKI CONGLOMERATE.

On either side of Kemijoki river the varved slates sometimes contain separate, rounded pebbles of black, dense, »glassy» quartzite. They do not form any conglomerate. Near Koskenkylä station in the Taivalkoski Rapids (Kemijoki river) and in their neighbourhood there are, connected with slate, schists rich in quartz and containing also small grains of quartzite. A conglomerate joins on to these schists. The conglomerate in the rapids is well exposed with an EW. strike of the strata and a vertical dip. The layers are not all similar, but some of them have pebbles in abundance and little matrix, whereas others have hardly any pebbles at all. Sorting according to the size of pebbles occurs in certain layers. Those layers that contain no pebbles often show current-bedding (see Figs. 10, 11 and 12). The boundaries between the layers are sharp.

The well-rounded pebbles mainly consist of quartzite; moreover, there are to be found some fragments of slate. Quartz, biotite, albite and apatite make up the cement. The quartzite pebbles are stratified, sometimes current-bedded, and strongly recrystallized. Some pebbles of dense, stratified, chalcedonic quartzite have also been met with.

The fragments of slate are angular and mostly occur in the interbedded layers, which contain few other pebbles (see Fig. 12). As the conglomerate joins on to the slate, there is a possibility that the slate had not yet been

Fig. 10. Conglomerate at the Taivalkoski Rapids (Kemijoki river).

fully recrystallized before the deposition of the conglomerate took place. Fragments of slate have not held together during the transport and therefore there are only few of its fragments left in the conglomerate and even those are angular. For the same reason they have been more easily deformable than the pebbles of other rocks. Sometimes pebbles of quartzite may be seen which have been pressed by tectonical movements into a fragment of slate.

Fig. 11. Conglomerate at the Taivalkoski Rapids. Current-bedded interstratified layers are common.

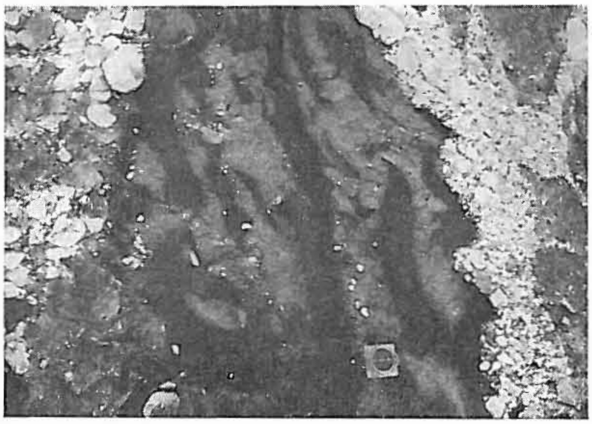

Fig. 12. Conglomerate at the Taivalkoski Rapids. Angular fragments of slate occur most often in layers which do not contain rounded pebbles of quartzite.

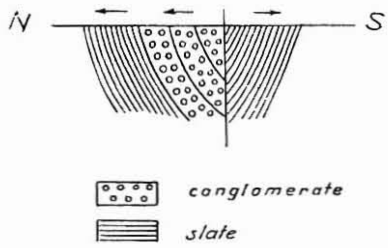

Fig. 13. Schematic vertical section of the conglomerate at the Taivalkoski Rapids. The arrows show the directions of the bottom appearing in these rocks.

The layers of conglomerate have a northerly bottom direction, as is also the case with the slate adjoining the conglomerate on the N. side. On the S. side conglomerate borders the slate with a 0.5 m. wide fissure, the bottom in the slate pointing towards the south. The conglomerate thus seems to belong to the surface of the slate or at least to its surficial parts (see Fig. 13). This is indicated also by the fold axes and lineations. The sorting of material, the current bedding and the sharp boundaries between the layers show that the conglomerate is a fluviatile deposit (Hausen 1936). — This Taivalkoski conglomerate is a formation about 3 km. long and several dozens of metres thick. The conglomerate boulders found in different localities of the investigated area give reason to assume that more similar formations might be found there.

CONGLOMERATES IN THE KIVALO RIDGE.

Two occurrences of conglomerate are to be found in the Kivalo ridge. One occurs 7.5 km. ENE. of Juokua and the other on the N. side of Lake Sompujärvi (see Figs. 14, 15 and 16). Each occurrence is situated as a long formation at the contact of ossipite and greenstone. The distance between the nearest exposures of ossipite and greenstone is only some dozens of metres and in this intervening space there is conglomerate. Judging from the surface, the thickness of each conglomerate is not more than 20 metres.

Fig. 14. Conglomerate. The surface is strongly weathered due to the carbonate content of the cement. Ab. 7.5 km. ENE. of Juokua. Kivalo, Kemi parish.

Both conglomerates are composed of similar material. The pebbles consist for the most part of granite and of ossipite (see pp. 26 and 34), further in some degree of greenstone and anorthosite, as well as of quartzite and slate. Anorthosite and slate occur as angular fragments, too, but on the whole the pebbles are well rounded. The big-

Fig. 15. Conglomerate. N. of Lake Sompujärvi. Kivalo, Kemi parish.

gest pebbles of granite are up to 0.5 m. in diameter and among them there are to be found migmatitic and even porphyritic granites from the SE. side of the supercrustal area (see p. 34). Sometimes the granite in these pebbles also contains granitized remnants of basic fragments. The pebbles of ossipite, anorthosite and greenstone are of exactly the same type as found in the outcrops around the conglomerate. The quartzitic pebbles consist of vein-quartz and of fine-grained, glassy quartzite and contain only little sericite. The fragments of slate are of exactly the same type as are the slates of the area investigated.

The matrix contains calcite in abundance and plagioclase of two kinds, one having 5 per cent of anorthite, the other 50 per cent. Besides there are in the cement microcline, quartz, biotite, epidote and chlorite.

Fig. 16. Pebbles of migmatitic granite in the conglomerate on the N. side of Lake Sompujärvi. Kivalo, Kemi parish.

Recrystallization has only taken place in the carbonate. The number of pebbles varies in places, but no clear stratification can be seen. Owing to the strong weathering of the cement, the pebbles are often projecting (see Fig. 14). — Ossipite and greenstone are strongly foliated near the contact zone. The conglomerate is in places almost entirely preserved and the pebbles are not deformed. — These conglomerates will be discussed later (p. 54).

OTHER CONGLOMERATES.

Local conglomerates occur also in connection with the dolomites. About 400 m. SE. of Lake Nosanjärvi dolomites are accompanied by a small conglomerate containing dense, rounded pebbles of quartzite and of dolomite in marly cement.

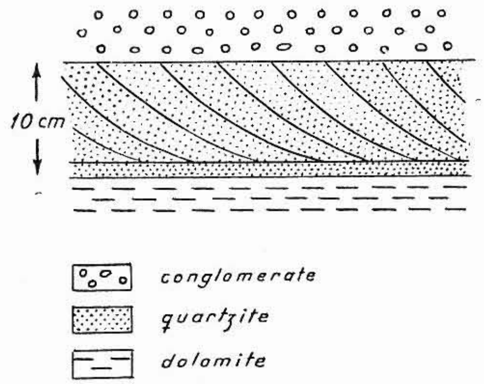

Fig. 17. Schematic drawing of the position of conglomerate as regards the dolomite. The current bedding shows that the conglomerate overlies the dolomite. W. of Kantojärvi, Alatornio parish.

Another small occurrence of conglomerate joining on to dolomite is situated about 3 km. north of Viitakoski. The pebbles consist of stratified dolomite, the cement of schist material rich in quartz. This conglomerate passes northwards through quartzitic interstratified layers over into purely yellowish dolomite.

Abount 2.5 km. W. of Kantojärvi, Alatornio, there is a small occurrence of conglomerate where rounded pebbles of dolomite are lying in quartz-carbonate matrix. Through a thin current-bedded interstratified layer of quartzite this layer of conglomerate passes into dolomite. The bottom direction indicated by current bedding shows that the conglomerate is overlying the dolomite (see Fig. 17).

INFRACRUSTAL ROCKS.

ANORTHOSITE-SERPENTINE SERIES.

Starting from the northern outskirts of the town of Kemi towards NE., there is to be found a series of outcrops of pale-coloured anorthosite. About 0.5 km. west of Lake Elijärvi this grades over into a fairly extensive exposure of serpentine-peridotite. After a break near Juokua the same rocks occur in the zone of the hills of Ala-, Keski- and Ylä-Penikka as well as of Kirakkajuppura, on the E. side of the quartzite ridge of Kivalo. There a broad zone of light greenish gabbro is well exposed. The chemical composition of the common types of this gabbro is nearest to that of the ossipite group of Niggli (1923). On its NW. side the ossipite gradually passes over into light anorthosite and on its SE. side into serpentine-peridotite. In this continuous zone, which is about 2—3 km. broad and over 20 km. long, the main part consists of ossipite, while anorthosite and peridotite occur as comparatively narrow zones. In general the belt of these basic plutonic rocks borders the greenstone with a more fine-grained ossipitic variety. As in this belt the gradual transition of rock members into each other can already be areally established in detail, this is to be considered a very clear differentiation series *in situ*.

The anorthosite contains plagioclase (An_{50-75}) in abundance, besides amphibole and chlorite. The plagioclase is weakly zoned and contains clinozoisite and also carbonate as products of saussuritization. The amphibole is often strongly chloritized. The rock is fairly coarse-grained, the texture is hypidiomorphic. Analysis 4, Table II, shows the chemical composition of the anorthosite.

In the ossipite the chief minerals are amphibole and plagioclase (An_{45-65}), besides chlorite and some remnants of pyroxene. The plagioclase is weakly zoned and often contains epidote as a product of saussuritization. The amphiboles are, at least partly, a product of uralitization, and chloritization of amphibole can be ascertained, too. The rock is often coarse-grained, the texture hypidiomorphic. Sometimes the plagioclase crystals are lamellar and to some degree subparallel in arrangement. Analysis 5, Table II, shows the chemical composition of an ossipitic type. In the analyzed specimen the ratio between the chief minerals is

amphibole ($\gamma \wedge c = 21°$, $2\,V\alpha = 62°$)	75 per cent
plagioclase (An_{60-64})	25 per cent

The refractive indices of this hornblende were found to be $\alpha' = 1.620$, $\beta' = 1.635$, $\gamma' = 1.641$ (determined by the immersion method). — The light-green amphiboles of the anorthosite and ossipite are very likely rather rich in CaO and Al_2O_3 because the An-content of the plagioclases in these rocks is relatively low compared with the high percentage of lime and alumina shown by the analyses 4 and 5, Table II.

The occurrence of serpentine in the peridotite is common, serpentine rocks being more rare. The serpentine occurs both in the form of chrysotile and antigorite. Olivine may be observed as remnants within the serpentine. The primary pigmentary contours of the olivine grains are still clearly visible. Here and there are met some big amphibole grains, which have enclosed olivine. The amphiboles are, at least partly, also a product of uralitization and have further to some degree altered into serpentine and chlorite. A serpentine-peridotite was analyzed, Anal. 6, Table II.

Table II. Chemical composition of the igneous rocks in the Kemi area. Including their norms and Niggli numbers.

N:o	1	2	3	4	5	6	7	8	9	10	11
SiO_2	48.95	49.23	54.84	49.25	47.45	41.01	49.96	56.66	57.84	67.41	48.51
TiO_2	0.30	1.30	2.21	0.12	0.19	0.23	1.21	0.92	0.94	0.34	0.51
Al_2O_3	14.61	13.00	13.25	20.14	17.64	5.22	15.76	14.59	15.24	16.12	15.50
Fe_2O_3	4.00	4.04	7.00	1.45	1.16	4.76	2.40	2.38	2.24	1.36	3.55
FeO	7.34	9.90	6.52	3.02	3.46	5.94	6.91	5.78	5.33	2.01	8.42
MnO	0.40	0.33	0.19	0.08	0.10	0.16	0.11	0.12	0.10	0.06	0.10
MgO	9.18	7.10	3.96	8.70	12.01	29.00	6.76	4.71	4.88	0.94	6.34
CaO	9.14	9.69	4.38	13.43	16.12	4.00	8.74	5.67	6.41	4.07	11.92
Na_2O	2.40	1.48	4.41	1.18	0.30	0.22	3.16	3.64	3.27	4.49	1.12
K_2O	0.26	0.10	1.44	0.22	0.20	0.22	3.16	2.76	2.68	2.05	1.48
P_2O_5	0.18	0.20	0.28	0.04	0.16	0.09	0.65	0.70	0.43	0.48	0.09
H_2O +	3.22	3.63	1.14	2.37	1.73	8.56	1.31	1.48	0.63	0.56	1.87
H_2O —	0.03	0.02	0.42	0.03	0.03	0.56	0.03	0.11	0.19	0.10	0.07
CO_2	—	—	—	—	—	0.11	—	—	—	—	—
	100.01	100.02	100.04	100.03	100.55	100.08	100.16	99.52	100.18	99.99	99.48

1. Greenstone. W. of Lake Ahvenjärvi. Anal. V. Leppänen.
2. Greenstone. Liedakkala. Anal. H. B. Wiik.
3. Greenstone. Kivalo. Anal. M. Tavela.
4. Anorthosite. Ab. 3 km. W. of Lake Elijärvi. Anal. H. B. Wiik.
5. Ossipite. Ylä-Penikka. Kivalo. Anal. V. Leppänen.
6. Serpentine peridotite. 0.5 km. W. of Lake Elijärvi. Anal. H. B. Wiik.
7. Gabbro. Kaakamo. Anal. H. B. Wiik.
8. Diorite. Ruottala. Anal. V. Leppänen.
9. Diorite. Kaakamo. Anal. H. B. Wiik.
10. Granodiorite. E. of Petäjämaa. Anal. P. Ojanperä.
11. Diabase dike. Viantie. Simo. Anal. M. Tavela.

N:o	1	2	3	4	5	6	7	8	9	10	11
qu	—	7.23	9.59	1.75	—	—	—	6.23	7.92	23.74	1.73
or	1.56	0.61	8.52	1.28	1.17	1.28	18.64	16.31	15.86	12.13	8.74
ab	20.29	12.53	37.28	9.96	2.52	1.84	25.96	30.78	27.68	37.96	9.49
an	28.31	28.51	12.13	49.04	46.20	12.63	19.50	15.35	18.97	17.05	32.90
ne	—	—	—	—	—	—	0.45	—	—	—	—
en	22.80	17.66	9.85	21.65	22.98	27.58	—	11.72	12.14	2.34	15.77
hy	10.39	13.55	2.89	4.29	4.05	2.64	—	7.35	6.57	2.12	11.87
fo	0.03	—	—	—	4.84	31.25	11.80	—	—	—	—
fa	0.02	—	—	—	0.94	3.29	6.90	—	—	—	—
wo	6.60	7.62	3.23	7.21	13.66	2.78	8.18	3.44	4.19	—	10.71
cor	—	—	—	—	—	—	—	—	—	0.27	—
mt	5.79	5.86	10.14	2.11	1.69	6.90	3.47	3.45	3.24	1.97	5.14
il	0.58	2.47	4.20	0.23	0.36	0.44	2.29	1.75	1.79	0.64	0.97
ap	0.44	0.47	0.68	0.10	0.37	0.20	1.55	1.65	1.01	1.14	0.20

si	110.9	117.6	159.4	111.6	95.4	69.2	120.5	168.0	168.8	284.7	112.6
ti	0.5	2.3	4.8	0.2	0.3	0.3	2.2	2.1	2.1	1.1	0.9
al	19.5	18.3	22.7	26.9	20.9	5.1	22.4	25.5	26.2	40.1	21.2
fm	52.6	53.3	48.7	37.7	43.7	87.1	42.8	40.8	39.4	17.6	44.5
c	22.2	24.8	13.6	32.5	34.6	7.2	22.6	18.0	20.1	18.4	29.6
alk	5.7	3.6	15.0	2.9	0.8	0.6	12.2	15.7	14.3	23.9	4.7
qz	—11.9	3.2	—0.8	0.1	—7.9	—33.3	—28.5	5.2	11.7	53.1	—6.2
k	0.07	0.04	0.18	0.11	0.30	0.40	0.40	0.33	0.35	0.23	0.46
mg	0.59	0.47	0.35	0.78	0.82	0.83	0.57	0.51	0.54	0.34	0.49
c/fm	0.42	0.47	0.28	0.86	0.79	0.08	0.53	0.44	0.51	1.05	0.66

Fig. 18. Strongly foliated ossipite near the contact with greenstone. The handle of the hammer is directed towards N. On the W. side of the Keski-Penikka hill. Kivalo, Kemi parish.

The analyses of the rocks described above indicate that the members of this series are very rich in Ca and Mg and poor in potassium. In this respect the average composition of this series greatly resembles that of the greenstones in the area. The average of the analyses 4, 5 and 6, Table II, is: $SiO_2 = 45.90$, $TiO_2 = 0.18$, $Al_2O_3 = 14.33$, $Fe_2O_3 = 2.46$, $FeO = 4.14$, $MnO = 0.11$, $MgO = 16.57$, $CaO = 11.18$, $Na_2O = 0.57$, $K_2O = 0.21$, $P_2O_5 = 0.09$, $H_2O = 4.43$. Its Niggli numbers are: si = 92.4, ti = 0.3, al = 16.9, fm = 55.2, c = 24.1, alk = 3.8, qz = — 22.8, k = 0.71, mg = 0.90, c/fm = 0.44.

A contact[1] of anorthosite with greenstone is met with on the northern outskirts of the town of Kemi. The greenstone at the contact is foliated and the same in some degree is the case with the anorthosite as well. Fragments of greenstone are found in the anorthosite. At the immediate contact the plagioclase of the anorthosite is albitic and there may be spilitization in question, as the anorthosite also contains carbonate. Because of the smallness of the exposure, it is difficult to obtain a clear conception of it, but it seems the anorthosite penetrates the greenstone.

At the contact with hypabyssal greenstone the ossipite is in general strongly schistose (Fig. 18), sometimes quite mylonitized, but in view of their long contacts, the boundary between them is remarkably sharp. In its coarse- as well as in fine-grained parts the greenstone borders the belt of anorthosite-serpentine series. No dikes of either rock have been met with in the other. — Instead veins of microcline granite are found in the peridotite (see further p. 37).

HAPARANDA—SERIES.

Black gabbro is met with on the shore SW. of Kaakamo. On its N. side there is brown diorite with unimportant parts of granodiorite. The gabbro area grows somewhat broader to the west and continues to the

[1] After this paper was already in print the present author had an opportunity to examine this contact in a cut quarried for the foundations of a building in Kemi. The contact was tectonically disturbed, but it was, however, possible to see that the anorthosite contains fragmentary inclusions of the greenstone. At the contact and especially in the fragments the greenstone was in places impregnated by pyrite. Close to the contact the greenstone is rich in carbonate, whereas it is typically rich in epidote already at a distance of few centimetres from the contact line.

neighbourhood of Tornio and further into Sweden. Between Kaakamo and Tornio the gabbro shows remarkable schistosity and is penetrated by dioritic and aplitic dikes. The diorite at Kaakamo contains schistose fragments of gabbro, which it has assimilated. There is no distinct line between the gabbro and diorite here, but all transitional members are met with. The diorite contains fragments of fine-grained, basic, pyroxene-bearing, wholly recrystallized rock, which is streaked as though stratified. The origin of these fragments could not be ascertained. The diorite is penetrated by granodioritic dikes and the granodioritic parts of the area contain fragments of diorite.

Plagioclase in the Kaakamo—Tornio gabbro is zoned, the An-content varying between 70 and 30 per cent in different zones. Pyroxene ($\gamma \wedge c =$ about 40°) on its borders has altered into amphibole and further into biotite. Pyroxene and amphibole ($\gamma \wedge c =$ about 18°) are often zoned, too. Microcline and quartz appear as last crystallized minerals.

Plagioclase in the diorite is idiomorphic and well zoned, the maximum and minimum values of the An-content are 50 and 28 per cent. There are two kinds of pyroxene: orthorhombic and monoclinic ($\gamma \wedge c = 35$—50°). Pyroxene, too, is in some degree zoned and contains concentric rings of iron oxide pigment showing the contours of crystalline forms. The amount of amphibole and biotite is smaller than in gabbro. Microcline and quartz also in this rock are last crystallized in the interspaces between other more idiomorphic minerals.

Plagioclase in the granodioritic parts is also weakly zoned (on the average oligoclase). Pyroxene is strongly uralitized, occurring only as remnants within the amphibole. Microcline and quartz occur as the last crystallized minerals.

Reddish brown diorite and granodiorite are found in some exposures at Ruottala. Here, in zoned plagioclase, the maximum and minimum values of the An-content in diorite were found to be 65 and 23 per cent. The corresponding values in granodiorite are 34 and 20 per cent. Each rock contains pyroxene only as remnants of uralitization. In the two rocks microcline and quartz occur as last crystallized minerals between more idiomorphic grains. The above mentioned rocks greatly resemble the diorite of Kaakamo. The higher amphibole and biotite content as well as the small amount of epidote show, however, that they represent a mineral facies of lower temperature. Saussuritization has taken place in the plagioclase, too, but it occurs, according to the distinctly limited zoning, only in certain zones.

At Alatornio, between Petäjämaa and Kantojärvi, there occurs a fairly great plutonic *massif*, the chief part of which is composed of grey granodiorite, but contains granitic parts also, as well as somewhat more fine-grained, basic varieties on its borders. The plagioclase in the granite and granodiorite is of well developed crystal form, well zoned, the An-content varying from 37 to 20 per cent. Pyroxene occurs as a remnant of uralitization. Microcline and quartz occur also here as last crystallized constituents between more idiomorphic minerals. Microcline also forms phenocrysts which include fairly big crystals of other minerals. As to texture and composition, the granite and granodiorite bear a great resemblance to the Kaakamo diorite.

More basic varieties on the margins represent a transitional phase towards the low temperature facies. Strong saussuritization has taken place in some zones of plagioclase, and the An-content is found to vary in different zones, the maximum and minimum values being 35 and 24 per cent. It is evident that there have also been zones with an An-content over 35 per cent, but under secondary metamorphism just these zones have been unstable and therefore become saussuritized. — These basic marginal varieties contain, as a rule, more or less uralitized pyroxene, as well as biotite and some epidote. Microcline and quartz occur also here as distinctly last crystallized minerals.

The formations on the N. side of the Kaakamo gabbro-diorite *massif* curve, following the contours of the *massif* (see map and further p. 45), but a still clearer curve is to be seen round the Petäjämaa—Kantojärvi *massif*. The neighbourhood of these *massifs* thus shows tectonic influences of intrusion.

About 3.5 km. north of Petäjämaa (Alatornio) there occurs the contact of the Petäjämaa—Kantojärvi *massif* with supercrustal rocks. There the basic marginal varieties penetrate the supercrustal rocks, granite cutting both these basic varieties and the supercrustal formation. Such is also the case about 1.5 km. WNW. of Lake Nosanjärvi. Dikes originating from these *massifs* are met with in abundance. The biggest of these dikes are as broad as 10 m. In the localities of Kukkola—Könölä and of Hammasjärvi, these dikes penetrate all rocks of the supercrustal formation. As to their composition, the dikes vary from granitic to gabbroic, being, however, always characterized by the occurrence of serially zoned plagioclase and more or less uralitized pyroxene. Besides, there are generally found microcline and quartz and, as a secondary product of reaction, biotite. About 900 m. SW. of Lake Nosanjärvi, for instance, quartzite with carbonate cement is penetrated by a dike of plagioclase porphyry, the plagioclase of which is wholly unaltered and serially zoned, the An-content in different zones varying from 65 to 22 per cent. This dike has caused a partial skarn reaction with the country rock.

On account of their petrographic character and similar attitude to the surrounding rocks the gabbros, diorites and the granites just described belong genetically together and form a differentiation series. This is also apparent from the analyses made of some of these rocks (Anal. 7, 8, 9 and 10, Table II). It is interesting to note that the potassium content seems to be higher in the gabbro than in more acid parts. This can be observed microscopically as a general feature of the series, although not without local exceptions. On the other hand the abundance of sodium in the acid portions is a very common phenomenon. — Rocks belonging to this series of differentiation occur in an extensive area, also on the Swedish side of the River Tornionjoki. (As to the denomination »Haparanda-series», see Ödman *e. a.* 1949.)

About 3 km. north of Kukkola railway station, by the railway line, there is an occurrence of diorite, which as to its texture and mineral composition obviously belongs to the same series. About 5 km. east of Kukkola station, on the River Liakkajoki, a small occurrence of gabbro also belongs to it. — At Lautiosaari, on the eastern side of Kemijoki river, in some outcrops, there occurs fine-grained, basic igneous rock containing a considerable amount of biotite and of microcline. Other basic rocks in the area are, without exception, typically poor in potassium, as stated before. In the immediate vicinity of this basic formation rich in potassium, there occurs no granite, nor is it cut by granitic veins which might secondarily have brought potassium. Therefore, the author regards this formation as also belonging to the gabbro-diorites of the Haparanda-series. At Lautiosaari, about 600 m. south of the electric plant on the shore of Kemijoki river, there occurs a small breccia in this formation, with pale-coloured greenstone fragments lying in a dark, basaltic matrix. The fragments are bordered by dark reaction rims. That this small formation at Lautiosaari belongs to the Haparanda-series, which is younger than the supercrustal formation, is proved by the fact that in the greenstone as well as in the quartzite the strike curves, conforming with this formation.

At the contact of the Petäjämaa—Kantojärvi granodiorite the country rock has been metamorphosed in the amphibolite facies. The same feature is generally to be noted also in the adjacent areas of the other *massifs* belonging to this series. On the border of the Kaakamo—Tornio *massif*, gradual amphibolitization of greenstone can be seen *i. a.* about 3 km. NE. of Ala-Raumo (Fig. 2). Around the Petäjämaa—Kantojärvi *massif*, amphibolitic schists as products of metamorphism occur *i. a.* on the S. and W. sides of Lake Nosanjärvi, as well as SE. of Kukkola, where also metasomatism has taken place (see pp. 20 and 53). At Kaakamo, on the western side of the estuary of Kemijoki river, as well as on the NW. side of Lake Hammasjärvi, and between Kukkola and Aapajoki, slates occur containing cordierite porphyroblasts, which were produced as a result of metamorphism caused by the intrusions of the Haparanda-series and of the dikes belonging to same.

The marginal varieties of the Petäjämaa—Kantojärvi *massif* are to be regarded as previously crystallized parts belonging to the same process of intrusion and differentiation. The dikes belonging to the Haparanda-series and cutting the supercrustal formation are mostly basic; granitic dikes are found in a lesser degree. On Tornionjoki river near Kukkola station, the granite of the Haparanda-series has brecciated stratified, slaty schist (see Fig. 19). An analogous phenomenon is to be seen ab.

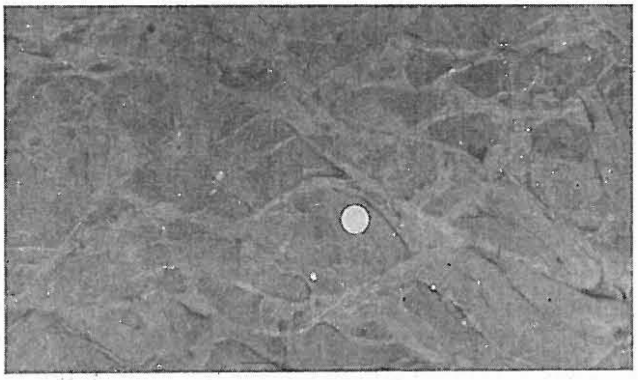

Fig. 19. Stratified slate brecciated and granitized by granite. The shore of Tornionjoki river near Kukkola railway station.

5 km. ESE. of Kantojärvi, where the dioritic marginal varieties at the contact have been brecciating and assimilating amphibolitized greenstone and basic schists.

MIGMATITIC GRANITE.

In the SE. and E. parts of the area investigated there occurs a wide area of granite extending as far as the schist formations of Utajärvi—Kiiminki and of Kainuu. The composition of this granite shows considerable variation. It is almost aplitic, the colour changing from grey to red. Although the composition does not depend upon the colour, the grey type is often rich in plagioclase (oligoclase) and most potash is present in biotite and in a small amount of sericite. The quartz is clear, possibly in part recrystallized. As accessory minerals epidote and apatite are met with. The red type is often rich in microcline, but also contains some plagioclase (albite-oligoclase). There is besides quartz, biotite, epidote, sericite, and apatite. Varieties of all degrees occur between these two types of granite. On the whole, the granite is in some measure foliated, belonging in the first place to gneissose granite, although tectonically undisturbed parts may be found in different types.

In this area of granite several outcrops and series of outcrops are met with consisting of hornblende-gabbro as well as of amphibolitized greenstones. In general, schistosity and lineation in these basic inclusions partly differs from the orientation of the granite in the vicinity. Especially near these basic outcrops, but also elsewhere, the granite contains fragments of these rocks, sometimes even as breccia (Fig. 20).

Fig. 20. Schistose amphibolite brecciated by granite. Viantie, Simo parish.

In a few more extensive outcrops the greenstone has partly preserved its epidote-amphibolite facies, while as breccia and fragments it belongs to the amphibolite facies. This rise to a high-temperature facies has thus evidently been caused by granite. Included gabbro is dark and partially recrystallized, but in places it can be classed with the gabbros of the anorthosite-serpentine series. East of the hills of Ylä-, Keski- and Ala-Penikka, granite contains fragments of biotite, chlorite and serpentine. They have still as relics similar features of texture as are seen in the serpentines of the hills of Penikka, to which they originally belong.

The basic fragments in granite are in general strongly foliated. It is evident that schistosity is an important factor in their granitization, for it has furthered the injection of felsic material into the fragments. In the granite area granitization of basic rocks takes place in a remarkable degree. This is shown by the fact that mafic minerals of these fragments have altered into biotite and also the amount of feldspar and quartz has increased in such measure that of these fragments only a darker part rich in biotite finally remains as a »nebulitic» remnant. Simultaneous tectonical deformation has often elongated them into long biotite-rich streaks. The fragments being closely spaced, the rock then assumes a structure quite resembling veined gneiss (Fig. 21).

Fig. 21. Schistose amphibolite brecciated and partly granitized by migmatitic granite. Rocks on the shore. Ab. 5 km. SE. of Kemi town.

Both microcline- and plagioclase-rich types penetrate and granitize these basic fragments. The absence

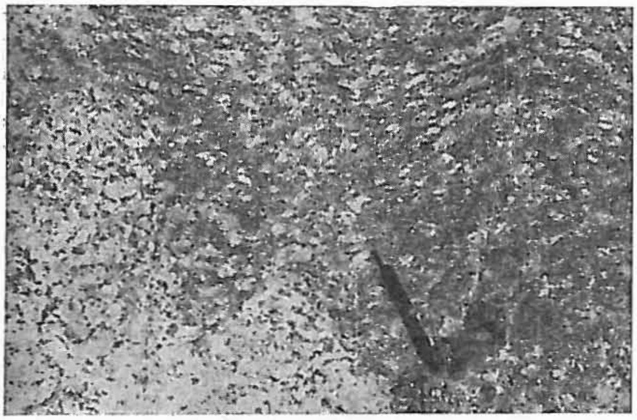

Fig. 22. Granitization of a basic inclusion. Below on the left is porphyritic granite, which has been injected also into the darker basic part producing porphyroblasts of microcline. Maksniemi, Simo parish.

of microcline locally may be due to the fact that potassium has gone to the production of biotite. Recrystallization of the amphibole takes place especially when a type rich in plagioclase acts as the cutting and granitizing granite. Thus small portions of hornblende granite can be formed locally. By granitization plagioclase rich in anorthite has altered into albite and in this connection epidote occurs often as small accumulations. Albite-epidote rock, or helsinkite (Laitakari 1918, Wilkman 1928, Mellis 1932) is sometimes met with locally.

In connection with granitization plagioclase has hardly formed any porphyroblasts, as microcline has generally done (Simonen 1941). Porphyroblasts of microcline, however, occur in those parts of the granite richer in biotite, where the abundance of biotite originates from basic rocks. Even though this granite is generally of a porphyritic nature in the whole investigated area, the proper porphyritic granite occurs in parts where granitization has been at its strongest (Figs. 22 and 23).

Fig. 23. Porphyritic granite. A quarry ab. 2 km. NE. of Kemi town.

The contact of granite with quartzite is exposed at Juokua, almost 15 km. NE. of Kemi. The contact is tectonically disturbed, so it is difficult to get a clear conception of the age relations between these rocks. In the contact zone there occur, furthermore, remnants of greenstones and of ossipite. No basal formations occur between the quartzite and granite. It seems evident that also in this locality there have been basic igneous rocks as thin sheets between granite and quartzite, as is the case elsewhere in the ridge of

Kivalo. However, during movements they have partly been crushed into mylonites and granitized for the most part. In connection with deformation, the contact zone has been brecciated and therefore quartzite fragments are to be found as inclusions in granite. The quartzite contains microcline-quartz veins, so that the granite rather appears to be cross-cutting. More remarkable granitization has not taken place. The assumption that the granite is younger than the quartzite is supported by the fact that quartzite here is fairly strongly recrystallized, although this phenomenon may also be caused by the basic, igneous intrusions.

The contact of migmatitic granite with the rocks of the anorthosite-serpentine series is not exposed. On the S. side of the hill of Ala-Penikka and on the E. border of Ylä-Penikka the microcline granite veins, however, cut these basic rocks. Besides, as granite has been found to cut and granitize inclusions originating from this basic series, the migmatitic granite must be younger than the anorthosite-serpentine series.

In general, the contact between greenstone and granite is covered by soil. Only on the N. side of the hill of Kirakkajuppura, where the zone of the anorthosite-serpentine series breaks off, are microcline veins found cutting greenstone on the SE. side of Palokivalo. Likewise, the granite contains more or less amphibolitized and granitized inclusions of greenstone in abundance.

At the estuary of Liakkajoki river, Alatornio, porphyritic microcline granite contains fragments and granitized remnants of the surrounding gabbro belonging to the Haparanda-series. The gabbro is cut by dikes of the porphyritic granite in many localities and these dikes have produced fairly big porphyroblasts in the country rock. Near the school-building at Ala-Raumo granitic material has been injected along the foliation planes and microcline has here produced porphyroblasts. When examining megascopically a section made at right angles to the foliation of this rock it seems to be a strongly foliated, porphyritic granite with biotite-bearing streaks. On the splitting planes along these streaks the rock appears as schist rich in biotite containing some microcline phenocrysts.

At Kiviranta, Alatornio, there occurs another small intrusion of porphyritic granite in gabbro. Microcline granite veins of porphyritic texture are generally met with in exposures of gabbro in the neighbourhood of Tornio.

Several diabase dikes penetrating migmatitic granite occur about 1 km. north of Viantie railway station. They border the granite sharply and are centrally more coarse-grained than near the contacts. These basic dikes consist of plagioclase, amphibole, sphene, and ilmenite which is altered into leucoxene. The plagioclase is saussuritized and amphibole is in part altered to biotite. Analysis 11, Table II, shows the chemical composition of this dike. We see that as to its composition it greatly resembles the ossipite in the Penikka hills (cf. Anal. 5, Table II). The granite, however, even between the diabase dikes, is of migmatitic character containing basic remnants of granitization and small accumulations of epidote. This migmatite is of the same type as are those parts of this granite which elsewhere penetrate greenstones and the anorthosite-serpentine series in the Penikka hills. These diabase dikes are tectonically entirely undisturbed and cut the schistosity of the granite. It therefore seems probable that they belong to a later phase, before which the migmatitic granite has already got its present appearance.

The question concerning the origin of this granite is not entirely clear. It is evident, anyway, that when the granite assumed its present appearance the temperature was fairly high, since the basic fragments have been amphibolitized. Seeing that the part rich in plagioclase penetrates and brecciates, it has been mobile, too. This is also indicated by the fact that tectonically undisturbed parts are met with there. So far as the old pre-Karelian granitic gneiss is in question, it must have been, at least partly, palingenetically re-fused (Eskola 1932 b, 1933) and an increase in the potassium content may have taken place in this connection. This process of »rejuvenation» could provide an explanation of the fact that this granite is »young» in appearance (Mantled dome, Eskola 1949) and occurs as a penetrating, syn-orogenic intrusion (Wahl 1936).

STRUCTURAL GEOLOGY.

The bottom direction shown by the varves varies greatly in the investigated area. These variations may be seen in different parts of the area, being specially clear in the exposures of slate on Kemijoki river. The horizon of quartzite is, however, not visible there. The slates, dolomites and basic schists have been strongly thrown into small folds, while the quartzites are generally gently folded.

Fig. 24. Gently folded quartzite. Dip 45° W. Kivalo, Kemi parish.

The strikes of strata and foliation on Kemijoki river run approximately EW., turning towards NE. when east of the river. The direction of the foliation curves more than does that of the strata and this has caused a general transverse schistosity. The dips are vertical or steep. The strike of strata in the quartzites of the ridge of Lautiosaari—Juoksua—Kivalo is NE-directed and the dip 40°—70° NW. (Fig. 24). On the SE. side of the quartzite the foliation in greenstone and in the rocks of the anorthosite-serpentine series is striking and dipping

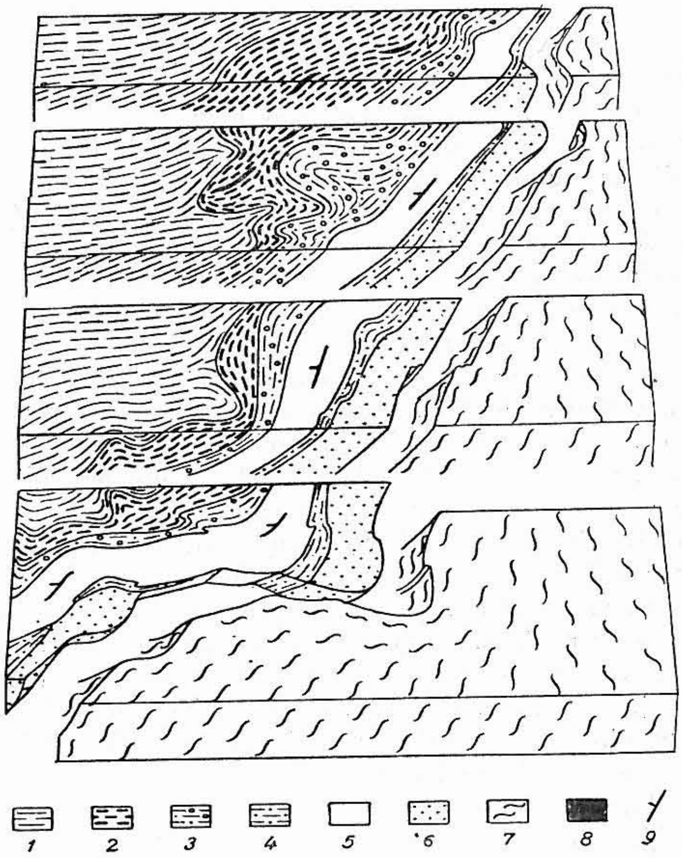

Fig. 25. Block stereogram of the Kivalo zone. 1 = slate, 2 = basic schist, 3 = amygdaloidal greenstone, 4 = hypabyssal greenstone, 5 = quartzite, 6 = anorthosite-serpentine series, 7 = migmatitic granite, 8 = dolomite, 9 = bedding.

parallel with the bedding of quartzite. The direction of bedding and foliation in the zones of quartzite and of basic igneous rocks thus shows remarkably great deviations compared with the directions in the schist area.

The bedding in the schist area on Kemijoki river is striking lineally, curving only gently. This, as well as the general character of the schist area, gives reason to assume that the primary folding has taken place in conformity with gently pitching fold axes. Only a few of such gently pitching axes and lineations have, however, been met with in the schist area. On the contrary, the pitches of lineations (E. Cloos 1946, Kvale 1946—47) are generally very steep or vertical and in varying directions. They cannot represent the direction of the primary fold axis, but may be caused by a lamellar gliding, which has taken place in connection with the folding of the schists as is the case *i.a.* in the areas investigated by H. Cloos and H. Martin (1932), as vell as by Neuvonen and Matisto (1948). Thus they are to be compared with the tectonic a-axis. They may partly also be connected with later, vertical movements, in which case their explanation is not possible without a detailed local analysis.

The quartzites and basic igneous rocks in the ridge of Lautiosaari—Juokua—Kivalo are only bent in gentle open folds, but their lineations and axes are more regularly parallel. They always trend WNW. or W. and pitch 30°—70° W. There the greatest part of the lineations are also parallel to the tectonic b-axis. The regular westerly pitch of the fold axes shows a culmination in the area of migmatitic granite. It is this culmination that has here produced lineations according to the b-axis.

The general strike in the area of migmatitic granite is NW. and dip SW. The lineation is also SW., but its dip varies. Towards the ridge of Kemi—Juokua—Kivalo (see map), the direction of foliation in granite, however, turns and is parallel to the contact, the dip generally being W. The lineations of granite in the marginal zone are pitching W. or NW. under the ridge of Kemi—Kivalo. Being younger than the supercrustal formation, the migmatitic granite as an intrusive culmination area has evidently risen in the manner of a cupola. Thus the ridge of Kemi—Juokua—Kivalo represents a stiffer, gently folded, lower horizon of the supercrustal area, which horizon has been flexed upwards against the rising granite (see Fig. 25). Flexing of this kind explains the remarkable difference between the directions of strikes and dips in quartzite in the Kemi—Kivalo zone and in the schist area.

In the ridge of Lautiosaari—Juokua—Kivalo, where the quartzites and basic igneous rocks run as coherent, long zones a NW-directed, nearly vertical, faultlike cleavage occurs in places, and this cleavage may appear as schistosity. In the contact between gabbro and granite on the SE. side of Ylä-Penikka it is clearly seen that there is a question of secondary movement which has produced faults crossing the zones of these rocks. The faults cut the zones of several rocks, not, however, rectilineally, but as fault series. These faults are connected with the dome-like uplift of granite. The gently folded basal horizon has been stiff and not able to bend upwards fully coherently and therefore the rising of the plastic granite has produced fractures. This phenomenon has also been the factor which, in connection with other tectonic movements, has caused a sharp break in the zone of the anorthosite-serpentine series at the S. end of Ala-Penikka and on the N. side of Kirakkajuppura.

As mentioned above, the foliation striking NW. and dipping SW. predominates in the migmatitic granite, except in the contact zone. The lineation pitches towards S. or SW. Under these circumstances this granite has in a remarkable degree the character of a tilted dome. The lineation pitching southwestwards may not be the direction of the tectonic b-axis, but obviously represents the direction of movement directed towards NE. In addition to the vertical uplift of the dome, a movement in the horizontal direction has taken place, too, and thus the combined influence of these two movements has been brought about. This has caused a foliation trending NW. and dipping SW., and a onesided lineation pitching SW. has been produced on the foliation planes.

An intrusion rising upwards often causes the bending of overlying formations to take place parallel with the margins of the *massif* (H. Cloos 1928, Billings 1942). Such is the case in connection with the uplift of the migmatitic granite on the SE. side of the supercrustal area. Thus it is to be understood that the strikes of strata and foliation turn in a NE. direction in the schist area on Kemijoki river, as is clearly seen on the E. side of the river (p. 38). Such a phenomenon accounts for the transverse schistosity so general and regular there. — The horizontal movement simultaneous with the vertical uplift causes a bending of the upliftet formations, at least in some degree towards the direction of the movement. It is possible that such movement has furthered the curving of the directions of strata and foliation in the eastern part of the supercrustal area.

In the Lautiosaari—Juokua—Kivalo zone the lineations and fold axes appearing in the quartzites, the basic igneous rocks and in the granite near the contact do not trend at right angles to the general contact lines, but deviate regularly from it towards W. or SW. Consequently, they have turned simultaneously with the uplift of the granite dome and this shifting has been furthered by the above-mentioned horizontal movement. In places, *i.a.* at Juokua, lineations of two types may be found, one of which lies almost at right angles to the direction of the contact zone, the other deviating considerably from it towards W. or SW. The former type has been produced in connection with the uplift of the granite dome. The development of the latter type has also been influenced by the horizontal movement, during which frictional drag took place in contacts of the dome, because the dome, being more plastic, was more easily transported by the NE-directed movement than was the case with the stiff neighbouring rocks.

As mentioned above, the primary folding in the schist area on Kemijoki river has evidently taken place in conformity with a comparatively gently sloping axis. However, there occur minor folds in accordance with nearly vertical axes. A flow cleavage transects the bedding in the direction of the axial plane of these folds (Leith 1905 and E. Cloos 1937) (see Fig. 26). This shows that the force to which this is due has been directed only at a sharp angle to the direction of the strata. In many places it can be found that this minor folding in accordance with a vertical axis is, at least to some extent, subsequent to the primary folding of schists. There must have been a force acting also in the EW. direction and in the first place such movement is to be connected with the uplift of the migmatitic granite dome. This has caused pressure towards the west and thus produced, at least in partially folded schists, secondary folding and simultaneously a flow cleavage in the direction of the axial plane.

Fig. 26. Minute folds in vertical strata. A flow cleavage transects the bedding parallel to the folding planes. The pen points towards N. On the shore of Kemijoki river. Liedakkala, Kemi parish.

An almost horizontal fracture cleavage (Leith 1905) occurs in the schist area on Kemijoki river. This appears as small fractures along innumerable parallel planes. On each cleavage plane there is a displacement of a few millimetres. Often such shear planes (Balk 1936) occur very closely, only at distances of some millimetres (see Fig. 27). The map (Fig. 28) shows where such a cleavage in the area has been established. This phenomenon is only to be seen in fine-grained schists, while megascopically it is hardly observed in more

Fig. 27. Vertical strata of slate transected by the nearly horizontal planes of fracture cleavage. The pen shows towards N. The shore of Kemijoki river. Liedakkala, Kemi parish.

coarse-grained intermediate layers. The primary vertical schistosity, even the folds occurring in beds, is transected by this cleavage, the shear planes dipping only 10°—20° S. or SW. This shear-like cleavage indicates distinct regularities, such as that the displacement at different points of observa-

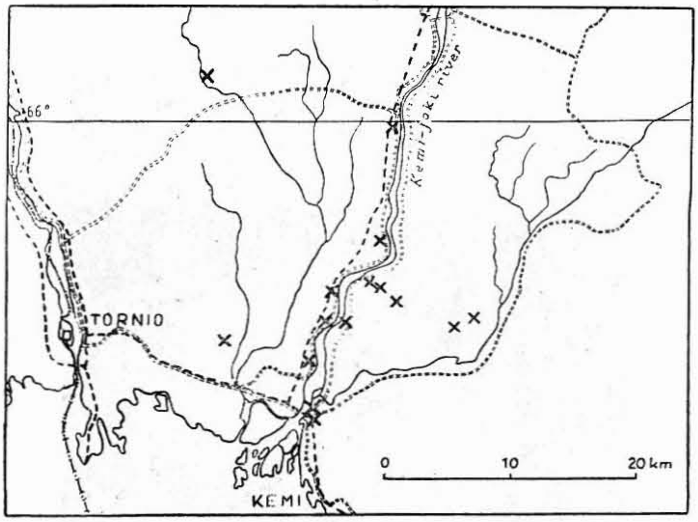

Fig. 28. The crosses (×) show the points where fracture cleavage has been established.

tion is of the same size and that the upper part of the shear plane has always, independent of the strikes and dips of primary foliation and strata, been displaced in a NE. or E. direction (Fig. 29). The shear plane is always a splitting plane and traces resembling lineation can be found there, showing the linear direction of shearing.

Long distances between points of observation show that there is not just a local occurrence in question, but because of its regularity it must be a simultaneous, coherent phenomenon. In the surficial parts of the supercrustal area there have been horizontal movements in a NE. or E. direction, which have produced nearly horizontal parallel fractures in the schists with vertical strata. The planes of this fracture cleavage must, on account of the regularity of the phenomenon, be still in their approximate primary position. The movement has taken place on lamellae, in a kind of overthrust. As to its age, it occurred subsequently to the primary folding of schists, but may also belong to the later stage of the movement which caused the proper folding.

The western part of the investigated area situated between the Rivers Kemijoki and Tornionjoki shows tectonically more varieties of small features than does the eastern part dealt with above. As enough rock exposures were not always available, it was not possible to elucidate the structure at all places. Judging by the abundance of exposures, the dolomite would seem to make up an actual horizon, at least in the western area. Mention has earlier been made of how the supercrustal formations have bent around the younger intrusive *massifs* belonging to the Haparanda-series. Also here the primary fold axis has obviously been gently pitched. These younger intrusions have, however, caused a

Fig. 29. The nearly horizontal glide planes of fracture cleavage transecting the primary vertical foliation of schist. N. of Lautiosaari. 20 ×.

pressure on their environment and in the directions nearly parallel with the vertical strata the force has produced in wide areas minute folds in accordance with vertical axes. These movements have simultaneously destroyed features of the primary folding. In the immediate vicinity of the intrusive *massifs* there occur also some minor folds in accordance with the nearly horizontal axis, and at least part of these may have been produced by a pressure directed outwards from these intrusions. — During their emplacement the younger intrusions have caused also vertical movements in their environment, the traces of which are to be seen as a secondary vertical cleavage and as lineations pitching steeply.

In the Kaakamo—Tornio *massif* belonging to the Haparanda-series the northern contact with its immediate vicinity is in general covered with loose deposits, so that a clear conception of the tectonical environmental influences of this intrusion cannot be obtained. The supercrustal rocks lying on the N. side of this *massif* seem, at least in some degree, to be curved in conformity with the *massif*. In the supercrustal area there generally occurs a fault-like cleavage, trending NS. and dipping steeply. Some zones of supercrustal rocks break off sharply in the directions of their bedding and foliation. Thus it seems that also here similar faults have taken place in connection with the intrusion of magmas, as is the case in the Kivalo ridge (p. 40). The *massifs* of the Haparanda-series have, however, not caused the bending upwards of the older formations on their margins to such an extent as is the case with the migmatitic granite in the Kivalo ridge. Instead these *massifs* border their environments more sharply. They are of a cutting, intrusive character, while the SE. migmatitic granite of the area gives the impression of an areally uplifted cupola (Wegmann 1930), so far as the investigated area is in question.

It is evident that the western part of the area represents a lower horizon than does the schist area on Kemijoki river. In part the lower horizon rises evenly towards the west, but in part fault-like uplifts (Hackman 1914) have also taken place in connection with the NS-directed cleavages mentioned above. These uplifts have been produced together with the intrusions of the Haparanda-series. Such a zone of fractures is represented by *i. a.* the chain of valleys which in the NS. direction runs from the gabbro-diorite *massif* of Kaakamo through the drained area of Laivajärvi and through Lake Ahvenjärvi as far as the Petäjämaa—Kantojärvi *massif*. Another similar zone of fractures runs in a NS. direction nearly parallel with the bed of Liakkajoki river. In a later stage this has been intruded, at the mouth of Liakkajoki, by a porphyritic granite penetrating the gabbro of the Haparanda-series (see p. 37). It is possible that the bed of Tornionjoki river represents a similar zone of fracture (cf. the map appended to this study and that of the corresponding Swedish area by Ödman 1939).

The general strike is WNW. and dip SW. in the gabbro and diorite *massif* between Kaakamo and Tornio as well as in the migmatitic granite penetrating the former at the mouth of Liakkajoki river. The lineation is exclusively pitched SW. This regularity may be explained as in the south-easterly migmatitic granite of the area, *viz.*, that the one-sided dipping of the foliation and pitching of lineation has been produced by a tectonic movement directed to NE.

Hausen (1936) has described the Kemi—Rovaniemi area as a great, coherent downfold lacking minor folds. As to the investigated area, it is in some measure of downfold character as regards the stiffer lower horizon, although it is to be noted also that this basal horizon is cut by younger intrusions. Instead, the more plastic upper horizon, the basic schists, dolomites, and slates are strongly folded, as can be judged by the changes of bottom directions. The depth of the downfold, however, cannot be calculated on the basis of the dips in marginal zones, because the strata there have been tilted up due to the rise of younger intrusive *massifs* (Metzger 1947).

The bottom direction in a horizontally stratified slate is found to be upwards at two places on Kemijoki river. A product of overthrust is perhaps not in question, only a small overturned fold.

Hausen (1936) and Väyrynen[1] have stated that the thrust causing the folding in the Kemi—Rovaniemi area has been directed southwards, at which time the southeasterly granite area has been a foreland. It is possible to suppose that the turning of the strikes in the easterly Kemijoki area (cf. p. 38) has been caused by a southwards directed thrust, because the supercrustal formation has been pushed against the granite area. Then it is not easy to interpret the W-turned directions of the lineations and fold axes (p. 41), which appear in the Kivalo ridge and in the contact zone of the migmatitic granite. During movements towards S. the supercrustal formations must have risen upon the granite area in the manner of an overthrust and then N-directed lineations would also appear in the contact zone. This, however, has not been ascertained. The fracture cleavage in stratified schist (p. 42) cannot be explained as caused by a movement from north to south. The SW-directed lineations generally occurring in the plutonic rocks of the area cannot be regarded as parallel to the b-axis of general folding, as they have the same direction in such wide areas, but, as appearing in synorogenic intrusions, they have to be regarded as produced by a movement directed towards NE. or E. There the plutonic *massifs* have not a clear character of a resistance area, because they are younger than the supercrustal formation. Especially the migmatitic granite area shows many features of an uplifted cupola. The present author does not, however, want to draw any conclusions as to which has been the direction of the t h r u s t causing the folding in the Kemi—Rovaniemi area, but only to ascertain in which direction the m o v e m e n t s in the area have taken place. The investigated area is too small to allow conclusions as to the direction of the general thrust to be drawn.

STRATIGRAPHY.

PROCESSES OF WEATHERING AND SEDIMENTATION.

The material of the stratified quartzites in the area is to be regarded as a weathering product of acid plutonic rocks on the basis of its plagioclase and microcline content as well as of the grain size of the quartz (Metzger 1924, Väyrynen 1928, Hausen 1930). No plutonic rocks older than the quartzites have been met with in the area, nor has the

[1] Lecture given at the meeting of the Geological Society of Finland, September 27th, 1947. Not published.

quartzite any basal formations. The material of the quartzites is for the most part a residue of far advanced decomposition, but there are to be met with, *e.g.* near Lautiosaari—Kallinkangas, parts whose chemical bulk composition greatly resembles that of the granites (cf. Anal. 1 and 2, Table I). As there is no certainty as to the origin of the material, no conclusions can be drawn on the basis of these local compositions of sediments. It is possible that remnants of pre-Cambrian granites occur in the migmatitic granite area, although clear evidence could not be gathered in the investigated area.

As mentioned above, the stratified basic schists gradually pass over into slates, while the bottom direction of the varves and tectonical features regularly show that the slates are the youngest member of the sedimentary series. Carbonate-bearing interstratified layers, even dolomite formations, often lie between other layers. The amygdaloidal types of greenstones are generally bordering stratified tuffitic schists and, judging by tectonical observations, seem to dip under these schists. Both mineral and chemical compositions point to the great similarity between the most basic tuffitic schists and the amygdaloidal rocks. It is more than likely that the material of the tuffitic schists is of the same origin as the amygdaloidal rocks.

The amygdaloidal rock as lava has covered wide areas and then the sedimentation of tuff and of material partly loosened by disintegration took place upon it. The well developed varve structure of many sediments indicates deposition in water. In the field as well as microscopically the series of basic schists and slates seems to be a coherent series of weathering and sedimentation. This opinion is supported by the analyses (Anal. 3—9, Table I) showing remarkable regularities which appear below.

The material of the tuffitic schists consists of the almost unweathered material of greenstone. The material of the series ranging from these basic schists to the slates is influenced by increasing decomposition (cf. pp. 14—15). The series of analyses show notably that the amounts of ferrous oxide and of magnesia fall sharply with increasing silica content. This is due to the fact that the effect of decomposition (Behrend und Berg 1927) has increased during continued sedimentation. The calcium content increases at first, but later on falls sharply. The amount of CO_2 in the basic schists increases with the enrichment in lime. The carbonic acid has evidently been a considerable factor in the weathering and has been precipitated with calcium. The sodium content increases at first, but then begins to fall. This is reasonable, as the plagioclase of the primary material has been albite, whose resistance to decomposition is notably great. Consequently, in some measure albitic plagioclase has first been enriched in the sediment and its amount decreases only with more advanced decomposition. The alumina content falls at first, but later on rises higher than before. There may be in question decay of aluminous minerals and enrichment of decomposition products in slaty parts.

On the other hand, it has to be taken into consideration that a few, even though carefully chosen, analyses cannot give a clear conception of a sediment, because their stratification already indicates non-homogenity. It cannot be supposed that only one kind of rock has been a starting material for the weathering sediment, even though it can act the leading part. The analyses and the conclusions drawn from them cannot be held as evidence, but they give support to observations made in many places during the field work, *viz.*, that upwards the basic schists gradually pass over into slates and that the basic schists lie immediately upon the amygdaloidal rocks. No slaty layers have been found beneath basic schists in the area investigated. Thin interbedded slaty varves occur between basic schists and the slaty parts contain also some thin, somewhat more basic layers. Notable sedimentation of clayey material has evidently not taken place simultaneously with deposition of tuffitic material, or the sedimentation of the material of tuffitic schists has been very rapid, as is to be expected in connection with volcanic eruptions. With retarding sedimentation the chemical weathering has started more strongly and its clayey products have been deposited. Then the more basic interbedded varves in the slaty part of the sedimentation series are to be regarded as »fractions» of mechanical sorting.

The greenstone is rich in calcium and magnesium and these elements have for the greater part become detached during decomposition. The dolomites are interbedded in the sedimentation series of the basic schists and slates, so it is quite probable that they, too, have got material from the products of the decomposition described above.

As to the chemical composition of these dolomites (Table III), attention is drawn to the relation between magnesia and lime occurring in them. This indicates that variations in the dolomite of Kalkkimaa are of the same order of magnitude as in the whole Kemi—Rovaniemi area (Eskola *e. a.* 1919, Eskola 1927). As the variations of these proportions are fairly small, the dolomites of the Kemi—Rovaniemi area are to be regarded as very homogeneous in their chemical composition. — Usually the quartzitic layers and silica-bearing minerals in dolomite have not reacted with carbonate. Whenever reaction has taken place, it appears to be due to regional metamorphism effected by synorogenic intrusions. If the carbonate deposits have been primarily magnesia-poor lime sediments, the increase in the magnesia content must have taken place in a comparatively cold condition, most probably through aqueous solutions, when no reactions with silicate occurred. — The sulphide-bearing carbonate-quartz veins in the dolomite are younger than the country rock, possibly originating from residual solutions of the synorogenic intrusions. As their carbonate consists of calcite, the possible

Table III. Chemical composition of dolomites in Kemi—Rovaniemi area.

N:o	1	2	3	4	5	6	7	8	9	10	11	12	13
Insoluble	5.52	8.40	8.12	0.48	6.54	12.80	10.83	4.62	9.37	2.10	2.25	3.54	8.53
Al_2O_3 } Fe_2O_3	1.20	0.30	0.91	0.46	0.30	1.64	0.67	1.75	2.43	1.10	1.05	1.23	2.06
FeO	1.44	1.22	1.01	0.70	1.78	—	—	—	—	—	—	—	—
MnO	—	—	—	—	0.03	—	—	—	—	—	—	—	—
MgO	19.55	19.02	18.37	19.24	19.65	17.99	17.33	19.29	18.08	19.91	19.82	20.09	19.20
CaO	28.76	28.25	29.50	33.12	28.32	27.00	27.38	29.00	27.73	30.19	30.01	29.65	27.74
H_2O	—	—	—	—	0.15	—	—	—	—	—	—	—	0.06
CO_2	43.93	42.76	43.19	47.00	43.58	40.55	43.79	45.34	42.39	46.70	46.87	45.49	43.02
	100.40	99.95	101.10	101.00	100.35	99.98	100.00	100.00	100.00	100.00	100.00	100.00	100.61
$\frac{[MgO]}{[CaO]}$	0.68	0.67	0.62	0.58	0.69	0.67	0.63	0.67	0.65	0.66	0.66	0.68	0.69

1. Arpela, Pirttimaa. Anal. B. Aarnio. (Hackman 1914.)
2. Tervola, Vaajoki. Anal. B. Aarnio. (Hackman 1914.)
3. Rovaniemi. Konttijoki. Anal. B. Aarnio. (Hackman 1914.)
4. Rovaniemi, Kalkkinulkki. Anal. B. Aarnio. (Hackman 1914.)
5. Tervola, Vähäjoki. Anal. P. Ojanperä. (A. Mikkola 1947.)
6. Alatornio, NW. of Hammasjärvi. Anal. M. Tavela.
7. Kalkkimaa. Anal. Renlunds Bergslab. (Hausen 1936).
8. Kalkkimaa. Anal. Renlunds Bergslab. (Hausen 1936).
9. Kalkkimaa. Anal. Renlunds Bergslab. (Hausen 1936).
10. Kalkkimaa. Anal. Renlunds Bergslab. (Hausen 1936).
11. Kalkkimaa. Anal. Renlunds Bergslab. (Hausen 1936).
12. Kalkkimaa. Anal. Renlunds Bergslab. (Hausen 1936).
13. Kalkkimaa. Anal. Renlunds Bergslab. (Hackman 1914).

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dolomitization must have taken place before the production of these veins.

Analysis 1, Table IV, made of carbonate in greenstone, shows its remarkably high magnesia content. The carbonate of tuffitic schist is on the contrary magnesia-poor according to Anal. 2, Table IV. The high lime content found in many basic schists thus appears to be present in the carbonate. While the carbonate of the tuffitic schists, for the greater part, is of sedimentogeneous origin, the carbonates deposited in that stage have been either magnesia-poor or dolomitization has for some reason not taken place.

Table IV. Chemical composition of carbonates in rocks of Kemi area.

N:o	1	2	3
Insoluble	91.53	46.59	87.95
Al_2O_3 Fe_2O_3	—	—	0.30
MgO	1.43	0.98	0.32
CaO	3.25	28.25	5.59
H_2O	1.25	1.58	1.02
CO_2	2.15	22.32	4.36
	99.61	99.72	99.54
$\frac{[MgO]}{[CaO]}$	0.44	0.03	0.06

1. Carbonate in greenstone. Lautiosaari. Anal. H. B. Wiik.
2. Carbonate in tuffitic schist. SE. of Ahvenjärvi. Anal. H. B. Wiik.
3. Carbonate in quartzite. Kallinkangas. Anal. M. Tavela.

Carbonate occurring in the quartzite horizon below the dolomites consists mostly of calcite, as shown by Anal. 3, Table IV. It has not undergone dolomitization. Supposing that dolomitization took place simultaneously in different sediments, it must have occurred only in the carbonate deposits of a higher horizon or for some reason it has not taken place in mixed sediments in the same degree as in the carbonate sediments proper (Barth—Correns—Eskola 1939, part Correns).

The dolomites of the area are generally fine-grained and, with some local exceptions, no noticeable recrystallization has taken place. The uniformity of the [MgO]:[CaO] ratio in the dolomites over wide areas as well as the low proportion of magnesia in the carbonate portion of the other sediments indicate that the possible dolomitization must have taken place already during the sedimentation phase, since there are no primary dolomitic sediments in question (Van Hise 1904). — No fossil relics have been found in these dolomites, only in places a small carbon content (cf. Hackman 1914).

STRATIGRAPHICAL SUCCESSION AND AGE RELATIONS.

The succession of strata and the age relations in the area investigated are to a great extent indicated by the ridge of Lautiosaari—Juokua—Kivalo. Quartzite without basal formations lies between sheets of greenstones. The bottom direction of the quartzite shown by the varves and the current bedding points to SE. The amygdaloidal greenstones occur on the NW. side of the quartzite and the hypabyssal types without amygdules on the SE. side of same. Thus the quartzite has remained as a plate-like inclusion between the greenstone sheets. As quartzite inclusions in greenstone, as well as greenstone intrusions between quartzite layers have been found also elsewhere, the greenstones are to be regarded as younger than the stratified quartzites.

The jasper quartzites might be partly sinter formations (E. Mikkola 1941, Sahama 1945, Kaitaro 1949), but, *e. g.* at Kalkkimaa, the jaspoid veins are probably precipitated from fairly cold, silica-bearing solutions and are therefore to be regarded as belonging to the vein quartz. — On the whole, the jasper quartzites of the area in many respects resemble the jaspers of Kittilä and may, at least in part, be compared with them, as these areas have also other petrological features in common.

The origin of the glassy quartzites cannot be ascertained accurately. The absence of stratification may be due to strong recrystallization and to metamorphism, which phenomena have in places been evidenced, too. On the other hand, the glassy quartzites are likely to be connected with the jaspoid quartzites of the area. A distinct limit cannot be drawn between them, as the glassy quartzites are also joined by very fine-grained types. The jaspoid quartzites (Kaitaro 1949) may, at least partly, be regarded as younger than the proper stratified quartzites.

The amygdaloidal greenstone immediately borders basic, stratified schists and according to tectonical observations the amygdaloid rock is dipping under these schists. Seeing that the material of the basic schists with regard to its mineral as well as chemical composition seems to have originated from the greenstones, consisting in the first place of tuff, the amygdaloid rock is to be considered as the bedrock of these schists.

Hackman in his explanation to the map sheets (1914) has mentioned that »slaty actinolite schists» occur in the Kalevian formations between the slates and metabasites. He regards these as slates intermingled with basic eruptive matter or as formations of tuffaceous origin. When describing the Jatulian formations Hackman has made mention, in connection with the metabasites, of similar schists lying between the metabasites and slates and representing a transitional stage between the amygdaloidal diabase and the slates. He regards them as slates »being highly injected and resorbed by basic eruptive rocks». »It is possible to assume that they have been formed of very fine-grained, ashy, volcanic deposits, which have later been foliated. This is indicated by the sometimes clastic, sometimes fairly effusive character of these rocks and by the fact that their mineral composition is not common in the slates. Under such conditions they must be regarded as belonging to the group of tuffaceous rocks, although they nowhere show conglomeratic or brecciated structure, which is characteristic of a tuffaceous deposit.»

The agglomerate near Lautiosaari station also joins on to the greenstones. Because of metamorphism, the origin of the fragments in the agglomerate could not be determined with absolute accuracy, although they seem to belong to the greenstones. On account of the paucity of outcrops, the position of this agglomerate is not fully clear, but it joins on to the amygdaloidal rocks at Lautiosaari, thus also showing the volcanic character of the greenstones in the area investigated.

As mentioned above, the basic schists gradually pass over into slates, the dolomites being interbedded in this stratified series. The bottom directions and tectonical observations show that the slates lie upon the basic schists. This is seen in several places, examples of which will be presented in the following.

In the Kivalo ridge, between Lakes Jouttijärvi and Jänkäjärvi, there is an abundance of tuffitic schists, which on the basis of the bottom directions and dips of strata seem to be sloping under the dolomites situated on their N. side. This zone of tuffitic schists runs westwards under the slates, as shown by observations concerning fold axes and lineations.

West of the amygdaloid on Akkunusjoki river, a broad belt of tuffitic schists is met with, which, owing to the fold axes, dips westerly under the slates. Areally there occur all intermediate stages between the most basic schists and slate. Dolomite is found as interbedded in this transition series ab. 5 km. E. of the Taivalkoski Rapids.

An occurrence of varved, tuffitic schists is met with at Kalkkimaa on the S. margin of the dolomite. Their bottom direction is S. and they dip 70° N. under the dolomites. On the N. side of the dolomite the slates overlie the tuffitic schists and dolomite.

On the W. side of Hammasjärvi, there are found varved tuffitic schists with the bottom direction towards S., the dip of strata being 40°—70°N. They are on the N. side overlain by dolomites. Slates showing a bottom direction S. overlie dolomites on their N. side. The slates here often contain porphyroblasts of cordierite.

Outside the investigated area, at the Narkauskoski Rapids (Tervola parish), there is a good section of the sedimentary series (cf. p. 17). Quartzite lies on its S. border and on the N. side there occur varved, carbonate-bearing basic schists showing the bottom direction towards S. Skarn reaction has partly taken place in these schists, but Anal. 10,

Table I (A. Mikkola 1947), shows so high a sodium content that they must be regarded as primary tuffaceous sediments. This opinion is also supported by the mineral composition and textural features. Thick dolomite layers are met with on the N. side of these schists. On the basis of bottom directions and the dips of bedding the dolomites seem to overlie the basic schists.

At the Kukkolankoski Rapids (Tornionjoki river) there are found varved schists of intermediate types between basic schists and slates. The stratum in the outcrops on the shore strikes EW., the bottom direction being N. At a distance of about 500 m. NE. of this point, the strike is NE. and the bottom directed to SE. The stratum strikes ESE. on the SE. side of the rapids. The lineation in the outcrops on the rapids is N.80°W., 40°W., which is evidently parallel with the fold axis. This shows a small culmination of fold axis east of the rapids. In this culmination area there appear amphibolitic schists of the lower horizon, to which the dolomites also join. As for these schists, it has already been stated above (pp. 19—20) that they contain pseudomorphic porphyroblasts. Anal. 11, Table I, shows the chemical composition of such a schist. The tuffitic schists generally contain magnetite and iron oxide pigment. The fairly high ferrous oxide content shown by the analysis may partly be due to the reduction of the ferric oxide during metamorphism. The rock has been carbonate-bearing, as shown by the interstratified carbonate layers, but for the most part the carbonate may have been calcitic (cf. p. 50). The magnesia and ferrous oxide content is relatively high compared to the amounts of CaO and Na_2O. If there were in question a basic rock produced only by skarn reaction, one would expect higher Na_2O and CaO content. This rock member has not been produced by metamorphism only, but metasomatism has also taken place (Eskola 1915). However, it may not have been very strong, because the structure of a stratified sediment is well preserved.

Strong regional metamorphism is in general to be ascertained around the *massifs* of the Haparanda-series (cf. p. 33). This small culmination area is partly surrounded by intrusions of the Haparanda-series and also a little *massif* of gabbro occurs in the eastern part of it. Thus it is more than likely that also the metasomatism there has been caused by this series.

According to the statements made above, the basic, stratified schists are to be classified in three types: 1. Schists which must be regarded as tuffaceous deposits; 2. Amphibolitic schists produced by skarn reaction; 3. Amphibolitic schists also affected by metasomatism.

No slaty beds have been found under the greenstone; only thin sericite-rich layers are interbedded in the upper parts of the quartzite series. Neither slates nor any other sediments produced by strong decomposition are to be found between the basic schists and greenstones. Only the stratified quartzites in places border the basic schists. Thus the eruption of greenstone magma in this area represents a break in sedimentation. The phase of eruptivity falls exactly on this epoch, and the character of sedimentation changes. This change has been comparatively sharp, because no intermediate sediments between the quartzites and the stratified schists have been found. It is very likely that volcanic activity (Kaitaro 1949) may have appeared in connection with this sharp transition of the conditions of sedimentation. As the stratified quartzite is older than the greenstone, it is possible that the greenstone magma has not covered the quartzites evenly at all places when erupting. This consideration may explain why the basic schists are in places bordering stratified quartzites.

As regards the position in the stratigraphic scheme of the above mentioned black schists (p. 15), it seems that they, at least in the neighbourhood of the Taivalkoski conglomerate, belong to the upper parts of the schist formation.

As described (p. 24) in connection with the conglomerates, the Taivalkoski conglomerate lies upon the slates or at least in the upper parts of the slate formation. Taking into consideration that this conglomerate has the character of a fluviatile deposit and considering the fact that it contains fragments of slate, too, it must be regarded as of younger age than the formations of the proper sedimentary cycle. In the first place it may be held as a molasse-like deposit. — The thin layers of conglomerates joining on to the dolomites (p. 26) may be of intraformational origin.

It is fairly difficult to explain the polymict conglomerates in the Kivalo ridge (see pp. 24—26). Their position in the contact zone of two igneous rocks, however, indicates that there may be no basal formation in question. This opinion is also supported by the fact that they contain pebbles of greenstones, quartzites and slates, which rocks belong to the horizons situated higher than these conglomerates. As in addition a great part of the pebbles consists of migmatitic granite, it is evident that these conglomerates are considerably younger than the proper cycle of sedimentation. The anorthite-rich plagioclase in the matrix shows that sedimentary material has not been affected by strong decomposition. This fact, as well as the absence of clear bedding, gives reason to assume that these Kivalo conglomerates have been deposited in large crevasses along the contact between the belts of greenstone and anorthosite-serpentine series. This has taken place at so late a stage that the migmatitic granite has been influenced by erosion. This opinion is also supported by the fact that these conglomerates are less deformed than the greenstone and ossipite near the contact (see Figs. 14 and 18).

As mentioned in connection with the stratified schists (p. 20), a small occurrence of stratified basic schist is situated at a distance of about 8 km. from Juokua towards NE. Mention has also been made of another similar occurrence of basic schist connected with dense, jaspoid quartzite on the W. side of Ala-Penikka. As both occurrences are small in size and occur in the same contact zone between greenstone and anorthosite-serpentine series, as do the afore-mentioned conglomerates, they are possibly to be regarded as similar deposits in crevasses.

The only contact known between the belts of hypabyssal greenstone and the anorthosite-serpentine series, on the N. edge of the town of Kemi, does not fully elucidate the age relations between these rocks. The afore-mentioned conglomerates and small outcrops of schists in the contact zone do not give the impression that they have been deposited directly upon the ossipite. The greenstone, which is younger than the quartzites and overlies ossipite, does not in any place cut rock members of the anorthosite-serpentine series situated beneath the greenstone. The contact between ossipite and greenstone is generally sharp and the ossipite is in some measure of finer grain size near the contact with greenstone (p. 27). With the exception of the contacts and NW-directed fault zones, only few traces of tectonic movements are to be seen in the rocks of the anorthosite-serpentine series. Although there is no absolutely clear evidence, many facts indicate that the anorthosite-serpentine series is younger than the greenstones. The zone of this series gives the impression of a large sill, which has intruded under the supercrustal formation. Under prevailing conditions basic magma has been able to crystallize undisturbedly and gravitative differentiation has then taken place. The serpentine peridotites occurring on the SE. border of the *massif* show this to be the bottom direction of the intrusive sill.

On the other hand, one cannot but note that the chemical composition of the greenstone magma and the average chemical composition of this series have some features in common (cf. Anal. 1, 2, 3 and 4, 5, 6, Table II). Both are characterized by a high MgO and CaO content and by a low amount of K_2O. If this series be considered younger than the greenstones, one could assume it to be only a plutonic intrusion of the greenstone magma intruded after the eruption. Its schistose contacts and NW-directed faults, however, show influences of orogenic movements.

Hackman in his explanation to the map sheets regarded the rocks belonging to the Haparanda-series as older than the supercrustal formation, even though he considered it to be already a differentiation series. As proved above, the rocks of this series are clearly penetrating the supercrustal formation (p. 32). However, the supercrustal formation is in many places observed to have been folded, at least partly, before the intrusion of the Haparanda-series. Dikes belonging to this series often run almost parallel with the stratification, but are, however, generally cutting the bedding and foliation. The gabbro between Kaakamo and Tornio has been deformed in a great degree, the dioritic portions being less deformed and only the contact zones have been foliated in the granodiorite of Petäjämaa—Kantojärvi. Thus the Haparanda-series is to be regarded as a series of synorogenic intrusions and of differentiation (Wahl 1936, Ödman *e. a.* 1949).

In some places, *e. g.* on an island in the Taivalkoski Rapids, basic dikes are penetrating stratified schists. As the greenstones of the area form the bedrock of stratified schists and consequently are older than the schists, these dikes cannot originate from greenstones. The dikes there have been metamorphosed to such a degree that their origin cannot be determined on the basis of their mineral composition. The anorthosite-serpentine series, being probably younger than the greenstones, may already have been able to penetrate the schists. The Haparanda-series has been proved to cut as veins the supercrustal formation, but it could not be ascertained if all the dikes penetrating the schists belong to this series. The dikes on the E. side of Kemijoki river are potassium-poor, whilst also the basic parts of the Haparanda-series contain fairly high amounts of potassium. This, however, does not exclude the possibility that there could be also potassium-poor portions in the Haparanda-series, as has been in part ascertained.

As has been mentioned above (p. 37), north of Viantie railway station there is an occurrence of basic dikes penetrating migmatitic granite. They seem to be the youngest of the igneous rocks in this area and so are likely to cut the supercrustal formation. The area investigated has been found to contain several basic intrusions younger than the supercrustal formation. The dikes penetrating the stratified schists also originate from them.

The occurrence of quartzites in abundance indicates in any case that during their sedimentation wide areas of granite must have been exposed. However, the conglomerates of Sariolian type (Eskola 1918, Väyrynen 1933 and 1938, Eskola 1941 and 1948) are entirely lacking at least in the area investigated. The contact between the migmatitic granite and quartzite at Juokua is evidently not primary, but later on the magmas of greenstone and anorthosite-serpentine series have also there been intruded under the quartzite (p. 36). The contact has been strongly deformed and the pre-Cambrian granite, which has most likely been the bedrock of quartzite has been migmatized, in consequence of which the last possibilities of finding here a basal formation for the quartzite have been destroyed.

Most probably the migmatitic granite contains also older granitic rocks of pre-Cambrian origin, but by granitization they have been altered to such an extent that acidic, older, plutonic rocks, at least in the investigated area, can no longer be determined. The basic inclusions in migmatitic granite must for the most part be regarded as more or less altered remnants of the greenstones and of the anorthosite-serpentine series.

Migmatitic granite penetrates the greenstones and the rocks of the anorthosite-serpentine series, as well as those of the Haparanda-series. Traces of tectonic movements generally occur throughout its parts. This granite is younger than other synorogenic plutonic rocks and it has risen as a diapir-like migmatite cupola. It seems as to age to be ser-orogenic (Wahl 1936, Ödman *e. a.* 1949).

The stratified quartzites and the greenstones of the Kemi—Rovaniemi area are typical in the whole area of Karelian formations. It is therefore most probable that these rocks belong to the Karelides, even though the Sariolian conglomerates are lacking here. No signs of unconformity have been met with between the tuffitic schists and slates. Thus also the stratified schists must be regarded as Karelian formations. On the contrary, the pebbles of migmatitic granite in the conglomerates of Kivalo bear evidence of a great unconformity and thus these conglomerates must be considerably younger than the proper cycle of sedimentation.

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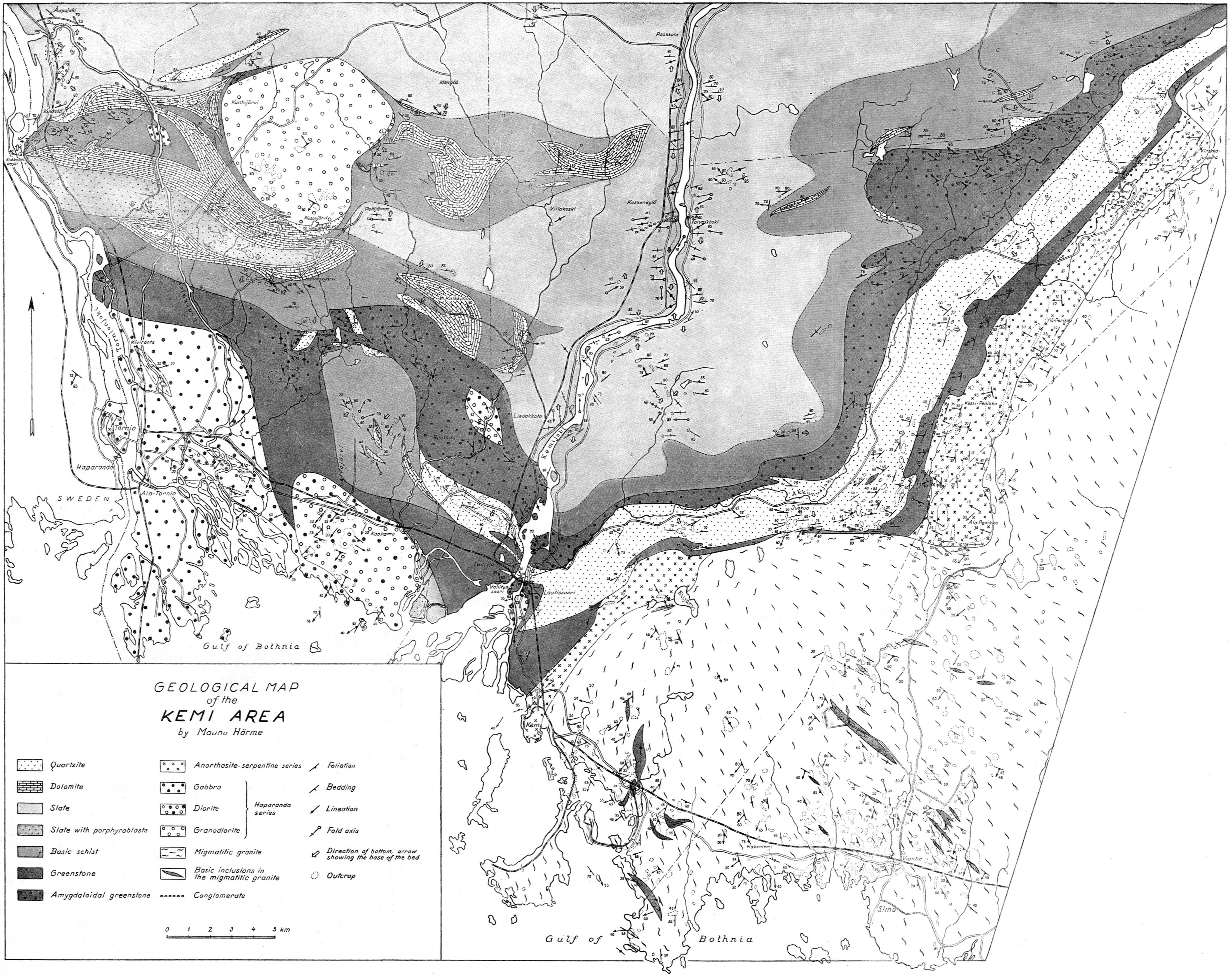
GEOLOGICAL MAP
of the
KEMI AREA
by Maunu Härme
Quartzite
Dolomite
Slate
Slate with porphyroblasts
Basic schist
Greenstone
Amygdaloidal greenstone
Anorthosite-serpentine series
Gabbro
Diorite
Granodiorite
Haparanda series
Migmatitic granite
Basic inclusions in the migmatitic granite
Conglomerate
Foliation
Bedding
Lineation
Fold axis
Direction of bottom, arrow showing the base of the bed
Outcrop
0 1 2 3 4 5 km
SWEDEN
Gulf of Bothnia
Gulf of Bothnia
Tornio
Haparanda
Ala-Tornio
Kemi
Kemijoki
Kantojärvi
Koskenkylä
Taivalkoski
Kivalo
Akkunusjoki
Simo
Maksniemi
Viantie
Liedakkala
Ruottala
Lautiosaari
Juokua
Paakkola
Viitakoski
Ala-Penikka
Keski-Penikka
Laurila
Kaakamo