GEOLOGINEN TUTKIMUSLAITOS

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COMMISSION GÉOLOGIQUE

DE FINLANDE

N:o 153

THE SCHIST BELT NORTHEAST OF TAMPERE IN FINLAND

BY

JUHANI SEITSAARI

WITH 53 FIGURES IN TEXT, 9 TABLES AND TWO MAPS

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PREFACE

The field work for this investigation was carried out mainly in the summers of 1945—47, in addition to which many revisions were made in 1948. The laboratory studies were done during the winters of 1948 and 1949.

I wish to dedicate this work to my father, who passed away before it was completed. He always took a great interest in my work, and I am very deeply indebted to him for supporting me in every way.

To my esteemed teacher, Professor Pentti Eskola, I wish to express my most sincere gratitude for his valuable instruction during the researches, and for his fruitful criticism of the manuscript.

I am very grateful to the Director of the Geological Survey of Finland, Professor Aarne Laitakari, for his kindness in permitting the publication of this work as a Bulletin of the Geological Survey. To the State Geologist, Dr. Ahti Simonen, at whose suggestion this investigation was begun, and who has afforded useful advice to me, I wish to present my sincere thanks.

Mr. Matti Mäntynen has carried out most of the chemical analyses presented in this paper. To him I am especially grateful. Some analyses have been done by Miss Gisela Stjernvall, Mr. Pentti Ojanperä, and Mr. V. Leppänen. For their valuable labour I wish to express my thanks.

To Mr. A. S. I. Matisto I am greatly indebted for photographing most of the micro-slide pictures presented here, and for drawing the texture figures. My thanks are also due to Mr. Ilmari Salli for his help in the photography. Furthermore, I wish to express my gratitude to Mrs. Toini Mikkola and Mr. A. v. Volborth for checking many of the optical determinations, to Miss Thyra Åberg for drawing the maps, and to her and Mrs. Suoma Vasakorpi for drawing the diagrams and figures.

The State Foundation I received to complete my investigation was of great help during the treatment of the large material. For this grant I wish to express my thanks.

Finally, I desire to express my special appreciation to Mrs. Joyce Preston for kindly revising the English of my manuscript.

Helsinki, March 1951.

Juhani Seitsaari

INTRODUCTION

The Tampere schist area and its location in Southwestern Finland (Fig. 1) has been well-known since Sederholm's investigations brought it before the attention of geologists half a century ago. His fundamental

Fig. 1. The location of the Tampere schist area in S. W. Finland.

investigation was published in 1897, and excited great interest especially owing to its far-reaching interpretations of the origin of early supracrustal rocks. This work has become a foundation of the uniformitarianism in the Archaean geology of Fennoscandia.

Sederholm divided the earliest Archaean formations into two age groups between which there was supposed a great unconformity, and put forward this opinion time after time (op. cit., and further publications in 1913, 1914, 1931, 1932). He called the older of these divisions the Svionian and the younger the Bothnian. The Tampere schists would belong to the Bothnian, and the porphyritic granite widely distributed immediately south of the schists would represent their basement rock. This granite, among others, was thus a »pre-Bothnian granite» in Sederholm's classification. Mäkinen (1915) was the first to observe that certain igneous rocks regarded as pre-Bothnian penetrate the Bothnian schists, and thus the great unconformity assumed could not exist. There is, indeed, evidence of deep denudation having taken place before the present Tampere schists were deposited (Sederholm 1931; cf. also p. 42), but nowadays both the Svionian and Bothnian are considered to belong to the same Svecofennian formation in which the Tampere schists, however, obviously represent a somewhat younger intraformational division (Wahl 1936).

It is characteristic of the »Bothnian» formations that metamorphism has only slightly obliterated the primary structures of the supracrustal deposits. Formations analogous to the Tampere schist area have been met, e. g., in Ylivieska and neighbouring parishes in Ost-Bothnia (from which the name »Bothnian» is derived) in Finland (Mäkinen 1916), and in Grythytte in Central Sweden (Sundius 1923). The Tammela—Kalvola area in Southwestern Finland, included in the Hämeenlinna map sheet of the Geological Survey of Finland (1949), in addition to which a brief report of it has earlier been published by Eskola (1936), also belongs to the »Bothnian». Especially in the Grythytte area have many analogies been observed. In both formations rather slightly metamorphosed clayey sediments, represented by fine-grained phyllite, are abundant. Conglomerates have clearly an intraformational character and an overwhelming majority of their pebbles originate from the underlying supracrustal rocks of the same continuous series. Intercalations that are easily recognizable as being incompletely decomposed volcanic materials with well-preserved primary phenocrysts, etc., are common. The ores in both the Grythytte and Tampere area have originated through late metasomatic processes, and differ from typical old ores in the Svecofennidic leptite region. Of course, differences can also be found, and further comparisons will be presented in several connections in the present paper. Mäkinen (op. cit.) suggested similar ideas as regards the conglomerates and the gradation from volcanics into sedimentary rocks in the Ylivieska area, but the phyllite proper is lacking there. In general, the grade of metamorphism in the Finnish Bothnian districts has been higher than that in the Grythytte area, in which low-temperature mineral assemblages are quite common. Concerning the stratigraphy, in the Tampere area the sedimentogenous series seems to be lower, as indicated by the varved phyllites, and is overlaid by volcanics. In the Grythytte area, and quite likely in the Ylivieska area also, this relation is the reverse.

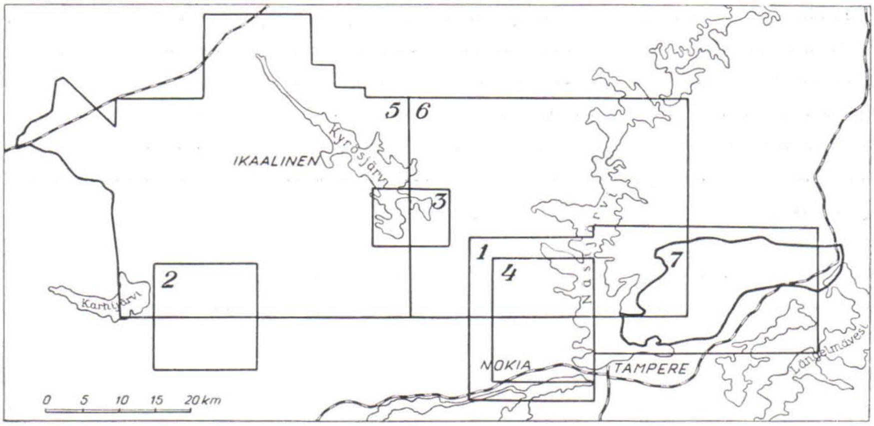

Fig. 2. The location of the areas in the Tampere district investigated and mapped in more detail. 1. The original area mapped by Sederholm (1897). 2. The Suodenniemi—Lavia area (Sederholm 1931). 3. The Viljakkala area (Stigzelius 1944). 4. The Ylöjärvi area (Simonen and Neuvonen 1947). A revised map of this last area is also included in the explanation to the Viljakkala—Teisko map sheet of the Geological Survey of Finland (in print). 5. Sheet —2122, Ikaalinen, of the Geological Survey of Finland, including the maps of the schist areas of Heittola—Kovelahti and Kankaanpää in the explanation to the map (in print). 6. Sheet —2124, Viljakkala—Teisko, of the Geological Survey of Finland (in print). 7. The area investigated by the present author.

In the last few years many complementary investigations have been carried out in the Tampere area. Stigzelius (1944) has presented a study in which the main attention is paid to the ore geology of the Haveri copper mine in the parish of Viljakkala. Saksela (1947) has described ore mineral assemblages in particular metasomatic schists. In 1945, the Geological Survey of Finland started a detailed revision work in this classical area, and as the results of this work two map sheets on the scale 1 : 100 000 will be published in the near future. A brief description of the metamorphism of the schists has already been published on the basis of these new observations (Simonen and Neuvonen 1947). In this connection the field work for the present investigation was also carried out, but as the area to be described has been mapped as part of a larger region, it does not, unfortunately, represent a complete entity.

The location of the areas investigated and mapped in more detail is shown in Fig. 2.

In the area northeast of Tampere exposures are abundant, and hence accurate mapping was possible. Low east-west ridges (i. e., parallel to the strike) are characteristic of the terrain. Many of the small lakes trend similarly, but others are across the strike. The latter represent joint directions in the rock crust, and judging by their trend corresponding to that of the numerous long and narrow lakes in the whole Archaean region of Southwestern Finland, they may be due to a uniform deforming force that affected large areas of the Svecofennides.

Most attention has been paid to the petrological side. The petrographical description is divided into three main parts, namely, (1) the supracrustal series, (2) intrusive rocks, and (3) metasomatism. However, in particular the northern boundary zone of the schist belt bears many indications of interesting phenomena that may somewhat hamper the clear picture of separate groups. Different infracrustal processes have apparently been made to converge.

The rock-forming operations, especially those at deep horizons, are not always easily divisible into particular groups. Convergence of normal-metamorphic and metasomatic processes is well in evidence. That of metamorphic and magmatic phenomena may not be very uncommon either, as has been suggested by Erdmannsdörffer (in several papers), Drescher-Kaden (1936), Koch (1939), and others. Read has recently (1944, p. 93; 1948 a, p. 3) advanced a completely new classification of rocks. It is: »neptunic» (the sedimentary rocks); »volcanic» (the magmatic, dominantly effusive rocks); »plutonic» (the metamorphic, migmatic, and granitic rocks). All the rocks of a deep-eroded district would thus be »plutonic», and Read frequently emphasizes the »unity of plutonism» (cf. 1948 b, p. 196); he also holds that some movement of material is a part of all metamorphic processes: there would be no closed systems and no absolute »normal-metamorphic» rocks.

In the present paper, some points concerning the evolution of the rock types may illustrate the convergence of the different processes in the Tampere area. Most of the schists, in any case, are so well preserved (e. g., the varved phyllites) that there is all reason to consider them to have remained approximately constant also in chemical composition.

THE SUPRACRUSTAL SERIES

The schist complex is composed of volcanogenous and sedimentogenous rocks of many different kinds, in addition to which there are certain transitional forms between these main groups. Volcanogenous rocks are situated mainly in the northern part of the belt, while sedimentogenous rocks rather definitely form the southern half of it.

VOLCANOGENOUS ROCKS

ROCKS OF RECOGNIZABLE LAVA ORIGIN

These rocks usually have a beautiful porphyritic texture with idiomorphic phenocrysts and a granoblastic, often very fine-grained groundmass. In places, however, the relict textures have been disturbed by intense dislocations.

Most of the ancient lavas have a *basic bulk composition*. Uralite porphyrite, uralite-plagioclase porphyrite, and plagioclase porphyrite belong to this group. These basic rocks have originally been basaltic lavas.

The largest occurrence of *uralite porphyrite* is situated W. of Lake Hankajärvi in the E. part of the parish of Teisko. In places, however, its lava origin is questionable. Very typical are comparatively thin beds in the central part of the area, especially between Lakes Paarlahti and Pulasjärvi in Teisko. They are 5—30 m. in thickness, but can be remarkably extensive along the strike. In thick beds the ground-mass is not as fine-grained as is usual.

Hornblende occurs as phenocrysts as well as smaller flakes in the groundmass. In the main occurrence of this porphyrite the primary crystal form of augite is rather uncommon, probably owing to a strong deformation. The hornblende is usually of the common green species, but in some cases it shows a slightly bluish colour for γ, the extinction angle ($\gamma \wedge c$) in that case reaching values up to 27°.

Plagioclase occurs mainly in the granoblastic ground-mass. A few small phenocrysts can be observed. The maximum extinction angle in the symmetrical zone is 24—25°, thus the plagioclase is andesine (An_{40-42}). (Most determinations of plagioclase have been carried out by this method. In most cases the determination was checked by measuring the refractive index, or by comparing the refringence with that of quartz or Canada Balsam.)

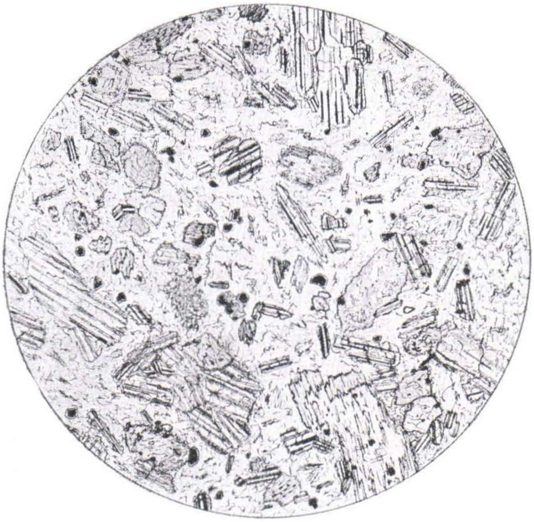

Fig. 3. Uralite-plagioclase porphyrite. Between Lakes Pulasjärvi and Syväjärvi, Teisko. Magn. 6 ×.

Biotite occurs as small, pale brown flakes, in some specimens in considerable amounts, having increased by secondary processes. Quartz, probably also of secondary origin, is found in the ground-mass.

Sphene as small rounded grains is the commonest accessory. The others are apatite and iron ore.

In the uralite porphyrites that have been strongly affected by mechanical dislocation, a lower-temperature metamorphism has usually taken place. In that case hornblende is pale-coloured and weakly pleochroic, and often entirely chloritized in the ground-mass, as in many phenocrysts. Epidote occurs in abundance. Sphene is often found as an alteration product (leucoxene) of titaniferous iron ore. Calcite is observed. Notwithstanding the clear evidence of low-temperature metamorphism, the anorthite percentage of plagioclase can be as high as 25—30 %.

Uralite-plagioclase porphyrite occurs in close connection with the uralite porphyrite, both types often gradually passing into each other. The best example of this rock is met with N. of Lake Pulasjärvi in Teisko. Its primary texture is well-preserved, and shows no parallel arrangement of the minerals, and the ground-mass is very fine-grained (Fig. 3).

The hornblende phenocrysts often display an excellent augite form, and many grains contain augite remnants. Only in this porphyrite is augite found.

Euhedral plagioclase phenocrysts are abundant. Their composition is An_{29-42} (the max. ext. angle in the symm. zone = 13—25°).

Hornblende and plagioclase are the essential constituents of the ground-mass, too. Biotite is present, but not in noticeable amounts. It is probably an alteration product of hornblende.

Epidote is observed in abundance in the ground-mass, and to a smaller extent as an alteration product of the plagioclase phenocrysts, often filling cracks in them. Quartz forms small accumulations.

Sphene occurs mainly as leucoxene rims around ilmenite grains. Some fairly big prisms of apatite are met with.

Plagioclase porphyrite without hornblende phenocrysts is only encountered in small amounts. Two or three thin beds are met with in the N. part of the complex. The thickest bed (about 25—30 m.) from which the specimen studied was taken, has been strongly affected by metamorphism, and hence its mineral composition does not correspond to that in the amphibolite facies.

The plagioclase phenocrysts measure up to 8 mm. in length. Many of them are well-shaped, but fragmentary crystals are also met with. The phenocrysts are still remarkably rich in anorthite, An_{35-40} (the max. ext. angle = 18—23°), but some individuals have partly recrystallized in a peculiar manner (see further p. 45). In consequence of the recrystallization the anorthite percentage is lower, sometimes less than 20. The plagioclase of the fine-grained ground-mass is probably more albitic than are the phenocrysts on the average, but it also shows a refringence higher than that of Canada Balsam.

Abundant biotite has been chloritized almost completely. Many large, elongated accumulations of pure chlorite are observed. They may also be alteration products of some earlier dark mineral.

Quartz forms lenses parallel to the foliation, and is, moreover, evenly distributed in the ground-mass. It may be for the most part of secondary origin.

The ground-mass is very rich in epidote. In the plagioclase phenocrysts euhedral epidote crystals are not uncommon. Calcite occurs around and between the phenocrysts. Microcline is met with as some small, elongated accumulations, its secondary origin being obvious. Apatite occurs as an accessory, as well as sphene in association with chlorite.

In the easternmost part of the schist area, on the shore of Lake Pappilanselkä in the parish of Orivesi, another type of plagioclase porphyrite is encountered. This occurrence has the form of a sill, about 200 m. in thickness. In many places the ground-mass can be very coarse-grained resembling some gabbros. The porphyritic texture is weakly developed and the foliation is indistinct. The main mineral components are plagioclase (An_{42}), and green or slightly bluish hornblende, this also forming some small phenocrysts. Biotite occurs in considerable amounts closely associated with hornblende. Probably this porphyrite belongs to the same volcanic period as the others, representing a hypabyssal mode of origin.

Intermediate rocks of lava origin are mainly andesitic or rather trachyandesitic in composition. A thick bed is situated along the southern shore of Lake Vaavujärvi, in the E. part of Teisko, and it extends from there several kilometres to the E. The ground-mass of the rock is fairly coarse-grained, except in the northern marginal zone in which the texture rather resembles that of the typical, metamorphic lava rock. This bed (or sill) is lying in approximately the same horizon as the hypabyssal plagioclase porphyrite treated above. Here also the occurrence is probably hypabyssal, unless the grain size of its main part is a primary feature of a thick (more than 300 m.) lava bed.

The marginal zone type was analyzed (Table I, N:o 1). The composition resembles that of a keratophyre from the W. part of the Tampere area (Simonen and Neuvonen 1947, p. 252), though it is slightly more basic. Silica might have increased secondarily. The name trachyandesite is preferred to keratophyre, in view of the comparatively high amounts of FeO and CaO. On the other hand, the $[Na_2O]:[K_2O]$ ratio is quite typical of a keratophyre.

Table I. Analyses of the supracrustal rocks.

	1		2		3		4		5		6	
	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.
SiO_2	58.79	9 789	68.76	11 449	59.84	9 963	56.26	9 367	60.64	10 097	64.14	10 679
TiO_2	0.90	113	0.35	44	0.75	94	0.81	101	0.67	84	0.67	84
Al_2O_3	16.77	1 645	15.37	1 508	14.19	1 392	15.05	1 476	16.86	1 654	16.41	1 610
Fe_2O_3	2.28	143	1.65	103	6.56	411	2.22	139	1.42	89	1.20	75
FeO	5.50	766	0.57	79	4.97	692	4.86	677	4.92	685	3.95	550
MnO	0.10	14	0.05	7	0.08	11	0.14	20	0.08	11	0.04	6
MgO	2.32	575	0.32	79	3.00	744	6.86	1 701	3.37	836	2.53	627
CaO	4.43	790	1.28	228	1.53	273	5.90	1 052	1.96	350	1.56	278
Na_2O	5.54	894	4.47	721	1.74	281	3.16	510	5.41	873	4.24	684
K_2O	2.04	217	6.25	663	4.64	493	2.36	251	2.83	300	3.44	365
P_2O_5	0.33	23	0.04	3	0.31	22	0.29	20	0.26	18	0.36	25
H_2O+	1.18		0.84		2.45		2.00		1.31		1.63	
H_2O-	0.07		0.12		0.07		0.12		0.07		0.10	
	100.25		100.07		100.13		100.03		99.80		100.27	
Niggli numbers												
si	189		328		212		157		207		250	
ti	2.2		1.3		2.0		1.7		1.7		2.0	
al	31.7		43.2		29.6		24.7		33.8		37.7	
fm	31.7		10.6		48.2		44.9		35.0		31.2	
c	15.2		6.5		5.8		17.6		7.2		6.5	
alk	21.4		39.7		16.4		12.8		24.0		24.6	
k	0.20		0.48		0.64		0.33		0.26		0.35	
mg	0.35		0.21		0.33		0.64		0.49		0.47	
c/fm	0.48		0.61		0.12		0.39		0.20		0.21	
qz	3		69		—		—		—		—	
Mineral composition												
Plagioclase .	An_{5-6} 49.5[1]		An_{4-8} 40.2[1]				An_{20-30} 0.4[3]		An_{15} 53.3[4]			
Quartz	10.7[1]		22.0[1,2]				4.1[3]		4.9[4]			
Fine-grained matrix of quartz and plagioclase .	—		—				14.6		—			
Microcline ..	—		34.7[1]				—		—			
Hornblende.	10.2		—				23.6		—			
Biotite	21.4		—				35.6		} 40.9			
Chlorite....	—		—				—					
Muscovite ..	—		3.1				—		—			
Epidote....	7.7		—				21.4		—			
Apatite	0.1		—				—		0.2			
Calcite	0.4		—				—		—			
Iron ore ...	—		—				0.3		—			
Tourmaline.	—		—				—		0.7			
	100.0		100.0				100.0		100.0			

[1] Calculated for the ground-mass.
[2] Including the accessories.
[3] Larger individual grains.
[4] Calculated.

1. Metamorphic trachyandesite. E. end of Lake Vaavujärvi, Orivesi. Analyst P. Ojanperä.
2. Feldspar porphyry. N. of Lake Valkeajärvi, Orivesi. Analyst M. Mäntynen.
3. Phyllite. N. of Lake Vaavujärvi, Teisko. Analyst P. Ojanperä.
4. Hornblende schist. N. W. shore of Lake Pappilanselkä, Orivesi. Analyst Gisela Stjernvall.
5 and 6. Successive evolutionary stages in the gradation towards the N. of the metamorphic trachyandesite (N:o 1). Analyst P. Ojanperä.

Fig. 4. Intermediate plagioclase porphyrite (metamorphic trachyandesite). E. of Lake Vaavujärvi, Orivesi. Nic. +, magn. 16 ×.

The mode has been determined by means of the integration stage, in this and all following cases, unless stated otherwise.

A microphotograph of the rock is presented in Fig. 4.

Plagioclase occurs as phenocrysts as well as in the ground-mass. A weakly developed zonal texture is observed in the phenocrysts. Some crystals are almost full of epidote, some others containing abundant intergrowths of tiny biotite and hornblende flakes. The maximum extinction angle in the symm. zone is about 14°, and the refractive index γ' is $\leq$ N of Canada Balsam, so the plagioclase is albite (An_{5-6}). In the ground-mass plagioclase occurs as minute, tabular crystals or needles. These often have a well defined parallel arrangement which resembles flow texture.

Biotite occurs chiefly as elongated accumulations and streaks.

Hornblende forms long, narrow prisms which are dispersed without any definite arrangement, or aggregated into small groups. It shows a clear bluish colour for γ, and the extinction angle $\gamma \wedge c$ is comparatively large, about 27°. Cf. p. 32.

Epidote is abundant in the ground-mass and occurs as an infilling of amygdules, too.

Some quartz is observed, especially at the ends of the plagioclase phenocrysts and filling cracks in them. Calcite is often seen in association with it.

Chlorite occurs in minute amounts as an alteration product, and apatite as an accessory mineral.

The mineral association is typical of the epidote amphibolite facies. As may be inferred from the great amount of epidote present as an alteration product, the anorthite content of plagioclase has primarily been much higher. The relative amounts of the minerals, as well as the grain size, are somewhat different in the main part of the bed. For instance, the amount of hornblende has diminished, while biotite has increased. No amygdules are observed, and the plagioclase has a slightly higher anorthite content (An_{13-15}).

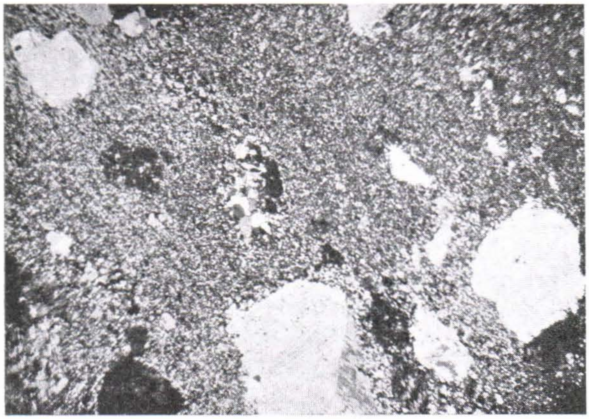

Fig. 5. Feldspar porphyry. N. of Lake Valkeajärvi, Orivesi. Nic. +, magn. 20 ×.

Acid lavagenous rocks of the area are feldspar porphyries, quartz porphyry being not met with. In Orivesi, in the central part of the complex, the feldspar porphyry forms two extensive beds, though not very thick (25—40 m.). One of these beds can be followed for 11 km., the other for 10 km. Other beds are found in the neighbourhoods of Lakes Vaavujärvi and Pulasjärvi.

This well-preserved porphyry is a good example of the effusive rocks of the area. It has an aphanitic, red to chocolate-brown ground-mass in which the rectangular or rhombic feldspar phenocrysts are seen very clearly. Earlier, Sederholm has described the porphyry from Vaavujärvi (1897, p. 67). Some parts of the long southern bed in Orivesi, however, are even better preserved. A microphotograph of this porphyry is seen in Fig. 5.

Fig. 6. A phenocryst of the rock seen in Fig. 5. White = albite, grey = microcline. Nic. +, magn. 40 ×.

The phenocrysts measure 1—3.5 mm. in length. They are composed of albite (An_{4-8}) and microcline intergrown with each other, the resulting texture resembling microperthite. The alternating parts may trend regularly, either being perpendicular to the long crystal faces or forming an angle of 65—70° to them (Fig. 6). The crystals mainly composed of one component, show a more irregular texture. Albite sometimes occurs as individual twinned crystals within the mixed phenocrysts, or close to their borders. The average composition of the phenocrysts is, according to determination on the integration stage, 62.7 per cent albite and 37.3 per cent microcline.

The grain size of the ground-mass is 0.01—0.02 mm. It consists mainly of quartz and alkali feldspar. Chlorite or green biotite is observed in minute amounts, and also some tiny ore grains with leucoxene rims.

At the ends of many phenocrysts larger microcline and quartz crystals are observed, usually together with muscovite. Apparently they have crystallized from circulating solutions. Yellowish epidote is found in cracks.

The rock described was analyzed (Table I, N:o 2). The amounts of both alkalies are remarkably high. Among the acid volcanics of the Tampere area the soda-rich types may be commonest, but many feldspar porphyries seem to represent a rather inverse case (Simonen and Neuvonen 1947, p. 252, and Sederholm 1897, p. 68). The analysis given by Sederholm represents the porphyry from Vaavujärvi. The rock described by the present author is related to some porphyries in the classical Oslo region, e. g., to those of the nordmarkite and the granitite series (Brögger 1933), and to a syenitic dike rock in the Kiirunavaara area (Geijer 1910, p. 49). Furthermore, Eskola mentions an aegirite granite from Miask, Ural, with nearly similar composition (1921, p. 76).

In effusive rocks with syenitic or alkali-granitic composition the mixed crystals of alkali feldspars are very common. The phenocrysts described may have primarily originated as anorthoclase crystals. The regular arrangement of albite and microcline parts could be explained as a perthitic texture resulting from complete recrystallization during the metamorphism. On the other hand, the author has observed certain phenomena that do not support this interpretation. They are in connection with the metasomatic increase of potash and will be discussed later on (p. 90 and 98). For the present it may be stated that undeniable cases of replacement, caused by secondary potash, are seen in many rocks, and plagioclase especially has been attacked by it. This is also true of the potash-extreme feldspar porphyry from Vaavujärvi. The textures resulting from an advanced replacement, however, are very irregular (Fig. 44, p. 99). A portion of the potash and silica has certainly been mobile in the rock described. The amounts of both alkalies are rather similar to those of the normal trachyte, but in all other respects this rock is more acid. We must assume, perhaps, that silica and potash have increased to some extent secondarily, while FeO, MgO, and CaO have decreased. The character of a primarily acid lava rock cannot, however, be denied. It is possible that the potash of the rock itself has also been mobile, probably causing replacement phenomena.

The feldspar porphyry beds N. E. of Vaavujärvi have been deformed more strongly. The ground-mass is coarser-grained and the rock contains muscovite and calcite in considerable amounts. The phenocrysts have been largely obliterated. It is noteworthy that their »replacement texture», if so assumed, is not at all as distinct as in the better preserved rock.

The most deformed type has the purest albite phenocrysts. This fact again is not in harmony with the »replacement theory», as strong deformation usually affords the best opportunities for metasomatic processes. On the contrary, it might be thought that unmixing of the mixed crystals has been still more advanced.

Sundius (1923) has described potash-rich porphyries in the Grythytte area in Central Sweden, and also mentions textural features similar to those described above. According to him, the phenocrysts would primarily have been mixed crystals composed of orthoclase, albite, and anorthite, from which the anorthite has later been leached away. He also regards the intergrowth of albite and microcline as presumably of perthitic character (op. cit., p. 94). Again according to Sundius, the actual chemical composition of the porphyries of Central Sweden is primary.

Although the possibility of some metasomatic changes must be considered, the existence of trachyandesitic porphyrite and alkali-rich feldspar porphyry may imply a gentle alkaline tendency of the lava differentiation in the area.

TUFFITIC ROCKS

Where the schists have not been too strongly metamorphosed, the rocks of lava origin may be distinguished from those derived from volcanic ashes. The ground-mass of tuffites is usually coarser-grained. The porphyritic texture, especially megascopically, is often indistinct; in many cases the feldspar phenocrysts are fragmentary, not idiomorphic. Even-grained types are not uncommon. Heterogeneity, or an indistinct bedded texture is often observed, and different types are closely alternating. Furthermore, the tuffites are usually more distinctly foliated owing to the character of the primary material. In many instances, of course, it is difficult to distinguish volcanic rock types one from another. On the other hand, a gradual passage into sedimentogenous rocks often makes an exact definition difficult.

For the greater part the tuffites are of basic or intermediate character.

Basic porphyritic tuffites with uralite and plagioclase phenocrysts have a wide distribution N. and E. of Lake Pulasjärvi and in the neighbourhood of Lake Hankajärvi, in connection with basic porphyrites of the same composition. On the whole their mineral assemblages are similar to those of their respective lava rocks. An amphibolitic type occurs in the northernmost part of the complex N. of Lake Pukalanselkä, at Lake Hankajärvi, and several kilometres farther to the W. It has been more or less affected by granitization and other secondary agencies, especially N. of Lake Paarlahti. Well-preserved amphibolite is met with between Lakes Pukalanselkä and Hankajärvi.

The rock is wholly granoblastic without any relict textures. The main mineral components are green hornblende and plagioclase. A well-developed linear texture is created by parallel hornblende crystals. Some accumulations of hornblende are observed. The plagioclase shows a maximum extinction angle of about 18° in the symmetrical zone (An_{35}).

Sphene and apatite occur as accessory minerals.

This amphibolite has also been somewhat influenced by the adjacent granite. Noticeable amounts of potash feldspar are observed between the primary minerals and the plagioclase has been considerably sericitized, and some chlorite and epidote have crystallized at the expence of hornblende. The texture and appearance of the rock, however, has remained fairly unchanged.

In the amphibolite some calcareous *concretions* are found. These consist of greenish diopside, quartz, and plagioclase as main components. Plagioclase is rich in anorthite (about An_{50}). The concretions are rimmed by a fine-grained aureole of quartz, hornblende, and anorthite-rich plagioclase. Sphene is comparatively abundant as small oval crystals in both the concretion and the rim.

In highly deformed zones the most basic tuffites are largely composed of chlorite, albite or oligoclase, and epidote. Calcite is observed in abundance as an infilling of cracks and as minute veins parallel to the foliation. Magnetite is also invariably present, sometimes as idiomorphic individuals, and probably the iron has been released from chloritized hornblende. Such a mineral association is related to a low-temperature facies.

Among the basic and intermediate volcanics of tuffitic origin plagioclase-porphyritic schists are by far the commonest. As regards the mineral composition of basic types, the description of the plagioclase porphyrites (p. 12) may be sufficient. Owing to their great extent, however, they may vary greatly according to the conditions in different places. Chlorite-epidote-rich varieties, often with calcite and magnetite, have been developed at low temperatures.

Schists of *intermediate bulk composition* seem to have been derived from materials of different origin, as may be deduced from their great amount compared with that of respective lava rocks. They often alternate with basic volcanics, the types gradually passing over one into another, but in many instances it is not at all certain that the composition of a more acid layer is primary, and such beds may even be of nonvolcanic origin. Weathering during deposition and later metasomatic processes have certainly produced rocks of intermediate composition. In the field the distinction between different cases is often impossible.

The following mineral association of the plagioclase-porphyritic intermediate schists best represents the amphibolite facies.

The main component is plagioclase (An_{23-30}). The size of the phenocrysts varies greatly, they are often fragmentary, and sometimes unevenly distributed forming accumulations.

Biotite occurs as long streaks as well as separate flakes.

A considerable amount of quartz is observed, but for the great part occurs in pressure minima around the plagioclase phenocrysts, or as an infilling of cracks, etc., and accordingly it is chiefly of secondary origin.

Iron ore, apatite, and sphene are present as accessory minerals. Epidote, calcite, sericite, and chlorite are observed as alteration products.

In most cases some microcline is present in these schists, occurring mainly in connection with the plagioclase phenocrysts either as indefinite tiny »veins» within them, or immediately around them. Moreover, it often fills cracks together with quartz and epidote, or also with calcite. The epidote occurring in connection with biotite sometimes forms idiomorphic crystals which may have a zonal texture. The kernel of such individuals is allanite. All these features show that there has been a circulation of materials. Whether there is real metasomatism or an autometasomatism in question is often difficult to decide. In a rock, e. g., of trachyandesitic composition the appearance of some potash feldspar is not unexpected. On the other hand, in the zone of Lakes Paarlahti—Peräjärvi—Kutemajärvi—Iso Teerijärvi, in which the intermediate schists are common, metasomatic changes of composition are well in evidence (p. 97). In this zone an intense mechanical deformation of the rocks has afforded opportunities for such changes.

In the lower-temperature facies chloritization of biotite is complete, unless the potash has increased secondarily, and epidote is abundant. Plagioclase is usually albite, but in some cases it may still contain 15—25 per cent anorthite.

Acid tuffitic schists. Acid schists rich in feldspar occur in many places in the southern and central part of the schist complex. What has been noted concerning the origin and character of the intermediate schists, is true of these rocks also. It is often almost impossible to decide whether an acid schist was primarily a volcanic product, or a sedimentary deposit. A close connection with phyllites is frequently observed. (For the term »phyllite» in this paper see the description on p. 22). Nevertheless, even within the phyllite zone truly volcanogenous acid schists are encountered, and probably there are true acid tuffites in connection with the feldspar porphyry beds. On the map the term »leptite», in the sense of Swedish geologists (Geijer 1944, p. 734), is used for all acid schists with the exception of the porphyries.

The leptites that are probably of volcanic origin have a more or less distinct porphyritic texture. Most leptites are comparatively fine-grained. The very fine-grained types are often banded, and their porphyritic texture is indistinct or it may be entirely lacking. They thus resemble the so-called »hälleflintas». More basic laminae are observed together with acid ones, and the banded texture has often resulted from such a variation. This type is met with in many places in Orivesi.

The mineral composition is quite or nearly similar to that of acid porphyries. A distinctly pyroclastic type from the E. part of Aitolahti will be described below. Megascopically, it is dark grey-coloured with darker and lighter layers.

The porphyritic texture is well-developed. Both feldspars occur as phenocrysts, the plagioclase being predominant. The plagioclase is albite (An_{5-10}), as determined from the refringence. Abundant fragmentary grains are observed. The phenocrysts sometimes form accumulations, especially those of plagioclase. Intergrowths of both feldspars with each other are rather uncommon.

The ground-mass is very fine-grained, in contrast to tuffites in general. It consists of biotite, muscovite, feldspar, and quartz. Potash feldspar dominates over albite, and occurs, moreover, as minute aggregates and lenses. Thus it seems that the potash might have been moving in the rock. The same feature is shown by the concentration of larger muscovite flakes around the phenocrysts. Biotite sometimes occurs more abundantly as elongated ovals. Probably this is to be regarded as a relic after vitrophyric texture (Rosenbusch 1910, Simonen and Neuvonen 1947).

The leptites that are regarded as sedimentogenous will be discussed in the following chapter.

As regards the mineral associations of the acid schists in different metamorphic facies, the differences between them are not as distinct as they are in the basic rocks. In the associations resulting from low-temperature metamorphism the plagioclase is always albite and chlorite occurs instead of biotite, though not always.

No analyses of volcanogenous leptites are available. From microscopical study it may be deduced that there are no extremities in their composition as regards the alkali ratio. According to the studies on the leptites of Finland in general, soda-rich types may be more common than potash-rich. One must not forget, however, the possibility of metasomatic changes in the rocks investigated. Potash has certainly been moving in the acid schists. No doubt the schists concerned have been primarily acid, and consequently the potash of the rock itself might have been set in motion. Potash seems to be a very mobile element, but it is just owing to its mobility we must always reckon with the possibility that its total amount also has increased secondarily in metamorphic rocks. For instance, the »hälleflintas» in Orivesi are nearly similar to certain potash-metasomatic schists (p. 97). Accordingly, great caution is necessary concerning the primary composition of such rocks. To quote Read (1948 b, p. 177), »some movement of material is a part of all metamorphic processes», all the systems are open in a sense.

AGGLOMERATES

Distinct and undoubted agglomerates are rather uncommon, and most of them are associated with the basic volcanics. Continuous layers form the base of the tuffitic beds here and there. In the immediate vicinity of lava rock beds, both basic and acid, apparent »bombs» of respective lava rocks are sometimes met with in tuffitic layers.

SEDIMENTOGENOUS ROCKS

THE GRADATION FROM VOLCANICS INTO SEDIMENTS

The schists that will be discussed below vary greatly in their mineralogical and chemical composition. This variability depends upon several factors during the deposition. The degree of decomposition has been of great importance. Sederholm (1897) has in detail described the main types of sedimentogenous rocks of the Tampere area, and therefore many details are omitted in the present paper.

PHYLLITE AND MICA SCHIST

For the greater part the sedimentary rocks are phyllites [1] and mica schists of common type, the typical fine-grained phyllite being predominant.

The characteristic phyllite almost always shows a distinct lamination, and often a varved structure. The varves are usually less than 15 cm. in thickness, their bottoms being comparatively fine-grained. Thus the similarity to glacial clays is striking, and the primary material is supposed to be a product of the most complete chemical weathering.

The main minerals are dark biotite and quartz, in addition to which some muscovite usually occurs. The parallel texture indicated by the mica flakes is exceedingly well-developed. Only seldom is feldspar observed.

Iron ore is always present and tourmaline is frequently met with.

The bottoms of the varves are somewhat heterogeneous containing larger residual grains in abundance. These are quartz with a little plagioclase and small rock fragments. The matrix between them consists of fine-grained quartz and mica. Such a composition is typically arenaceous and the texture clearly blastopsammitic. The sharp boundary between two varves, as well as a well-developed transversal cleavage, are seen in Fig. 7.

A fine-grained phyllite N. of Lake Vaavujärvi in Teisko was analyzed (Table I, N:o 3). Analyses of the phyllites of the Tampere area have earlier been published by several authors, for instance, by Sederholm (1897, p. 88; 1913, p. 23), and by Simonen and Neuvonen (1947, p. 253). All these analyses indicate a more or less typical clayey composition.

Along the southern boundary of the schist complex, and in places in the W. part of Aitolahti, coarse-grained varieties are predominant. In these the varved structure is often lacking, and even the bedding is indistinct in some cases. Where varvity is seen, the varves may measure up to 2 m. in thickness. The original material of the bottoms has sometimes been rather gravelly, and the rock resembles greywacke. It contains

[1] This term is used in the meaning »fine-grained mica schist with well-preserved bedding or varvity», as is done especially in Finland and Sweden; also used for slate.

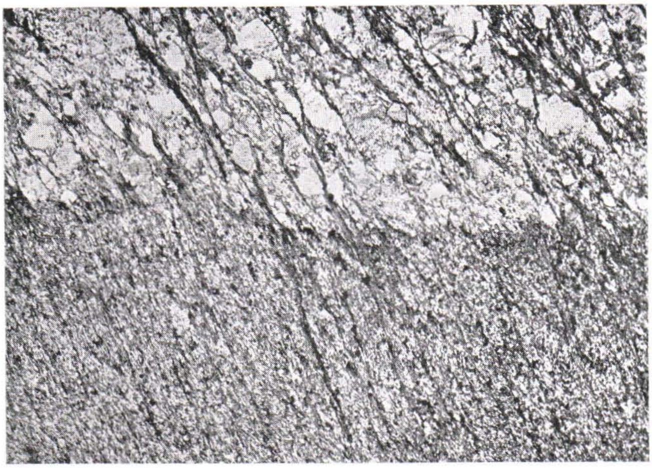

Fig. 7. Varved phyllite showing distinct transversal cleavage. S. W. of Lake Paalijärvi, Teisko. Nic. ||, magn. 16 ×.

abundant quartz grains and rock fragments measuring up to 0.5 cm. in diameter. The varves may consist of coarse-grained material throughout without any phyllitic upper portion.

The usual mineral composition is biotite, quartz, and plagioclase, with muscovite in some cases. Quartz predominates over plagioclase, both forming rounded or irregular residual grains. The matrix also is plagioclase-bearing, and the composition of the plagioclase varies (about An_{20-35}). Potash feldspar is rare. Small fragments of some fine-grained rocks are found.

Some apatite is always present, as well as epidote especially in the matrix.

The biotite-rich varieties with sparse residual grains pass over into mica schist. On the other hand, in the case of quartz and feldspar dominating over mica, the terms »meta-arkose» or »arkose gneiss» may be used. Such rocks are encountered especially in the N. corner of the parish of Kangasala.

The feldspar-bearing, mostly coarse-grained sedimentary schists are supposed to contain products of mechanical disintegration in addition to those of chemical weathering. Thus the large amount of feldspar can be understood.

The typical accessories of sediments deposited in water are commonly observed in the schists described. Thus pigmental carbon often occurs in the phyllites. The carbon content, according to several earlier analyses, is usually a fraction of one per cent, and as a rule, it is concentrated either in the tops of varves or in definite layers. The occurrence of tourmaline has already been mentioned. It is occasionally found also in the coarse-grained type where the borders of the tourmaline grains have recrystallized into new individuals showing different colour and pleochroism. This tourmaline may be derived from detrital tourmaline grains of the original sediment. Zircon again is a common accessory in sandstones, and is in fact often found also in blastopsammitic schists in the Tampere area. Iron sulphides are not met with in appreciable amounts. In fine-grained, usually amphibole-bearing »black schists» (some narrow belts in Orivesi), however, sulphidic ores may be present in considerable quantities.

In strongly deformed zones the phyllites and mica schists have a mineral assemblage that is due to a lower-temperature metamorphism. Chlorite is in that case an essential constituent together with biotite and muscovite. If present the plagioclase is albite.

The bottoms of the phyllite varves are as a rule directed to the south, but some exceptions, however, were observed, apparently owing to the folding of the beds. Some observations of such folding were made, mainly in Orivesi. Unfortunately, in the well-exposed cliffs of Lake Näsijärvi where the most accurate observations could be made, the primary structure has often been disturbed by a secondary minor folding (p. 112).

In the varved phyllite on the shore of Lake Näsijärvi, in Aitolahti, the well-known *Corycium enigmaticum* is seen. This peculiar figure was first discovered and studied in detail by Sederholm (1897, 1913, etc.). Sederholm considered it a fossil alga, and he saw in it a clear evidence of Archaean formations having originated under conditions such as exist today. Recently, however, the oval-shaped or longish sacs of the *Corycium* have been interpreted otherwise by van Straaten (1949, p. 9). According to him, the *Corycia* were caused by incompetent clayey layers sliding between sandy ones, causing an intense minor folding of the beds and thrusting wedge-shaped or wholly isolated parts of phyllite into the coarse-grained bottom of the upper varve. In any case, the organic origin of the carbon of the *Corycium* cannot be denied and has been established in full through the isotope determination carried out by Rankama (1948). In his recent paper (1950), Rankama completely agrees, too, with Sederholm as to the primary fossil nature of the *Corycium*.

Lime-bearing *concretions* were observed mainly in the southernmost part of the complex. It is noteworthy that in most cases they are met with in coarse-grained and feldspar-bearing types of schist. Many of the concretions are comparatively big, up to 65 cm. in length, but less than 10 cm. in breadth, having been strongly elongated by tectonic movements.

The main constituent is epidote, rather poor in pistacite, as appears from its birefringence. Quartz occurs as irregular patches and stripes. Small crystals of pale hornblende are met with occasionally, mainly in the marginal zone. Magnetite and sphene (as leucoxene) are accessory minerals.

In thin sections the boundary between the concretion and the surrounding schist is not sharp. The amount of epidote decreases and that of hornblende increases gradually. Immediately outside the concretion proper a darker green hornblende is abundant as comparatively big prisms without any regular arrangement. The rim rich in hornblende is about 1 cm. in breadth, and the surrounding schist contains no hornblende. The most noticeable accessories of the rim are apatite and sphene. The apatite occurs, for instance, as some small accumulations.

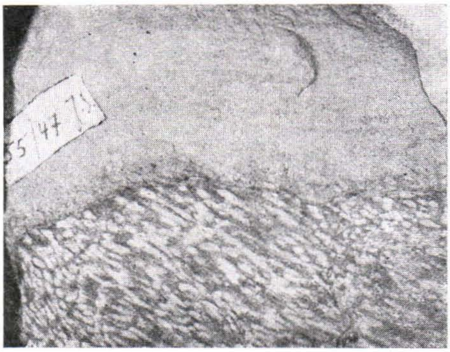

Fig. 8. Varved phyllite with porphyroblasts in the fine-grained part. S. E. of Lake Iso Lumajärvi, Aitolahti. 3/4 natural size.

The chemical composition of the concretions well corresponds to that of marl. The rim has obviously been developed as a reaction product by later metamorphic differentiation. Fe, Mg, Ti, and probably Si have migrated towards the concretion, while Ca and P (presumably originating from the phosphorite included in the primary concretion) have moved in the opposite direction. Mg seems to have migrated farther than Fe, since the hornblende within the concretion is paler than that in the rim. This is conformable to certain observations of Jung (see Read 1948 b, p. 183).

Influence of intrusive magmas on clayey sedimentary rocks. Whenever the composition has been rich enough in alumina, porphyroblasts rich in this constituent have recrystallized in the surroundings of the intrusions, often for a distance of more than 100 m. away from contacts. They have never been preserved unaltered, however, but instead accumulations mainly of muscovite occur at present. The primary porphyroblast might have been andalusite, since similar pseudomorphs with andalusite relics have been observed in Ylöjärvi, N. W. of Tampere (Simonen and Neuvonen 1947, p. 254). The pseudomorphs are very abundant in the veined gneiss (original mica schist) S. E. of Lake Paalijärvi in N. Kangasala, and in the varved phyllite immediately S. of the central granodiorite massif in Aitolahti. The pseudomorphs occur definitely in the fine-grained top portions of the varves (Fig. 8).

There is no need to suppose an increase of potash for the alteration of Al-rich porphyroblasts into muscovite; the rock being originally rich in potash, a decrease in temperature after the crystallization of the porphyroblasts accounts for this change. However, separate, often large flakes of muscovite interspersed at random might have been formed through a metasomatic influence. In addition, an alteration of plagioclase into muscovite and quartz can be observed, as described also by Hietanen (1943, p. 34) in the plagioclase-sillimanite schist in the Kalanti area.

In the schist itself, almandite is not found as a contact mineral, but occurs, sometimes in abundance, in veins of aplite, pegmatite, and quartz cutting phyllite and mica schist.

SEDIMENTOGENOUS SCHISTS RICH IN LIME

This type of schist occurs especially in Orivesi immediately W. of Lake Pappilanselkä, but also at other places in Orivesi, Kangasala, and Teisko as separate narrow beds among phyllite and mica schist. The »black schist» (p. 24) belongs to them. This amphibole-sulphide-bearing schist is well-known in the Karelian formation (Frosterus and Wilkman 1920, Wilkman 1921).

The deposit W. of Lake Pappilanselkä is about 400 m. in thickness, varying greatly in composition. On either side there are basic volcanics, and in many places the deposit itself may contain volcanic materials besides arkosic and clayey sediment. A part of the bed has a more or less distinctly conglomeratic character with pebbles mainly of several volcanic rocks.

A very typical composition is as follows·

Biotite occurs as long coherent stripes as well as minute flakes parallel to the schistosity.

Quartz is seen as some elongated and granulated residual fragments, and is abundant in the matrix.

Much plagioclase is observed in the matrix. Some larger wholly deformed grains are found, which are supposed to be residuals of weathering. The plagioclase is often largely sericitized. Its composition is about An_{20-23} (from comparing the refringence to that of quartz and Canada Balsam).

A further mineral of importance is weakly pleochroic hornblende with γ pale green, α almost colourless. The arrangement of amphibole prisms is not as clear as that of biotite, many individuals having crystallized at random.

Epidote poor in pistacite, and chlorite occur as alteration products, sphene, apatite, iron ore, and zircon as accessory minerals. Some black pigment, probably graphite, is somewhat concentrated into certain horizons.

The main occurrence of this rock being situated near the southern granite massif has often been cut by granite or pegmatite veins. Secondary quartz and microcline are then abundant, the plagioclase is albite, and the amphibole is even paler-coloured, probably nearly tremolitic. Chlorite and epidote have crystallized especially along the boundaries of veins.

Another common kind of schist, occurring as a cement of the conglomerate in the same area, consists of plagioclase (about An_{25}), pale green amphibole, and quartz as the main components. For the amphibole, the values $2V\alpha = 70°$ and $\gamma \wedge c = 15° \pm 2°$ were found on the U-stage. Refractive indices determined by the immersion method are $\gamma' = 1.657$ and $\alpha' = 1.639$ indicating a fairly high content of magnesia. In addition, the rock contains considerable amounts of sphene, and secondary calcite is met with, but biotite only occasionally. The heterogeneous distribution of minerals and the lack of parallel arrangement are characteristic. More fine-grained layers rich in quartz and poor in amphibole sometimes occur.

In a certain variety the amount of lime varies very definitely. The lime-extreme layers consist of epidote, amphibole like that described above, and quartz. The calcic minerals dominate over quartz very greatly. Epidote often forms euhedral crystals. On either side of such a layer pale biotite appears, and epidote decreases gradually while quartz increases. Epidote does not disappear entirely, but where it has decreased to a certain extent, magnetite occurs in noticeable quantities. Amphibole is lacking. On the weathered surface the Ca-rich layers rise above their surroundings as ridges 1—3 cm. in breadth.

In the N. W. part of Kangasala a further lime-rich schist is found in connection with coarse-grained »meta-arkose» and mica schist. The high anorthite content of its plagioclase (up to 84 per cent) is especially to be noted.

The rock is composed of quartz, pale-coloured amphibole, plagioclase, garnet, and epidote as main constituents.

Amphibole sometimes occurs more abundantly in certain layers. The crystals tend towards a parallel arrangement.

Epidote (clinozoisite) is mainly present in certain zones parallel to the bedding, or as some indefinite areas. In these, plagioclase is lacking and quartz decreases greatly.

The abundant plagioclase is somewhat unevenly distributed occurring as small indefinite patches of tiny irregular grains (see Fig. 9). For the composition see below.

Garnet is seen as minute rounded grains or as groups of grains. A few bigger crystals show the form of rhomb dodecahedron.

Calcite and sphene are observed in appreciable amounts.

Certain somewhat coarser-grained parts occur as definite layers, 1—3 cm. in thickness and often forming boudinages. They contain more quartz, and are devoid of garnet, epidote, and calcite. A microphotograph of such a layer is seen in Fig. 9.

Fig. 9. Calcareous schist layer with hornblende, bytownite, and quartz. Grey = bytownite. E. of Lake Peurnajärvi, N. W. Kangasala. Nic. ||, magn. 16 ×.

For determining the *plagioclase*, the only applicable methods were the determinations of the refractive index and the specific gravity, owing to the fine grain and to the twinning being observed only incidentally. A little of fairly pure plagioclase could be separated from the coarser-grained layer, and the determinations gave the results as follows: N_m =

Fig. 10. Schist with chlorite, garnet, and bytownite. The grey fine-grained mass is bytownite. S. W. of Lake Rukojärvi, Kangasala. Nic. ||, magn. 35 ×.

1.572—3 (by the immersion method); the specific gravity = 2.737 ± (by means of the Clerici solution). The corresponding composition is An_{82-84}.

In another related type, the only abundant calcic mineral proper is the plagioclase rich in anorthite. A microphotograph of this rock is presented in Fig. 10.

Two kinds of layers are seen that differ from each other in both the grain size and the mineral composition.

The main minerals of the coarser-grained layers are plagioclase, quartz, chlorite, and garnet. The mode of occurrence of plagioclase is similar to that described above. N_m = 1.568—9, corresponding to the composition An_{72-73}, was determined. The chlorite flakes measure 0.1—0.5 mm. in length. The garnet grains are often well-shaped, but they contain numerous inclusions of plagioclase, quartz, and ore. The ore content of the rock is noticeable, oxides as well as sulphides being present. Biotite occurs in small amounts.

The mineral composition of the fine-grained layers is rather similar to that of the common mica schist. In addition to quartz and biotite it also contains chlorite, and considerable amounts of magnetite. This latter constituent seems to characterize many schists of this kind, and is associated with more abundant biotite mainly in thin definite layers.

The occurrence of *chlorite* in such an assemblage is of special interest. The chlorite was analyzed (Table II) and studied in detail optically. The properties are as follows: non-elastic flakes, distinct basal cleavage but not as perfect as in mica; optically positive ($2V\gamma$ = 51—52°), elongation negative; pleochroic with $\alpha \approx \beta$ pale greyish or bluish green or green $> \gamma$ almost colourless; the extinction angle $\gamma \wedge c$ is about 10° and twinning lamellae can be seen; the refractive index α' = 1.624 ± 0.002, the birefringence weak. The specific gravity is = 2.968 ± 0.005, as determined by means of the Clerici solution. According to Winchell (1933), the mineral is a ferriferous corundophilite (ripidolite or prochlorite?), although the optic angle looks too large. The chemical composition is in close harmony with many analyses of prochlorite given in Dana's old »System of Mineralogy» (1899, p. 654). An aphrosiderite (op. cit., p. 660, anal. 10) is almost identical. According to Dana this chlorite, however, is uniaxial, and according to Winchell the aphrosiderite is optically negative.

Table II.

	%	Mol. prop.
SiO_2	27.95	4 654
TiO_2	0.68	85
Al_2O_3	22.58	2 215
Fe_2O_3	2.87	160
FeO	19.34	2 692
MnO	0.25	35
MgO	14.17	3 514
CaO	1.50	267
Na_2O	0.45	73
K_2O	0.15	16
H_2O+	11.02	6 115
H_2O-	0.15	
	101.11	

Chlorite from chlorite-garnet-bytownite schist. S. W. of Lake Rukojärvi, Kangasala. Analyst M. Mäntynen.

Unfortunately, the *garnet* could not be analyzed, because material sufficiently pure for that purpose could not be separated owing to the inclusions. The refractive index of the garnet is $N_D = 1.809 \pm 0.003$, determined by the immersion method. Its specific gravity was also determined by means of the Clerici solution, but the result is not quite reliable, owing to the inclusions again. The values varied between 3.89 and 3.99. As quartz and feldspar inclusions are commoner than those of ore, the correct value may be nearer the latter figure, probably a little more than that. Such properties may indicate the garnet as almandite-pyrope with a noticeable content of grossularite and some andradite (Winchell 1933).

These rocks show a similarity to the garnetiferous layers and the sandy beds in kinzigite described by Hietanen (1943, pp. 18—24). Both are characterized by anorthite-rich plagioclase and garnet. The garnet of the intercalations in kinzigite was found to contain grossularite and spessartite in appreciable quantities.

A particular type of hornblende schist occurs in a horizon situated farther north. The most extensive occurrence is seen at the boundary of the main zones of phyllite and volcanogenous rocks. This belt is almost uninterrupted, about 17 km. in length (from Lake Pulasjärvi in W. to Lake Pappilanselkä in E.) and 20—50 m. in breadth. The type is also

Fig. 11. Hornblende schist. N. E. of Lake Vaavujärvi, Orivesi. Nic. ||, magn. 16 ×.

met with here and there elsewhere, usually accompanying the phyllite among the volcanics. Its sedimentary character is often as apparent as that of the other hornblende schists. It sometimes shows a bedded structure with thin converging and diverging layers rich in hornblende, and even varvity may be observed. As compared with the southern type, a distinctive feature is the species of hornblende.

Microphotographs of these schists are presented in Figs. 11 and 12. The mineral assemblage does not deviate noticeably from that of the southern hornblende schist at Lake Pappilanselkä. The main constituents are hornblende, quartz, plagioclase (An_{20-30}), biotite, and epidote. Plagioclase and sometimes quartz occur as bigger, rounded residual grains. When feldspar predominates over quartz, the biotite disappears. Magnetite is always present, sometimes as idiomorphic crystals.

A specimen from the bedded variety was analyzed (Table I, N:o 4), and the result was unexpected. The Niggli numbers show a great similarity to those of certain syenito-dioritic magma types (Niggli 1923, p. 125 and 147), as shown in Table III. Could that mean a sediment originating from an eruptive rock decomposed, but without transportation of the products away from the scene (cf. p. 34)? Or might such a composition have resulted from the intermingling of various materials in a suitable ratio?

The *hornblende* is unevenly distributed, as separate prisms interspersed at random, as accumulations often with radial arrangement of the crystals, etc. The mineral is always rather dark-coloured with γ deep bluish green $>$ β grass green $>$ α pale greenish yellow, but the other properties may vary somewhat. An example was optically studied in more detail, and chemically analyzed (unfortunately not from the rock

Table III. Comparison of Niggli numbers.

	1	2
si	157	150
al	24.7	25.5
fm	44.9	43.5
c	17.6	17.0
alk	12.8	14.0
k	0.33	0.31
mg	0.64	0.55
c/fm	0.39	0.44

1. The Niggli numbers of the rock in Table I, N:o 4.
2. Average values of the Niggli numbers of soda-lamprosyenitic and normal-dioritic magma types, according to Niggli (1923).

analyzed, due to lack of material). The extinction angle $\gamma \wedge c$ is 18°, but it may be mentioned that in the rock analyzed it can reach up to 28° (determined without the U-stage). The refractive indices are $\alpha =$ 1.664, $\beta = 1.681$, and $\gamma = 1.685$; $2V\alpha = 66$—67°. The specific gravity is about 3.25. The chemical composition is seen in Table IV, including the atomic proportions calculated according to the principles applied, e. g., by Winchell (1945) and Sundius (1946). The high content of alumina as well as the ratio [FeO] : [MgO] are as may be expected in an amphi-

Fig. 12. Hornblende schist. N. W. shore of Lake Pappilanselkä, Orivesi. Nic. ||, magn. 5 ×.

Table IV.

	%	Mol. prop.	Atomic prop. (O = 24)		
SiO_2	40.12	6 680	Si 5.92	2.08	8.00
TiO_2	0.80	100	Al 3.25	1.17	
Al_2O_3	18.68	1 832	Ti 0.09		
Fe_2O_3	5.43	340	Fe^{III} .. 0.60		
FeO	13.20	1 837	Fe^{II} .. 1.63		4.93
MnO	0.29	41	Mg ... 1.40		
MgO	6.36	1 577	Mn ... 0.04		
CaO	11.10	1 979	Ca 1.75		
Na_2O	1.29	208	Na 0.37		2.23
K_2O	0.58	62	K 0.11		
P_2O_5	trace		OH ... 2.28		2.28
H_2O+	2.32	1 287			
H_2O-	0.24				
	100.41				

Hornblende from hornblende schist. N. end of Lake Kutemajärvi, Orivesi. Analyst Gisela Stjernvall.

bole of a sedimentogenous rock. The percentage of alumina is extremely high, however. According to the proposal of Winchell (op. cit.; cf. also Sundius, op. cit., p. 21) such an amphibole is termed *tschermakite* (ferrotschermakite). The properties do not deviate essentially from those presented by Winchell (op. cit., p. 36 and 37) and Sundius (op. cit., p. 26 and 29). The bluish colour may be due to the high content of ferric iron (cf. Kunitz 1930, p. 201). According to Winchell, the sodium content influences the extinction angle, so that especially in members richer in magnesia the angle increases remarkably with increasing sodium. This may be of certain significance as regards the hornblende of the rock analyzed. It is noteworthy that in the metamorphic trachyandesite (p. 15) there is a bluish green hornblende with a large extinction angle.

The preceding treatment shows that the composition of many sedimentogenous schists may deviate noticeably from that of the products of complete chemical weathering. The lime-bearing schists considered above may represent re-sorted material which has been more or less decomposed. The bulk composition may occasionally be almost like that of certain volcanic rocks, yet a determinative difference is apparent in the texture. That of volcanics is porphyritic (or blastoporphyritic), and the phenocrysts are more or less idiomorphic. The materials decomposed by weathering have recrystallized and texture relics are lacking. For example, most of the primary feldspar has been wholly destroyed. Abundant epidote and iron oxide are present in most cases, these having probably been formed from the disintegrated material.

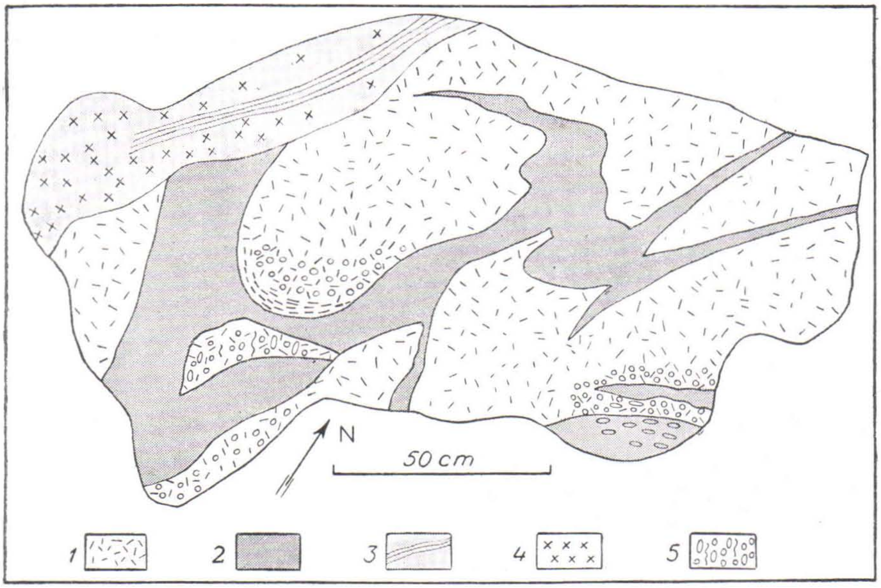

Fig. 13. Sketch of breccia. 1.3 km. E. of Lake Syväjärvi, Teisko. 1. Plagioclase-porphyritic rock. 2. Fine-grained schistose crack infilling. 3. Stratified schist. 4. Hornblende crystals. 5. Accumulations and tiny veins of quartz.

THE RELATIONS OF VOLCANIC AND SEDIMENTARY MATERIALS TO EACH OTHER

In E. Teisko, about 1.5 km. S. of the E. part of Lake Paarlahti, a peculiar breccia formation is seen here and there along a horizon that can be followed for about 3 km. The breccia does not seem to have been caused by tectonic factors. Its appearance is sketched in Fig. 13.

The south-side rock is a plagioclase-porphyritic volcanic. A fine-grained schistose material fills cracks in it and immediately on its north side a stratified schist forms a continuous bed. The fine-grained layers of this schist, and the crack infillings in the breccia consist mainly of quartz, chlorite and a little biotite, and varying amounts of epidote. The coarser-grained parts contain, in addition, highly altered grains of plagioclase, residual quartz grains, and tiny rock fragments. In places, the lowest part (several metres) of the stratified bed is interspersed with hornblende crystals. Ore, either magnetite or sulphide, is present in all the types.

Some details of the contacts in the breccia are illustrated by Figs. 14 and 15. The microphotograph in Fig. 14 shows a small fragment severed from a larger block and embedded in the fine-grained cement. The fragment is surrounded by an indistinct rim of iron oxide. The sketch in Fig. 15 reveals the close relation between the stratified schist and the crack infilling in the adjacent porphyritic rock.

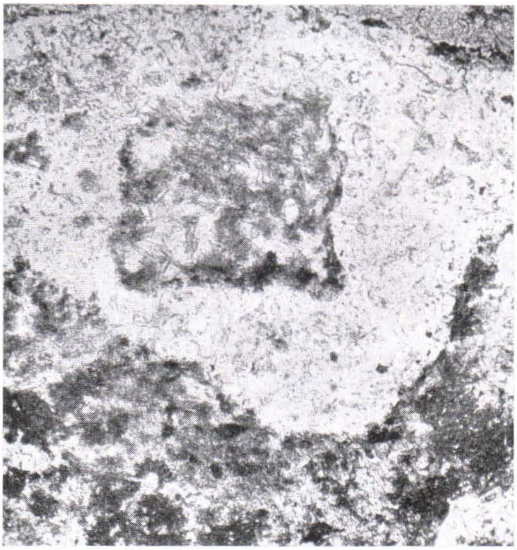

Fig. 14. A small fragment of the porphyritic rock in Fig. 13, embedded in the fine-grained crack infilling. Nic. ||, magn. 35 ×.

The most plausible interpretation of this formation is that of an original weathering breccia *in situ*. The lime leached out by the decomposition of the underlying volcanic has been deposited in part among other products of weathering. Calcic minerals, such as epidote and hornblende, have crystallized from the lime-rich material present. The heterogeneity of the existing rocks might be due to that of the original material. However, the uneven distribution of constituents under surface conditions does not account for all the heterogeneity in the texture. In the whole zone secondary circulation of materials seems to have taken place. Accumulations and small fragmentary veins of quartz are common, especially in the big fragments of porphyritic rock in the breccia. Larger epidote crystals and some chlorite and sulphide are often associated with the secondary quartz. An uneven distribution of epidote is conspicuous. Yet there is no need to suppose a transportation from the outside.

Sederholm has described (1931, p. 33 and 61) formations which he regarded as original weathering breccias from the Lavia—Suodenniemi area. Calcic minerals, such as diopside, hornblende, lime-bearing garnet, calcite, and sphene, were observed as essential constituents in the cement of the breccia, and in the adjacent sedimentary schist to some degree; iron oxide is present. The petrological analogy to the breccia and the associated schist described by the present writer is obvious. It is evident, however, that in Teisko there is no unconformity in question, but such a horizon only represents a »hiatus» in the genesis of the complex.

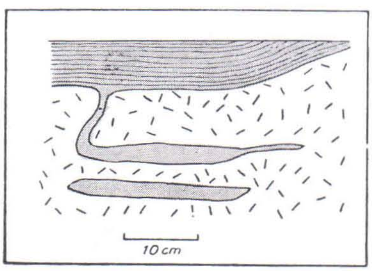

Fig. 15. A detail of the contact between the porphyritic rock and the stratified schist. The key is similar to that in Fig. 13.

Farther N. of the breccia horizon concerned, a reddish »leptite» (rather a greywacke) appears as intercalated in the stratified schist, and especially on its N.

side where it forms a thick bed immediately E. of Lake Syväjärvi. It contains altered plagioclase grains (An_{8-10}) and microscopic rock pebbles in abundance, whereas residual quartz grains are rather rare. Some of the pebbles seem to come from a plagioclase-porphyritic rock. The cement consists mainly of quartz, feldspar, and unevenly distributed epidote of which the last-mentioned mineral often fills the interspaces between the pebbles and feldspar grains almost entirely. The other constituents are magnetite, chlorite, and muscovite. Northwards this rock gradually passes into phyllite in which some intercalations of volcanogenous material are observed. Immediately N. of the phyllite is an uninterrupted zone of conglomerate which extends through the whole area. Several kilometres eastwards hornblende schist (with bluish hornblende), associated with phyllite, occurs along the S. border of conglomerate over a long distance, so the calcareous sediments are represented also there. This whole extensive zone of various sediments obviously means a phase of remarkable erosion.

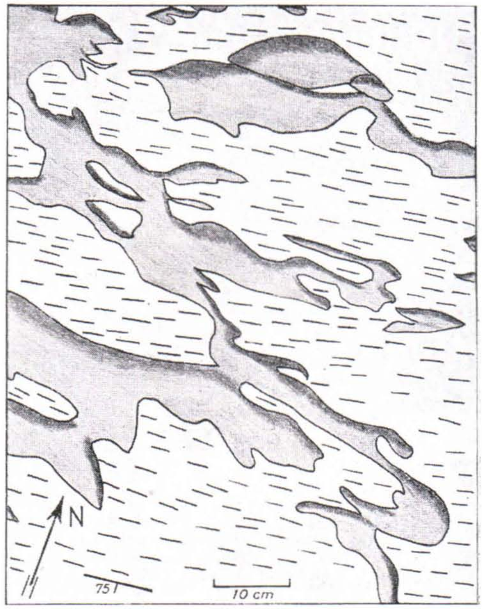

Fig. 16. Sketch of breccia. N. E. of Lake Vaavujärvi, Orivesi. The epidote-rich cement rises above the brecciated plagioclase-porphyritic rock on the weathered surface.

Similar but by far more local occurrences of breccia and associated sedimentary schist are observed also in some other horizons. An excellent but sporadic breccia was encountered N. E. of Lake Vaavujärvi (Fig. 16). In this case, the cement consists of epidote with a little quartz, oligoclase, and biotite, thus resembling the concretions in the mica schist as to its composition.

Furthermore, a schist bed W. of Lake Hankajärvi in Teisko shows some analogy to the formations described. The basement rock is a very basic uralite porphyrite. A reddish, heterogeneous, epidote-rich rock N. of it may represent a breccia, but it is questionable whether it is a weathering breccia. Immediately N. of the breccia is an »intermediate» schist with plagioclase (An_{37}), epidote, and green hornblende as the main components. Plagioclase often occurs as bigger, irregular, epidotized, pigment-filled grains, and epidote forms big, well-developed crystals. Horn-

Fig. 17. Hornblende-plagioclase-epidote schist. W. of Lake Hankajärvi, Teisko. Nic. ||, magn. 16 ×.

blende is quite unaltered. Some quartz is observed and unevenly distributed microcline is present in considerable amounts. Its mode of occurrence somehow suggests a non-primary origin. A microphotograph of the rock is seen in Fig. 17. The existence of abundant idiomorphic epidote in obvious equilibrium with andesine is especially noticeable. — A little towards the N. in the same bed the lime content is even higher, as indicated by the larger amount of hornblende. The N. part of the bed consists, however, of mica gneiss or mica schist in which bedding and even a varved structure can be seen and the sedimentary origin of which seems to be undeniable.

The materials of the hornblende-epidote-rich schist W. of Lake Pappilanselkä might have originated from those basic volcanics parts of which are seen close to the boundary of the southern granite. The main zone of the hornblende schist with bluish hornblende seems to have entirely consisted of decomposed volcanogenous material. In general, it represents a transition northwards from phyllite and associated sedimentary rocks into intermediate or basic volcanics. If the stratigraphic sequence is as supposed, the weathering products of the volcanics cannot be situated on their S. side, so the zone concerned does not yet represent the beginning of the volcanic complex *in situ*.

In other cases, series of weathering differentiation have evolved which lack the facies rich in lime. For instance, such a gradation of trachyandesitic plagioclase porphyrite (p. 13 and Table I, N:o 1) is visible at the E. end of Lake Vaavujärvi. This rock passes quite gradually into a sedimentary schist showing a good foliation and chiefly consisting of biotite, plagioclase (about An_{15-20}), quartz, and chlorite. Among the accessories, tourmaline is especially worthy of note. This schist is again followed by a fine-grained »leptitic phyllite» with a sharp contact. As compared with the former, quartz has increased while plagioclase has decreased, and some muscovite is present. The following phase is a normal phyllite, but it is not visible on the same outcrop. The chemical composition of these schists is given in Table I, N:os 5 and 6. As shown, *al* and *k* are continuously increasing in the gradation series, while *c* is decreasing. A considerable excess of alumina appears. The numbers were plotted on a diagram (Fig. 18) from which the gradual development towards clayey sediment is visible.

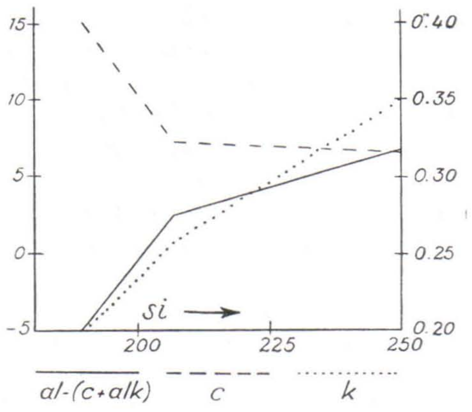

Fig. 18. Diagram showing the gradation of trachyandesitic plagioclase porphyrite at the E. end of Lake Vaavujärvi, Orivesi.

The volcanogenous beds in the S. part of the schist belt are hardly those *in situ* except a few cases, yet decomposition there seems to have been mainly mechanical. In such instances the designation of tuffites is used on the map. Many of them are apparently of basic origin, as indicated by comparatively anorthite-rich plagioclase (andesine). Plagioclase and biotite are the main constituents, the former occurring both as abundant larger fragments and in the matrix. Some quartz is observed, but not as residual grains. The texture is outwardly like the porphyritic one, and these rocks greatly resemble many true volcanics. A further decomposition has led to sediments that cannot be linked to any main types. They often simulate some intermediate tuffites, for example. The plagioclase may be more albitic than that of the above-treated rock, some increase of quartz is observed, and idiomorphic magnetite crystals are not uncommon. This rock often occurs between a basic volcanic and a true sedimentary schist as an apparently transitional form, thereby telling its story. In addition, similar material is very common as the cement of many conglomerates. The fine-grained varieties which the present author has called »half-sediments» may have originated from intermixed materials of variable origin. The fine-grained matrix between bigger grains usually contains epidote to a considerable extent as small aggregates, although the plagioclase is always oligoclase (An_{20-30}). For instance, the basal parts of the phyllite varves often consist of such a material.

Similar changes are also seen in connection with acid volcanic beds. At the S. end of Lake Pulasjärvi there is a series from feldspar porphyry to mica schist in which muscovite aggregates soon appear indicating pseudomorphs probably after andalusite. In the half-decomposed transitional form the residual feldspar fragments are both plagioclase and potash feldspar, and the fine-grained matrix is rich in quartz. A typical leptite has thus been developed. Many other leptites are as well to be regarded as sedimentary, especially in the S. part of the complex, because of their occurrence among the phyllite and their alternation with it. Some of them have been derived from acid volcanics, some others are associated with the many different decomposition products of more basic rocks, as are the fine-grained, banded »hälleflintas» within the largest occurrence of leptite (Aitolahti—Pulasjärvi—Vaavujärvi). Their banded structure is caused by variation in the mica content and to some extent also in the grain size. The main constituents are quartz and feldspar, but the very fine-grained laminae contain much muscovite, and some biotite and epidote. Residual zircon grains are observed. — In the case of several leptites occurring as the cement of conglomerates evidence of their sedimentary origin is apparent.

Where leptitic decomposition products have been intermingled with pure clayey matter, sediments have been produced which more and more approach phyllite in their present consistence. They are very fine-grained, pale pink or greyish schists with laminated structure. The rock differs from the hälleflinta described above by containing more mica (muscovite) and less feldspar. A great part of the leptite belt from Lake Paarlahti to the N. end of Lake Kutemajärvi belongs to this type. In certain cases such a rock type is situated along the southern borders of phyllite beds, and thus apparently implies the end stage in the gradation from substratum to overlying pure sediment.

In some extensive beds such gradual changes along a certain stratum are also seen that have been described above as observed transverse to the bedding. Variations between phyllite and leptite along the same horizon are especially common.

Accordingly, the close alternation of different schist types is characteristic of a great part of the complex. Besides the »pure», easily determinable kinds, the »mixed» ones have a great extent. In plotting such a multiplicity on the map even the most accurate field work is not enough, and many difficulties are at hand even in microscopical study. The origin of certain pre-Cambrian sediments formed through partial weathering of pre-existing rocks was not unknown to earlier authors among whom Sederholm (1897, 1913, 1931, etc.) is especially worthy of note. In addition, Mäkinen (1916), Sundius (1923), and other Fennoscandian geologists have described similar phenomena. In many particulars the present writer can only confirm the results attained by them. As regards the Grythytte area (Sundius, op. cit.), the great extent of acid schists is striking, and according to Sundius, they are of distinct volcanic origin, except some subordinate occurrences of banded hälleflintas. The leptites and hälleflintas of the Tampere area are regarded by the present writer as sedimentary rocks for the most part. The schists in the Grythytte area seem to be very well-preserved showing distinct relict textures, and on these Sundius has classified his rock types. The huge occurrence of exclusively acid volcanics is somewhat surprising, however.

CONGLOMERATES

Conglomerate occurs mainly as one uninterrupted bed which extends through the whole area mapped. N. of Lake Pulasjärvi in Teisko the bed measures about 900 m. in thickness, including some subordinate intercalations which do not contain pebbles. A little N. of this tract are further more separate layers. Farther E. all the layers converge and are constricted, after which the bed, some tens of metres in thickness, continues eastwards. It may be mentioned that an apparent continuation of this conglomerate is seen between the central granodiorite massif and Lake Näsijärvi. Even W. of Näsijärvi, at Lake Veittijärvi in the parish of Ylöjärvi there is an occurrence of conglomerate (Sederholm 1897, 1913) which probably belongs to the same horizon. Less significant occurrences are exposed in places near Lake Pulasjärvi and at the N. W. boundary of the parish of Kangasala, and even larger deposits of somewhat conglomeratic character in connection with other sedimentary schists (p. 26).

Sederholm was very interested in the conglomerates of the Tampere area, first discovered by himself. Reference to his detailed description (1897) spares the author from extensive treatment in this connection. Besides the varved phyllite, the existence of true conglomerate was his main argument in proving the theory of uniformitarianism as applied to the interpretation of early Archaean rocks.

Among the *pebbles* of the conglomerate various volcanogenous and hypabyssal rocks are the commonest. They are usually well rounded, but have been strongly elongated by orogenic movements. The bigger pebbles which can measure as much as 0.5 m. in diameter, usually consist of various lava rocks. On both sides of Lake Syväjärvi in Teisko and N. E. of it there are big pebbles of plagioclase porphyrite, which are often closely packed in the subordinate cement. Acid feldspar porphyry pebbles are encountered N. E. of Lake Syväjärvi and at the N. W. end of Lake Pulasjärvi. The N. part of the conglomerate layer near Lake Kutemajärvi often contains pebbles of a feldspar porphyry which borders it on the N. Their number and size increase to the N., and at last they are very closely packed, surrounded by a thin basic cement. This formation close to the porphyry bed might be regarded as a block lava, indeed, and

Fig. 19. Aplitic granite in a pebble of conglomerate. N. E. of Lake Sisällyspohja, Teisko. Nic. +, magn. 32 ×.

the pebbles S. of it probably represent lava bombs. Hence the occurrence would be rather agglomeratic in character.

Tuffitic pebbles are very common, and in many places fine-grained leptitic and phyllitic rocks are seen as pebbles in considerable amounts. Quartzite pebbles are uncommon in general, but were found in a few localities S. of Lake Paarlahti and in the beds of N. W. Kangasala. Fragments of plutonic rocks are as uncommon as those of quartzite. Many of them that were interpreted as syenite or quartz diorite by Sederholm (op. cit.), may have been derived from hypabyssal intrusives, or even from coarse-grained effusive beds. However, pebbles of true plutonic rocks can be found here and there over the whole zone of conglomerate. In a few cases they were studied microscopically. Some of them appear to be aplitic granite rich in microcline (Fig. 19).

The pebble consists mainly of microcline, quartz, and plagioclase. Biotite is present to a slight extent. Microcline is distinctly idiomorphic in relation to quartz, with a well-developed perthitic texture.

Certain big pebbles of unknown origin were met with beyond the limit of the area mapped, at a place lying near the highway a little N. W. of the central granodiorite massif. The rock is coarse-grained and rich in plagioclase. A microphotograph is presented in Fig. 20.

The prevailing mineral is plagioclase (about An_{20}, determined by comparing the refringence with that of Canada Balsam). It forms

Fig. 20. Coarse-grained rock rich in plagioclase in a pebble of conglomerate. S. W. of Lake Matehinen, Teisko. Nic. ||, magn. 16 ×.

idiomorphic crystals some of which can be 9—10 mm. in diameter. Within many grains others with different orientation are observed. Zonal texture is also common. The mineral has been strongly epidotized.

The other constituents are biotite, epidote, quartz, apatite, and calcite, but their amount is not very notable except certain patches of biotite and epidote. Quartz occurs as intergrowths with plagioclase in the manner of micropegmatite, but such a texture might have resulted from some replacement processes.

Pale green hornblende, ore, and sphene are present in very small amounts.

In the absence of more detailed examinations the character of the rock cannot be ascertained. As may be deduced from the strong epidotization of the plagioclase, the anorthite content has primarily been essentially higher. Probably we are dealing with an anorthosite, but to the author's knowledge anorthosite has never been described from the Svecofennidic territory of Southwestern Finland.

Furthermore, the conglomerate sometimes contains rather big fragments of quartz and feldspar the original rock of which might have been a pegmatite.

The *cement* varies very greatly in character. All kinds from uralite-porphyritic volcanogenous matter to phyllite are represented. Between Lakes Kutemajärvi and Pappilanselkä in Orivesi the cement of the main occurrence is often distinctly acid, and on both sides of the bed a leptitic schist, not very fine-grained, has a considerable extent. In many cases it resembles greywackes containing microscopic rock fragments in abundance. The various types are present also as intercalations which do not contain pebbles. Some conglomerates show layering in which the pebbles have been sorted according to size, and even a varved structure has sometimes been developed. The bottom of the varves is usually to the south as it is also in the phyllite. N. of Lake Syväjärvi in Teisko there are in places abundant patches of pyrite in a fine-grained cement.

The association of the conglomerate with other sedimentary schists has been previously described (p. 35). The occurrence of conglomerate in a purely volcanic milieu without gradual development is very uncommon. The general character is sometimes comparatively basic indicating the slight degree of decomposition of the original materials. It is then difficult to decide, whether there is a conglomerate or an agglomerate in question.

Sederholm already suggested in the last century that these deposits were real conglomerates. The significance of the main conglomerate zone as evidence of a remarkable intraformational erosion period was pointed out in the preceding chapter. The fragments of quartzite, granite, vein quartz, etc., even though not common, prove that a far-reaching denudation had taken place before the deposition of the conglomerates. As a further evidence some pebbles may be mentioned which are cut by a quartz vein which does not continue beyond the limit of the pebble. It seems, however, that the conglomerates have originated mainly from

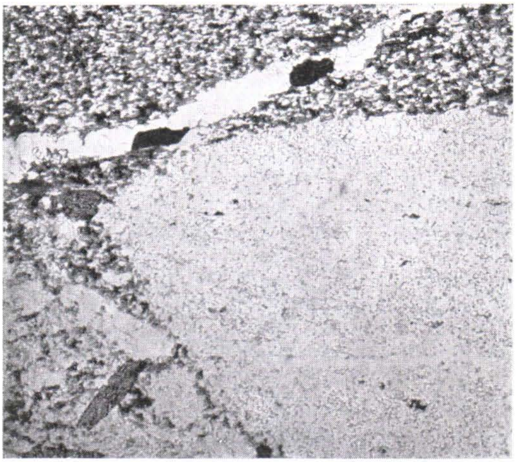

Fig. 21. Quartzite conglomerate. S. of Lake Rukojärvi, Kangasala. Nic. ||, magn. 16 ×.

the products of the contemporaneous volcanic activity. The term »volcanic conglomerate» thus can be used in characterizing them.

As the only but remarkable exception to the common type, a *quartzite conglomerate* occurs S. of Lake Rukojärvi in Kangasala (Fig. 21).

More than a half of the pebbles consist of quartzite, in some parts of the bed almost exclusively. The other pebbles are phyllite, fine-grained volcanogenous rocks and leptite, and fragments of feldspar. In a few cases pebbles were observed that have the appearance of an infracrustal rock, probably granodiorite. The pebbles are comparatively small, usually measuring 1—1.5 cm. in diameter.

The cement consists of fine-grained, hornblende-bearing mica gneiss or mica schist. Ore, both oxidic and sulphidic, is present in appreciable amounts.

The bed is 55—80 m. in thickness, and it can be followed for about 1.5 km. On the S. E. side it is bordered by phyllite with a sharp contact. Northwestwards it passes gradually into an arenaceous schist, and then into mica gneiss and phyllite. A more fine-grained, arenaceous variety is also observed as intercalations.

There is no unconformity in the strictest sense to be observed in connection with the conglomerate described. The Svecofennian formation to which the Tampere schists are referred, is the earliest one known to us. The existence of quartzite pebbles in a conglomerate proves, however, that a still earlier metamorphic rock crust must have existed. It is credible that the whole schist complex concerned has resulted from an intraformational deposition during the orogeny in question. Also Wahl (1936, p. 500) has expressed the same opinion.

SUMMARY AND DISCUSSION OF THE METAMORPHISM OF THE SCHISTS

The variability in the grade of metamorphism has often been stated in the preceding treatment. It is related mainly to the tectonic evolution of the area. The primary regional metamorphism has apparently taken place under conditions of the amphibolite facies, as in most other parts of the Svecofennidic territory. During the later stage of movements, however, zones have been formed in which the rock has been strongly deformed or even mylonitized. In such cases the present mineral associations are due to recrystallization at lower temperatures. These zones are usually parallel to the general strike of the formation. The most remarkable of them extends through the whole belt, and Lakes Paarlahti, Peräjärvi, Kutemajärvi (the northern end), and Iso Teerijärvi are situated in it. The east-west trend of Lakes Hankajärvi, Pukalanselkä, and Aihtianjärvi indicates another crush zone. More or less clear traces of such a deformation are observed in numerous places.

Similar variations of the mineral facies in the western part of the Tampere area have been described by Simonen and Neuvonen (1947).

The common mineral association of basic and intermediate volcanics is *hornblende — biotite — plagioclase* (An_{23-42}) which typifies the normal amphibolite facies. In the calcic concretions of the amphibolite, near the boundary of the northern intrusive massif, the assemblage *diopside — hornblende — plagioclase* (up to An_{50}) is found. The association *hornblende (tremolite) — chlorite — epidote — plagioclase* (An_{3-15}) corresponds most to the epidote amphibolite facies. The common paragenesis *chlorite — epidote — albite* (or albite - oligoclase) refers to the conditions of the greenschist facies. Naturally, transitional forms between these type combinations also occur. Moreover, biotite is often met with instead of chlorite in associations that are obviously due to recrystallization at low temperatures. In some cases this is to be explained by assuming a metasomatic increase of potash. In the metamorphic trachyandesite (p. 15) a quite unaltered biotite, however, is present together with epidote, albite, and hornblende, although the content of potash is low. According to Simonen and Neuvonen (1947), in certain lime-bearing schists W. of Lake Näsijärvi the association epidote — biotite seems to have been stable at a low temperature (the epidote-biotite schist facies according to Th. Vogt, 1927). The lime content of the trachyandesite is not notably high, however.

In the acid schists the association *biotite — muscovite — plagioclase* (An_{16-25}) means that they have recrystallized under the PT-conditions of the amphibolite facies. The common assemblage of shear zones, *chlorite — muscovite — (epidote) — albite* refers to both the epidote amphibolite and the greenschist facies according to Eskola (1939). However, in many porphyries and tuffites richer in potash the association *biotite —muscovite— albite* is as common as the former. Epidote is in that case usually subordinate or lacking. There are not always any recognizable traces of late movements to be observed, for instance, as regards the separate bed of acid tuffite in E. Aitolahti. The rock being rich in potash and very poor in lime, such a paragenesis might have crystallized under the conditions of the amphibolite facies. We may think that lime has not been present in sufficient quantities for the formation of anorthite. On the other hand, this association corresponds to the biotite - muscovite schist facies of Th. Vogt (1927) which belongs to the greenschist facies according to Eskola. In such cases the conditions of recrystallization are not evident, unless the parageneses of associated rocks have been studied.

In many sedimentogenous amphibole-bearing schists the parageneses are similar to those of basic and intermediate volcanics. In the types richest in lime the combination biotite — epidote seems to have a comparatively wide range of stability.

In phyllite and mica schist the amphibolite facies is indicated in the assemblage *biotite — muscovite — plagioclase* (An_{20-35}). In many cases muscovite may be lacking, however. As a transitional form towards the lower-temperature paragenesis the association *biotite — chlorite — muscovite — plagioclase* (up to An_{20}) is observed. Parageneses indicating the low-temperature facies proper are but met in limited areas in the Paarlahti shear zone, and in connection with the strong fracture cleavage near the southern granite contact. The commonest association is *biotite — chlorite — muscovite — albite,* biotite being sometimes almost absent. Such an assemblage implies a combination of two subfacies of the greenschist facies, viz., the biotite - muscovite, and the muscovite - chlorite schist facies (Th. Vogt, op. cit.); or the biotite-chlorite, and the muscovite-chlorite subfacies (Turner 1948). The same association can be stable under the conditions of the epidote amphibolite facies also. It proves that in phyllites biotite can be stable down to a low temperature, owing to the high potash content of these sediments. Thereby the chloritization of biotite is retarded (Vogt, op. cit.).

Besides the »ordinary» cases treated above, there are mineral assemblages which somewhat deviate from them. The commonest instance is the occurrence of abundant epidote together with non-albitic plagioclase. In the sedimentary schists consisting of incompletely decomposed materials the association *biotite — epidote — plagioclase* (up to An_{31}) was observed in numerous cases. Muscovite also sometimes belongs to the association. In the hornblende schist between the main zones of phyllite and volcanics the assemblage *hornblende — biotite — epidote — plagioclase* (An_{20-30}) is predominant. In layers with dominating hornblende the epidote forms rather big euhedral crystals. The epidote-rich concretions and the cements of breccias carry some oligoclase (An_{23-28}), and hornblende or biotite. A further, more striking example is the lime-rich schist W. of Lake Hankajärvi (p. 35) with the combination *hornblende — epidote — andesine — microcline.* The abundant idiomorphic epidote is quite an essential constituent.

The plagioclase associated with epidote in the lime-rich schists of N. W. Kangasala has an extremely high content of anorthite. The assemblage is *hornblende — epidote — garnet — bytownite.* The garnet may contain a considerable amount of grossularite. In a related rock (p. 28;

cf. further p. 47) there is the association *chlorite* (of the corundophilite group) — *biotite — garnet — bytownite*. The chlorite forms very well-crystallized flakes.

In the basic volcanics of shear zones the associations *hornblende — chlorite — epidote — plagioclase* (An_{25-30}), and *chlorite — epidote — plagioclase* (An_{35-40}) are found. In corresponding cases the intermediate schists sometimes display the combination *chlorite — (muscovite) — plagioclase* (An_{20-30}).

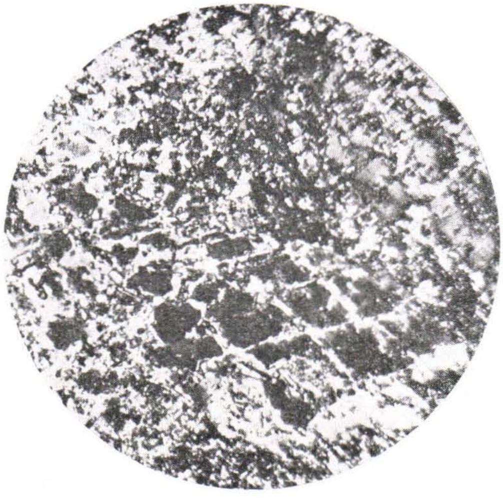

Fig. 22. Recrystallization of plagioclase phenocryst in plagioclase porphyrite. Light oligoclase between squares of dark andesine. S. W. of Lake Koskuenjärvi, Orivesi. Nic. +, magn. 20 ×.

It is obvious that many of the associations described do not show any real equilibrium, but they can be referred to an »inadequate» mechanical deformation (in respect to the time or the power). That seems to be especially true of the assemblage chlorite — (epidote) — andesine (oligoclase) in the basic volcanics. The hornblende reacting readily to the changes of conditions has been able to change, whilst the plagioclase has followed but with incomplete reaction. In a plagioclase porphyrite the plagioclase phenocrysts have partly recrystallized in a peculiar manner (Fig. 22). The original plagioclase (An_{35-40}) forms separated, nearly square sections which are welded by later-formed plagioclase (ab. An_{20} on the average), the latter consisting of a single individual crystal. Some »half-sediments» are also situated in more or less deformed zones, and hence the same explanation, perhaps, is to be applied to them. The fairly calcic plagioclase is present mainly as residual grains, while abundant epidote occurs in the fine-grained matrix. Probably recrystallization has taken place more readily in the fine-grained part, while the fragments have not yet adjusted themselves.

As regards most of lime-bearing sedimentary formations, however, their present mineral associations are certainly due to the regional metamorphism and have not been influenced by late movements. Thus an equilibrium has been attained in them. In the oligoclase zone of the Sulitelma area (Th. Vogt, op. cit., p. 209; corresponding to the amphibolite facies according to Eskola, 1939) there are lime-bearing schists with the paragenesis biotite — epidote — plagioclase (An_{16-29}). In schists still richer in lime the association is hornblende — biotite —

epidote — plagioclase (An_{17-34}). In the Kongsberg-Bamble formation Jens Bugge (1943, p. 134) has the assemblage hornblende — epidote — oligoclase-andesine, and refers it to the epidote amphibolite facies. In some parts of the Caledonian chain in Norway the stable combination epidote — plagioclase (up to An_{50}) was found by Ramberg (1944, p. 109). This author has considered the epidote — plagioclase equilibrium from the physico-chemical point of view (op. cit., p. 120). According to him, with rising temperature more and more basic plagioclase can be stable together with epidote. Concerning the latter, however, »at the high temperature - - - - - does not epidote often occur because of the possibility of the plagioclase carrying relatively much anorthite in stable solid-solution - - - - -» (op. cit., p. 170). On the other hand, with increasing pressure the range of the stability of epidote increases, and plagioclase can become more acid in favour of epidote. We thus may think that in both high temperature and high pressure epidote can be stable together with very basic plagioclase. In this sense the epidote amphibolite facies extends over a very wide range of PT-conditions, reaching up to a temperature at which the epidote gives way to other Ca, Al minerals, among other the p u r e anorthite. A somewhat similar thought is expressed by Turner in his summarizing memoir (1948, p. 81). An interesting assemblage plagioclase (up to sodic labradorite) — hornblende — biotite — epidote — microcline in rocks with excess potash is referred by Turner (op. cit., p. 84) to the staurolite - kyanite subfacies of the amphibolite facies (cf. above, p. 36). Since epidote amphibolites with non-albitic plagioclase are stable in the amphibolite facies, he prefers the term »albite-epidote amphibolite facies» to the previous »epidote amphibolite facies».

We have the combination (without any potash) bytownite — hornblende — epidote — garnet in N. W. Kangasala. The locality is situated at a place where two rather large intrusive massifs most closely approach one another. Forces that later have caused the secondary transversal cleavage, distinctly visible on both sides, have not been acting here. Ramberg's investigation suggests that it is just at a place like this where such a paragenesis can be formed. It is true, however, that the epidote does not occur in the closest conjunction with the bytownite, but forms patches and stripes that do not contain the latter. Near this locality the association bytownite — chlorite (of the corundophilite group) — garnet was encountered. In that case the confining pressure might have been of more importance, inasmuch as a chlorite mineral could hardly have originated at a high temperature. N. E. of this place there is a phyllite strongly deformed by fracture cleavage, in which the association biotite — muscovite — chlorite — (albite) was found. The chlorite occurs as well-developed porphyroblasts (Fig. 23) the appearance of which greatly resembles that of the chlorite just mentioned. The optic properties are quite different, however. It is optically negative, and its

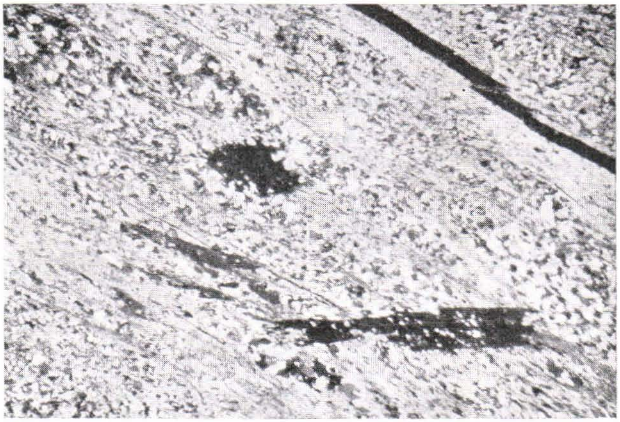

Fig. 23. Phyllite containing some well-shaped porphyroblasts of penninite. S. W. corner of Lake Paalijärvi, Teisko. Nic. +, magn. 35 ×.

elongation is positive; pale green-coloured and weakly pleochroic with $\gamma > \alpha$; the birefringence is very weak; the extinction angle $\alpha \wedge c$ of about 3° is found. These properties correspond to those of a ferriferous penninite (delessite), according to Winchell (1933). The chlorite concerned is suggestive of a pseudomorph after corundophilite, formed at a low temperature during late shear movements.

The mineral facies of the metasomatic rocks will be discussed in connection with the description of these rocks (p. 108).

INTRUSIVE ROCKS

In the area there are parts of two large massifs, N. and S. of the schist belt. In addition, in the western part of the complex is a separate stock of granodiorite named the »Värmälä granodiorite» after a village in the parish of Teisko. This regional division will be followed in the description.

All these rocks are younger than the supracrustal series, but nowhere do the massifs come into contact with one another, so it is difficult to decide their mutual age relations. Some data will be presented later (p. 86).

INTRUSIVES OF THE NORTHERN SIDE

The parts investigated of the northern massif represent the southern marginal zone of the so-called »Central granite of Finland». The study was restricted to the vicinity of the boundary.

The rocks are fairly variable. North of Lake Pukalanselkä is some hornblende gabbro which soon passes westwards into diorite. North of Lake Hankajärvi there is quartz diorite, often showing transition into granodiorite. The rock of the neighbourhood of Lake Savonjärvi is again a little more basic, but farther W. the main rock is of granodiorite with incidental quartz diorite. There is, however, a fairly large occurrence of gabbro and diorite near the northwestern corner of the area. Many of the rocks have evidently had a later addition of potash, and only parts of the basic portions are quite unaltered. Thus an exact classification of rocks is difficult to carry out; for instance, the predominance of granodiorite may be due to such a secondary process. Granitization is especially evident N. and N. W. of Lake Pukalanselkä, and microcline granite proper is seen in many places through the whole zone. South of Lake Pukalanselkä and E. from there to the eastern end of the area the rock is rich in silica and soda, fairly fine-grained, and porphyritic. It is thus like the marginal variety of many of the synkinematic Svecofennidic granodiorites.

The above-mentioned rocks usually pass more or less gradually one into another. Only the most acid kinds sharply penetrate the most basic ones forming definite veins. The contacts of all the intrusive rocks against the schist are mostly fairly complicated. In the parish of Teisko, especially N. of Lake Paarlahti, is a contact zone which can be up to 1 km. in breadth, and consisting of many different materials. In the intrusive rock there are highly altered portions of schist, sometimes several hundreds of metres in length. The rocks seem to have been fairly plastic, the contacts are concordant, and most of the intrusive rocks are foliated. This gives the impression of a synkinematic intrusion. A detailed description of the contact relations of the different rock types will be given in their respective connections.

GABBRO AND DIORITE

Unaltered *hornblende gabbro* occurs mainly in two localities, N. of Lake Paarlahti and S. E. of Lake Savonjärvi. The latter small massif consists of very typical gabbro. A slight foliation can be seen megascopically, but is not observed in thin section. The analysis of the rock is presented in Table V, N:o 7. The Niggli numbers accord with those of the normalgabbroic magma type according to Niggli (1923).

The texture is nearly hypidiomorphic, and plagioclase is the most idiomorphic constituent.

Plagioclase forms fairly fresh tabular crystals. The maximum extinction angle is 29°, and a' is a little over ε' of quartz, so the composition is An_{51-52}.

Hornblende is of a common green species, but in a few cases the kernel of the crystals is pale-coloured and very weakly pleochroic. (For the properties see Table VI, N:o 1). Small amounts of biotite occur as an alteration product.

Magnetite is comparatively abundant, some quartz is seen between other minerals, and apatite is accessory.

The massif N. of Lake Paarlahti is situated about 5 km. W. of the eastern end of the lake. It is much larger than the former. The rock is characterized by long prisms of hornblende and lack of foliation (Fig. 24).

Fig. 24. Hornblende gabbro. N. of Lake Paarlahti, Teisko. Magn. 6 ×.

The texture is hypidiomorphic, and plagioclase is idiomorphic in relation to hornblende with some exceptions.

Plagioclase is well-preserved for the greater part. The composition is An_{43-45} (the max. ext. angle = 25°).

Hornblende prisms are up to 7 mm. in length. Pleochroism is as follows: γ brownish green, β greenish brown > α pale greenish brown. The other properties are presented in Table VI, N:o 2, and the chemical analysis in Table VII. Abundant small, tabular crystals of ore, probably ilmenite, occur as inclusions, the regular arrangement of which (see figure) gives the impression of an exsolution of Ti from the hornblende. The material analyzed includes the ilmenite.

Some large flakes of chlorite are observed as an alteration product of hornblende. In certain cases considerable amounts of prehnite as small narrow laths are associated with the chlorite. Biotite is almost lacking.

Oxidic ore is rather abundant, while quartz is quite accessory.

The analysis of the rock is presented in Table V, N:o 8.

Against the large inclusions of basic schist occurring in the massif there is often a somewhat finer-grained marginal variety. In this, the plagioclase is a little poorer in anorthite and a part of hornblende is of a common green species showing irregular shapes. The kernels of such hornblende crystals sometimes consist of cummingtonite. (For the occurrence and the properties of cummingtonite see the description of gabbro-hornblendite later on in this chapter). Some pale brown biotite occurs, but the ore is less abundant. The analysis of the marginal type is seen in Table V, N:o 9.

The chemical composition of this gabbro is rather peculiar showing no analogies to those of usual types. Indeed, the marginal variety resembles some ossipites (Niggli, op. cit., p. 130), with the exception of the low figure of *mg*. The remarkable content of alumina in the main type is due to the great amount of this constituent in the *hornblende*. The high content of Ti, if assumed as primary, suggests a hornblende

Table V. Analyses of the intrusives of the northern side.

	7		8		9		10		11	
	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.
SiO_2	48.80	8 125	45.04	7 499	47.18	7 855	50.00	8 325	56.76	9 451
TiO_2	1.05	131	1.44	180	1.64	205	1.06	133	0.64	80
Al_2O_3	15.61	1 531	21.24	2 084	19.49	1 912	21.35	2 094	21.69	2 128
Fe_2O_3	4.78	299	1.36	85	2.24	140	2.15	135	2.55	160
FeO	8.48	1 180	9.84	1 370	9.48	1 320	8.33	1 160	3.02	420
MnO	0.14	20	0.16	23	0.26	37	0.16	23	0.09	13
MgO	5.84	1 448	4.56	1 131	3.92	972	3.44	853	0.75	186
CaO	9.26	1 651	9.94	1 772	9.78	1 744	8.30	1 480	6.80	1 213
Na_2O	3.16	510	3.06	494	3.43	553	3.90	629	6.13	989
K_2O	0.94	100	0.90	96	1.06	113	0.35	37	0.93	99
P_2O_5	0.36	25	0.31	22	0.30	21	0.27	19	0.11	8
H_2O+	1.56		1.98		1.38		1.18		0.86	
H_2O-	0.20		0.24		0.06		0.10		0.12	
	100.18		100.07		100.22		100.59		100.45	
Niggli numbers										
si		115		105		113		127		176
ti		1.9		2.5		3.0		2.0		1.5
al		21.7		29.2		27.6		32.0		39.6
fm		46.1		37.7		37.6		35.2		17.5
c		23.5		24.8		25.2		22.6		22.6
alk		8.7		8.3		9.6		10.2		20.3
k		0.16		0.16		0.17		0.06		0.09
mg		0.45		0.42		0.37		0.37		0.20
c/fm		0.51		0.62		0.67		0.64		1.29
Mineral composition										
Plagioclase	An_{51-52}	40.2	An_{43-45}	47.0	An_{40}	51.5	An_{45}	60.9	An_{30}	77.1
Hornblende		47.6		40.7		39.7		22.8		11.7
Cummingtonite		—		—		2.5		9.7		—
Biotite		3.6				3.4		—		
Chlorite		—		6.2		0.3		3.2		3.9
Prehnite		—				—		—		—
Quartz		4.6		1.2		1.3		0.4		6.4
Oxidic iron ore		2.5		4.8		1.2		2.2		—
Accessories		1.2		0.1		0.1		0.8		0.9
		100.0		100.0		100.0		100.0		100.0

7. Hornblende gabbro. Between Lakes Hankajärvi and Savonjärvi, Teisko. Analyst M. Mäntynen.
8. Hornblende gabbro. N. of Lake Paarlahti, 5.5 km. W. of the eastern end of the lake, Teisko. Analyst M. Mäntynen.
9. Marginal variety of the gabbro in N:o 8. Analyst M. Mäntynen.
10. Gabbro-diorite. N. of Lake Paarlahti, 3.5 km. W.N.W. of the eastern end of the lake, Teisko. Analyst M. Mäntynen.
11. Diorite rich in plagioclase (»anorthosite-diorite»). S. of Lake Savonjärvi, Teisko. Analyst M. Mäntynen.

crystallized at a high temperature, whereas the small amount of ferric iron, as well as the high percentage of water does not accord with such an explanation. According to Sundius (1946, p. 21), the amphibole is intermediate between *pargasite* and *hastingsite*, or a »femag-hastingsite» (Billings 1928), though some difference appears in the amounts of ferric

Table V (continued).

	12		13		14		15		16	
	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.
SiO_2	57.66	9 600	62.06	10 333	73.94	12 311	74.56	12 414	71.01	11 823
TiO_2	0.56	70	0.50	63	0.25	31	0.27	34	0.27	34
Al_2O_3	20.10	1 972	17.77	1 743	14.35	1 408	13.46	1 320	15.54	1 524
Fe_2O_3	1.74	109	1.50	94	0.48	30	1.01	63	trace	
FeO	5.40	752	3.30	459	0.43	60	0.86	120	1.30	181
MnO	0.13	18	0.08	11	0.02	3	0.03	4	0.04	6
MgO	0.97	241	2.26	561	0.55	136	0.36	89	0.42	104
CaO	5.92	1 056	4.26	760	2.68	478	1.32	235	1.68	300
Na_2O	5.43	876	3.66	590	5.84	942	2.92	471	4.00	645
K_2O	1.28	136	3.72	395	0.49	52	4.88	518	4.88	518
P_2O_5	0.19	13	0.20	14	0.03	2	0.02	1	0.05	4
H_2O+	0.61		1.04		0.68		0.34		0.68	
H_2O-	0.01		0.08		0.20		0.14		0.10	
	100.00		100.43		99.94		100.17		99.97	
Niggli numbers										
si		182		220		392		431		361
ti		1.3		1.3		1.0		1.2		1.0
al		37.4		37.0		44.9		45.8		46.5
fm		23.3		25.9		8.2		11.8		8.9
c		20.1		16.2		15.2		8.1		9.1
alk		19.2		20.9		31.7		34.3		35.5
k		0.13		0.40		0.05		0.52		0.45
mg		0.20		0.46		0.53		0.26		0.36
c/fm		0.86		0.62		1.85		0.69		1.03
Mineral composition										
Quartz		14.6		13.2		32.6		44.3		28.0
Plagioclase	An_{30-32}	58.6	An_{25}	41.2	An_{12-17}	62.0	An_{15-17}	23.6	An_{18-22}	33.4
Microcline		—		13.2		—		26.6		31.7
Biotite		15.6		19.1		0.8		4.6		3.5
Hornblende		10.6		12.1		3.8		—		—
Chlorite		—		—		—		0.5		3.3
Accessories		0.6		1.2		0.8		0.4		0.1
		100.0		100.0		100.0		100.0		100.0

12. Quartz diorite. N. shore of Lake Paarlahti, 5 km. W. of the eastern end of the lake, Teisko. Analyst M. Mäntynen.
13. Granodiorite. 2.5 km. S.W. of Lake Savonjärvi, Teisko. Analyst M. Mäntynen.
14. Soda-rich marginal modification of the northern massif. 2 km. N.W. of Lake Kutemajärvi, Orivesi. Analyst M. Mäntynen.
15. Microcline granite. N. of Lake Paarlahti, 4.5 km. W. of the eastern end of the lake, Teisko. Analyst M. Mäntynen.
16. Granitized granodiorite. N. of Lake Paarlahti, Teisko. Analyst M. Mäntynen.

iron and soda. The optic properties are in fair accordance (Sundius, op. cit., p. 26 and 29). The axial plane is symmetrical like that of most of the hornblendes. The chemical composition of the gabbro S. E. of Lake Savonjärvi (Table V, N:o 7) deviates greatly from those just presented, though the mineralogical compositions are fairly similar. It is obvious

Table VI.

The properties of the hornblende in some of the rocks of the northern contact zone.

	1	2	3	4	5	6	7
α	1.650	1.667	1.657	1.678	1.685	1.673	1.649
β	—	1.679	—	1.695	—	—	1.667
γ	1.678	1.684	1.678	1.703	1.708	1.691	1.673
$2V\alpha$	58°	68°	72—74°	70°	54°	66°	—
$\gamma \wedge c$	18°	18°	18°	14°	14—15°	13—14°	17°
Approximate [FeO] : [MgO] ratio according to Winchell (1933)	2 : 3	5 : 4	2 : 3	7 : 2	8 : 1	7 : 4	1 : 2

1. Hornblende gabbro (Table V, N:o 7).
2. Hornblende gabbro (Table V, N:o 8).
3. Gabbro-hornblendite. N. of Lake Paarlahti, 3.5 km. W. of the eastern end of the lake, Teisko.
4. Plagioclase-rich diorite (Table V, N:o 11).
5. Quartz diorite (Table V, N:o 12).
6. Plagioclase-porphyritic contact variety of schist. 2 km. W.S.W. of Lake Savonjärvi, Teisko.
7. Gabbro-like contact variety of schist. N. of Lake Paarlahti, 5.5 km. W. of the eastern end of the lake, Teisko.

The values of the refractive indices are approximate, determined by the immersion method in the cleavage splinters. $2V\alpha$ and $\gamma \wedge c$ have been determined on the U-stage.

Table VII.

	%	Mol. prop.	Atomic prop. (O = 24)			
SiO_2	39.00	6 494	Si	5.84	2.16	8.00
TiO_2	3.60	451	Al	2.87	0.71	
Al_2O_3	16.26	1 595	Ti	0.41		
Fe_2O_3	1.62	101	Fe^{III}	0.18		
FeO	16.60	2 311	Fe^{II}	2.08		5.17
MnO	0.24	34	Mg	1.76		
MgO	7.90	1 959	Mn	0.03		
CaO	10.84	1 933	Ca	1.74		
Na_2O	1.40	226	Na	0.41		2.26
K_2O	0.57	61	K	0.11		
P_2O_5	—		OH	2.12		2.12
H_2O+	2.12	1 176				
H_2O-	0.20					
	100.35					

Hornblende from the hornblende gabbro in Table V, N:o 8. Analyst M. Mäntynen.

that its hornblende is much poorer in alumina suggesting quite a »common hornblende», in addition to which it is richer in magnesia as indicated by the refractive indices.

A few very small portions of an even more basic rock occur at the margins of the Paarlahti gabbro close to the basic schist. It can be called *gabbro-hornblendite*, because the plagioclase (An_{43-45}) is fairly subordinate. In addition to green or slightly brownish hornblende, cummingtonite and tremolite are observed in considerable amounts. The properties of the hornblende are seen in Table VI, N:o 3. The relative amounts of the colourless amphiboles cannot be determined without an accurate study by means of the U-stage, and inasmuch as they sometimes occur as aggregates of small laths, the difficulties are even greater. According to some determinations cummingtonite seems to be the most abundant, however. In contrast to its occurrence in the gabbroic marginal variety, it often surrounds the hornblende crystals. At times the cummingtonite (or, perhaps, the tremolite) shows a kind of zonal alternation with the hornblende. The boundary of the latter against the cummingtonite is often indistinct, and this can show a very slightly greenish colour. It is most often homoaxial in relation to the hornblende, so the extinction angle is the same. Polysynthetic twinning according to the augite law is common. The refractive indices determined by the immersion method are $\alpha' = 1.642$ and $\gamma' = 1.668$, $2V\gamma = 74$—$76°$, and the estimated ratio [FeO] : [MgO] = 4 : 5 (Winchell 1933). The tremolite also seems to be homoaxial in relation to the other amphiboles. The optic angle $2V\alpha$ is $82° \pm 2°$.

The estimated [FeO] : [MgO] ratios in the hornblende and cummingtonite may show the cummingtonite to be somewhat richer in iron. This is in agreement with Eskola's observation (1950) of a similar conjugation of these amphiboles in a hornblende-bytownite rock in Muuruvesi, Central Finland.

The gabbro is most often accompanied by *diorite*, which forms, for instance, most of the southern and western parts of the basic massif N. of Lake Paarlahti. The rock is usually moderately foliated.

The texture is almost hypidiomorphic, and plagioclase is distinctly idiomorphic in relation to hornblende.

The main minerals are plagioclase (about An_{35}) which is clearly predominant, green hornblende, and often cummingtonite (see later on p. 58). The plagioclase grains are up to 5 mm. in diameter. The cummingtonite always occurs in the kernels of the irregular hornblende crystals, often with distinct boundaries. The relation of the amphiboles is as described above.

Some biotite occurs at the borders of the hornblende crystals. Apatite is fairly abundant.

East of the above-mentioned massif small basic portions occur in many places, usually in the immediate vicinity of the schist. A considerable number of them consist of diorite or gabbro-diorite rich in alumina. An analysis is presented in Table V, N:o 10. The composition does not notably deviate from the average between the normal-dioritic and the ossipitic magma types according to Niggli (1923). Mineralogically the rock differs from the diorite described above by containing more plagioclase (ab. An_{45}) and no biotite. The plagioclase crystals are often distinctly zoned. Cummingtonite occurs around the hornblende in some cases, and as individual crystals as well.

Fig. 25. Plagioclase-porphyritic contact variety of schist. N. of Lake Paarlahti, Teisko. Nic.+, magn. 8 ×.

At Lake Savonjärvi is an area about 2 km. in length of a rock which is for the most part very rich in plagioclase. The analysis of the rock is seen in Table V, N:o 11. It is to be linked to the diorite class, though such a composition corresponds rather to that of an »anorthosite-diorite» and differs from anorthosite-gabbros in the composition of its plagioclase, in addition to which the figure of *mg* is remarkably low.

The texture is nearly granoblastic, and the dark minerals show a weakly-developed parallel arrangement.

Plagioclase occurs as roundish, often untwinned grains up to 5 mm. in diameter. The composition is about An_{30}, determined by comparing the refractive indices to those of quartz.

Hornblende is dark-coloured (γ deep turbid green). The properties are seen in Table VI, N:o 4. Biotite is partly chloritized.

Some quartz is present between the plagioclase grains. Sphene and a little epidote are associated with the dark minerals. Apatite is comparatively abundant.

The rock passes into microcline-bearing quartz diorite and granodiorite in its western part near to which granitized rocks are widely distributed.

Contact relations. The gabbro and diorite are most abundant where the broadest contact aureole of intermingled rocks has been formed. The best example of this is N. of Lake Paarlahti, where the largest occurrence of gabbro-dioritic rocks is situated around some large fragments of basic schist. Only rather indistinct remnants of these are preserved.

When close to the basic intrusives, the schist (amphibolitic, or occasionally uralite-porphyritic) becomes distinctly plagioclase-porphyritic, or contains small accu-

Fig. 26. Plagioclase phenocryst in the schist presented in Fig. 25. Nic.+, magn. 16 ×.

mulations of larger plagioclase crystals. Where the schist has been intermingled with greater amounts of external material, such an altered zone can be several tens of metres in breadth, but in general it is much narrower. In this change the schistosity almost entirely disappears, and the rock may become nearly hypidiomorphic in texture. Biotite and quartz have always increased considerably. A microphotograph of a typical example is presented in Fig. 25.

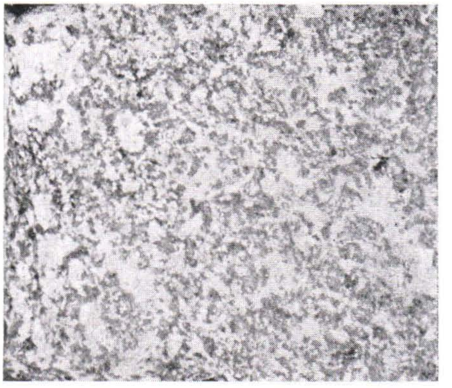

Fig. 27. Gabbro containing accumulations of plagioclase. N. of Lake Paarlahti, Teisko. Natural size.

The plagioclase phenocrysts, as well as the smaller plagioclase grains, are sometimes idiomorphic in relation to the dark minerals, but even biotite can often be idiomorphic in relation to plagioclase. At least a part of the phenocrysts certainly represent a recrystallization, judging from the present outlines and the well-developed zones of some crystals not in accordance with the trend of the indistinct twinning lamellae (Fig. 26). These crystals may be inversely zoned, too (see figure). The composition varies from about An_{35} up to about An_{50}, the latter value being determined in the border of a big crystal (α equals ε of quartz approximately). In the matrix the composition is usually An_{33-35} (the max. ext. angle = 19—20°).

The properties of the hornblende are presented in Table VI, N:o 6. Its colour sometimes shows a greyish green tint, and it may contain appreciable amounts of ilmenite inclusions.

Biotite is medium to dark brown.

Fig. 28. Recrystallized, gabbro-like variety of basic schist. N. of Lake Paarlahti, Teisko. Nic. ||, magn. 8 ×.

The contacts of the plagioclase-porphyritic rock against gabbro and diorite are often indistinct, and xenoliths of it are common in many diorites and some gabbros. At certain localities the gabbro at such an indistinct contact is heterogeneous containing accumulations (up to 2 cm. in diameter) of plagioclase with a little quartz (Fig. 27).

Another type of recrystallized schist (Fig. 28) is quite similar to a fine-grained gabbro (the grain size 0.3—0.4 mm.), but deviates from other gabbroic rocks in the area by containing some augite. The mineral composition is as follows:

Hornblende	53.3
Plagioclase (An_{41-43})	38.7
Quartz	2.7
Augite	1.8
Colourless amphibole	1.8
Accessories	1.7
	100.0

Hornblende occurs as rather irregular, short prisms, and its colour often shows a brownish tint. Its properties are seen in Table VI, N:o 7.

The plagioclase crystals are also fairly irregular in shape; when well-shaped, they are sometimes idiomorphic in relation to hornblende, but the reverse case can be observed as well.

Augite tends to occur in association with small patches of plagioclase and quartz.

Colourless amphibole is seen as small spots within the hornblende crystals as a rule, but also as a rim between augite and hornblende. Whether it is cummingtonite or tremolite, or maybe both, could not be decided owing to the small size of the individuals and because it commonly passes gradually into hornblende. However it may be, it is hardly credible that the above-mentioned rim between two Ca-rich minerals could consist of almost Ca-free cummingtonite.

The ore content is remarkably low in comparison with that in other gabbroic rocks.

This contact variety is not very common, and seldom seen immediately against the magmatic rock, with the exception of some most basic intrusives. Where such a type is present together with the plagioclase-porphyritic one, it is usually isolated from the intrusive by the latter. In places there are fairly large fragments of schist with the longitudinal directions approximately parallel to the general foliation. In the neighbourhood of the fragments the intrusive rock is much richer in hornblende than elsewhere. Some fragments consist of amphibolite, indistinctly hornblende-porphyritic and still showing foliation. In other fragments the plagioclase-porphyritic rock occurs as borders, and the fine-grained »gabbro» forms the centre.

The gabbro S. E. of Lake Savonjärvi (p. 48) passes both N. and S. quite gradually into an indistinctly foliated amphibolitic schist with small hornblende accumulations. A little farther outwards this changes into well-foliated amphibolite containing scattered plagioclase phenocrysts. Both these rocks carry biotite in essential amounts. The amphibolite is bounded by a quartz-dioritic rock, and this last transition is rapid, the transitional zone being about 1 cm. in breadth. Near the contact the quartz diorite is more distinctly foliated and contains hornblende in considerable amounts, in addition to which certain plagioclase grains are larger and resemble phenocrysts. The structure of this complex thus shows obvious similarities to that of the schist fragments treated above. As was seen, also the chemical character of the central gabbro deviates decidedly from that of the gabbros and gabbro-diorites N. of Lake Paarlahti. Furthermore, its hornblende (Table VI, N:o 1) is similar to that in the gabbro-like schist variety (Table VI, N:o 7), but differs distinctly from that in other gabbros. Thus this gabbro is rather suggestive of a completely recrystallized schist remnant, in spite of the beautiful hypidiomorphic texture and the »normal-gabbroic» chemical composition.

Some xenoliths with gradual boundaries greatly resemble the gabbro-hornblendite previously described. Hornblende-rich fragmentary rims are sometimes seen along the contacts of the plagioclase-porphyritic xenoliths.

As stated above, the gabbro and gabbro-diorite close to the schist are cummingtonite-bearing, in addition to which their hornblende is of

Fig. 29. »Gabbro migmatite». N. of Lake Paarlahti, Teisko. Photo H. Tuominen.

a different kind in comparison with that farther away from the contact. The same evolution is sometimes seen around small xenoliths on a minute scale. In connection with the basic massif N. of Lake Paarlahti a very heterogeneous »gabbro migmatite» has been formed in some localities. The rock is composed of alternate hornblende-rich and plagioclase-rich parallel schlieren (Fig. 29) between which there are some broad bands of rather unchanged schist containing scattered phenocrysts and accumulations of plagioclase. In these bands are several roundish, coarse-grained patches of gabbroic rock with long hornblende prisms idiomorphic in relation to plagioclase. The patches pass gradually into their schistose wall-rock, but may enclose small amphibolite fragments with quite sharp boundaries. The fragments have undergone a moderate recrystallization, as indicated by slight foliation and tiny spots of coarser plagioclase (An_{54-55}) and hornblende. Around them there is a narrow aureole consisting of plagioclase (An_{46-47}) idiomorphic in relation to amphibole, and of xenomorphic green hornblende, and abundant cummingtonite usually occurring within the latter. However, in the border of the same thin section long, idiomorphic hornblende prisms with brownish colour already occur, and cummingtonite is not found in association with them. — The cummingtonite-bearing diorite (p. 53) always contains xenoliths of the plagioclase-porphyritic schist modification, and the occurrence of cummingtonite is probably in connection with the xenoliths. Cummingtonite thus only occurs in the intrusive rocks close to the schists.

Sufficient attention has not hitherto been paid to the occurrence of cummingtonite in hornblende gabbros and related rocks, though it seems to be fairly common in them. It has been suggested that it might be an alteration product of hypersthene, and it has also been considered to be of primary-magmatic origin in certain cases (Nockolds 1941, p. 477). In the opinion of the present writer, its mode of occurrence in the above-described rocks might be explained by assuming a migration of an excess of Fe and Mg from the basic schists into the adjacent intrusives, on account of which the crystallization of a Fe, Mg mineral is favoured. When cummingtonite occurs w i t h i n hornblende, it has been concluded (Stewart 1947, p. 483) that it has existed before the latter, and Stewart believes that the hornblende might have resulted from a reaction between cummingtonite and anorthite.

It is rather peculiar that sharp fragments of well-preserved schist are sometimes encountered in such a gabbroic rock that itself has apparently been derived from the schist. It seems as if the thorough recrystallization is accompanied by remarkable mobilization of the material, otherwise such phenomena are very difficult to understand.

QUARTZ DIORITE AND GRANODIORITE

Quartz diorite is found north-northwest of Lake Hankajärvi mainly in the immediate vicinity of the schist contact, and N. of Lake Paarlahti between the gabbro—diorite massif and the veined gneiss close to the lake. The occurrences are rather inconspicuous. The rock at the first-mentioned locality has usually been more or less granitized and does not represent any pure type. The quartz diorite N. of Lake Paarlahti is fairly similar in composition to the plagioclase-rich diorite described on p. 54 in the previous chapter. An analysis is presented in Table V, N:o 12.

The rock is rather strongly foliated and the texture is blastohypidiomorphic, almost granoblastic.

Plagioclase forms oval or somewhat rectangular grains, which are often weakly zoned and only occasionally twinned. The composition is An_{30-32} (determined by comparing the refraction to that of quartz).

Biotite and hornblende often occur as sinuous schlieren. Both are dark-coloured. The refractive indices of the biotite are: $\alpha = 1.607 \pm 0.002$ and $\beta \approx \gamma = 1.666$ indicating the ratio [FeO] : [MgO] to be about 5 : 2 (Winchell 1933). The properties of the hornblende are seen in Table VI, N:o 5.

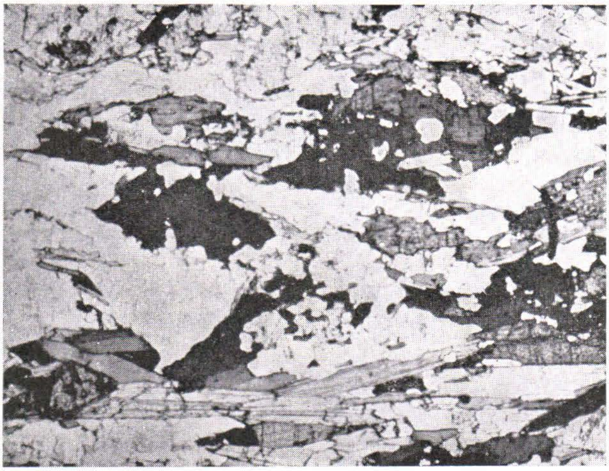

Fig. 30. Gneissose granodiorite. N. of Lake Paarlahti, Teisko. Nic. ||, magn. 16 ×.

In places the rock contains appreciable amounts of almandite.

The main occurrence of *granodiorite* is in the area N. of Lake Paarlahti where it is widely distributed. It is distinctly or strongly foliated without exception, and the texture is granoblastic. A microphotograph of the rock is presented in Fig. 30.

Plagioclase is somewhat sericitized. The refractive indices are slightly lower than those of quartz, but $\alpha' > N$ of Canada Balsam, so the composition is about An_{25}.

Biotite and hornblende form schlieren of fairly large crystals. The minerals are quite unaltered.

Quartz and microcline are present in equal amounts. The latter is unevenly distributed and usually occurs as xenomorphic grains between other minerals, but some larger, nearly idiomorphic crystals can be also seen. Myrmekitic intergrowths of plagioclase and quartz are common, and especially well-developed in connection with larger microcline grains. The myrmekite is regarded as being due to late addition of potash, as will be further discussed in the chapter on the metasomatic rocks (p. 93), and consequently such microcline crystals are considered to be porphyroblasts formed at least after the main consolidation of the rock. The granitization common to several neighbouring rocks further supports such an interpretation.

Sphene, epidote, and apatite are fairly abundant, and epidote often forms idiomorphic crystals. A little chlorite is associated with it.

The chemical composition (Table V, N:o 13) may also afford evidence of the secondary addition of potash. The potash content is high and many of the other percentage figures are typical of granodiorite, but the amount of silica is comparatively low. This also appears when comparing the Niggli numbers to those of the granodioritic magma type (Niggli 1923). In comparison with quartz monzonites (op. cit.), again, they show differences characteristic of many of the above-treated intrusives in respect to *al* and *fm*. It is worth noting that the figure of *mg* is unexpectedly high as compared with that of the other intrusives, further suggesting the rock to have been primarily more basic.

Contact relations. Quartz diorite and granodiorite are rather uncommon close to the boundary of the schist complex. In the northwestern corner of the area they are in contact with veined gneiss. In most of the other cases there is a more basic zone against the schist, but proceeding outwards the intrusive rock soon turns more acid and more and more homogeneous too.

The quartz diorite N. of Lake Paarlahti is bordered by a heterogeneous contact zone in many places. On the whole, this zone is approximately dioritic, but its appearance and composition are variable, and xenoliths of plagioclase-porphyritic gneiss with more or less gradual boundaries are common. The marginal parts of the schist have usually been changed into the plagioclase-porphyritic modification described in the previous chapter.

The xenoliths in the homogeneous types have been affected rather moderately. However, in places the changes are more thorough and, instead of schist inclusions, gabbro-like patches or hornblende-rich loosened accumulations are seen. Such accumulations sometimes have »tails» from which hornblende has spread into the surrounding rock.

Very small apophyses are occasionally observed at the contact between these rocks and the coherent schist or the gabbro. They are, however, more basic than the respective intrusive, probably owing to local mobilization and recrystallization of the material of the wall-rock.

THE VEINED GNEISS N. OF LAKE PAARLAHTI

In the northwestern corner of the area the basic schist close to the intrusive complex passes over into veined gneiss in a zone some hundreds of metres in breadth. Transition from the gneiss into quartz diorite is observed in some places. More basic intrusive rocks have seldom been found in immediate contact with veined gneiss.

The rock is composed of alternating darker and lighter portions in varying amounts and parallel one to another. Even when the veins have grown larger, the parallel structure often remains. Mineralogically, most of these rocks are as follows:

The essential constituents of the schistose part are plagioclase, biotite, quartz, and epidote. The schist has largely recrystallized, since the plagioclase crystals are often nearly idiomorphic and distinctly twinned, as they are in magmatic rocks. The foliation is well-developed, however, and especially in finer-grained parts the texture is granoblastic.

Abundant, large and often idiomorphic epidote grains in association with biotite and the lack of hornblende afford evidence of an addition of potash.

The veins mainly consist of plagioclase and quartz with some biotite and a little epidote. Their boundaries are fairly indistinct. The texture is nearly granoblastic, and a slight foliation is shown by the biotite flakes.

The composition of the plagioclase is about An_{40} approximately, and constant through the whole rock (determined by comparing the refractive indices to those of quartz).

In other examples the whole is more basic, hornblende being present throughout the rock, while quartz is almost lacking in the schistose part. Biotite is always more abundant than hornblende, but the relative amount of the latter is often greater in the vein, though the absolute quantities of the dark constituents are of course smaller there. The composition of the plagioclase is constant in this case too.

It is noteworthy that the light veins are poorer in potash than the dark wall-rock as a rule. Potash feldspar is usually lacking in both, but biotite is by far more abundant in the wall-rock. Indeed, microcline-bearing veins are also observed, but the distribution of microcline in them is conspicuously uneven, and it often forms porphyroblasts which may have been distributed over the whole rock, in both the veins and the wall-rock. In all probability, this constituent is of late origin and not in genetical connection with the original light veins in the gneiss.

At certain localities on the shore of Lake Paarlahti the veins can be several tens of metres in breadth. The schist passes more or less gradually into the vein which is biotite-quartz-dioritic in composition and shows a fairly hypidiomorphic texture, although it is considerably foliated. The following special features are to be noted: the plagioclase crystals are distinctly zoned (the composition varying from An_{40} in the kernel down to An_{25} in the shell), in many cases allanite is found in the centres of the fairly abundant epidote grains, and a little almandite is present. Quartz is rather subordinate.

In the schistose parts of more basic gneiss there are sometimes minute dioritic »impregnations» with quite diffuse boundaries, which correspond to the gabbroic patches in the schist (p. 57) in their occurrence. The schist close to these impregnations is biotite-bearing, granoblastic amphibolite, in which the hornblende is rather dark-coloured and slightly bluish green and does not contain ilmenite inclusions. The texture of the »impregnation» approaches hypidiomorphic as indicated by the often euhedral plagioclase crystals. The larger hornblende individuals, at least, are lighter than in the adjacent schist and show a slightly greyish tint. They sometimes contain ilmenite inclusions in considerable amounts in the manner previously described (p. 49). The amount of hornblende, in relation to that of biotite, is also in this case greater in the vein than in its amphibolitic surroundings. No gabbros or diorites are seen in the vicinity of such impregnations, and thus these cannot be any intrusive apophyses, but look quite »venitic». A related phenomenon may be in question, when certain strongly recrystallized amphibolites contain hornblende patches (several cm. in diameter) with a surrounding aureole of plagioclase.

At the northern border of the veined gneiss belt there are, in places, small (some metres in diameter), roundish or elongated portions of dioritic rock within the schist. The boundaries of these portions are quite gradual. It seems as if such formations do not differ essentially from the »impregnations» treated above, and thus they may represent a more advanced »magmatization» of the supracrustal material. Such dioritic parts can also trend parallel to the schistosity as narrower stripes. In the outer contact zone beautiful concordance in the structure is seen in the veins, large »impregnations», and the elongations of the schist xenoliths being parallel one to another, as well as to the general schistosity. The different parts have been largely intermingled with each other and the whole begins to resemble a diorite or gabbro. The straight lines and the parallellism of the alternating stripes have sometimes remained to the last. The »gabbro migmatite» (p. 57) presents an example of such an evolution. This migmatic complex itself, as well as the gabbroic patches in its amphibolitic parts may enclose schist fragments with sharp boundaries. Thus the whole has been mobilized to such a degree that its behaviour has become like that of a magma.

SODA-RICH MARGINAL MODIFICATION

This kind of rock forms a continuous zone, in places more than 1.5 km. in breadth, between the main part of the schist complex and the schist belt N. of Lake Pukalanselkä which, with some interruptions, continues eastwards beyond the limit of the area mapped. The most typical rock consists mainly of sodic oligoclase and quartz with only small amounts of dark minerals. It is always plagioclase-porphyritic and sometimes also contains quartz phenocrysts or accumulations. The foliation seems to depend upon local factors, in certain cases the rock being entirely unfoliated. A soda-extreme type near the schist contact S. of Lake Pukalanselkä was analyzed (Table V, N:o 14). The extremely low number of k is especially to be noted.

The ground-mass is granoblastic, rich in quartz, and fine-grained (0.1 mm. on the average).

Plagioclase phenocrysts are 1—5 mm. in length, fairly well-shaped, usually weakly zoned, and more or less saussuritized. The composition of the plagioclase (by comparing the refraction to that of Canada Balsam) is An_{12-17}.

Quartz, in addition to that in the ground-mass, sometimes occurs as oval or elongated accumulations (up to 5 mm. in length) which are distinctly coarser-grained than the ground-mass.

Hornblende and biotite form small aggregates and streaks here and there. Both are rather pale-coloured, and sometimes considerably chloritized.

Sphene and sometimes calcite are present as accessory constituents.

Farther E., between Lakes Pukalanselkä and Iso Teerijärvi, the rock is usually more strongly foliated, and muscovite is observed in appreciable amounts associated with biotite or abundantly as an alteration product of plagioclase. Hornblende is lacking. At the eastern end of the contact zone the foliation is even more distinct having afforded opportunities for further secondary changes. Considerable amounts of potash feldspar are present occurring together with quartz in pressure minima, within the plagioclase phenocrysts as thin »impregnations», as well as in the ground-mass between other minerals, etc. Epidote and sericite are rather abundant. The composition of the plagioclase is about An_{20} which may indicate a less acid primary composition of the rock; moreover, the amount of the dark constituents is somewhat greater and the biotite is distinctly richer in iron. Northwards from the schist contact the determination of the primary composition is also difficult owing to the secondary potash. The purest soda-rich and iron-poor rock seems to be limited to the immediate vicinity of the schist contact S. and S. E. of Lake Pukalanselkä. North of this lake, rocks of the diorite class are predominant, but in certain shore cliffs a rock occurs which resembles the soda-rich modification. Its porphyritic texture is indistinct, even the larger plagioclase crystals are not very well-shaped, and the ground-mass is coarser. Plagioclase (An_{27-28}) very distinctly predominates over quartz. Hornblende is lacking, nor is biotite abundant, potash feldspar being quite subordinate or absent. The rock is thus intermediate between quartz diorite and »soda granite». Unfortunately, transition into other intrusive rocks could not be studied. Close to the amphibolite belt such a rock was not encountered.

Contact relations and some textural features. Along the borders of the soda granite there is usually a broad zone containing abundant xenoliths of the country rock. The xenoliths can be very close one to another up to several tens of metres from the coherent schist, and such portions have the appearance of an intrusive breccia. However, xenoliths can be seen almost everywhere within the soda granite belt.

Many investigators have recorded that the soda granite and its wall-rock can pass more or less gradually into each other. In the Tampere area this phenomenon is also very common. In places, especially N. W. of Lake Kutemajärvi, it is often almost impossible to distinguish the intrusive rock concerned from its wall. This can be due to several reasons. Potash metasomatism and associated processes which have taken place in more sheared rocks have sometimes changed the original compositions, so that primarily different rocks have become almost similar. Secondary structural and textural features, identical in both rocks, have resulted from the strong deformation. However, the gradual transition is seen in any case, though no dislocation and metasomatism have taken place.

Fig. 31. Schist penetrated by a vein of »soda granite». The upper part is the vein. S. shore of Lake Pukalanselkä, Orivesi. Nic. ||, magn. 16 ×.

Small veins, penetrating the schist with a parallel structure, also show well-developed foliation (Fig. 31), and both rocks resemble each other in mineral composition. The difference is sometimes so slight in all respects that it can be seen only on the weathered surface, hardly in thin section. In general, however, the light minerals are more abundant and their crystals bigger in the veins. In the case of intrusive rock predominating, and especially when small separate xenoliths are considered, no parallel arrangement is seen in either the xenolith or the intrusive (Fig. 32). The larger inclusions also have sometimes been completely recrystallized and have the appearance of a basic intrusive rock. Their core is coarsest-grained, while the grain is much finer at the margins.

In the schist not primarily porphyritic plagioclase phenocrysts are seen within a narrow marginal zone. Where small veins with diffuse boundaries cut the schist, the occurrence of phenocrysts in the latter is undeniably in connection with the veins. In recrystallized contact portions of the schist the plagioclase sometimes forms indistinct laths arranged at random (Fig. 33). At the borders of the laths some clear plagioclase has crystallized, and they are often corroded by quartz. Such a texture can also be observed in the adjacent vein, but the laths are bordered by more abundant new plagioclase, or contain intergrowths of it. Furthermore, similar phenomena are seen in the plagioclase phenocrysts of the main »granite», especially in the somewhat muscovitized type, and the ground-mass also carries two kinds of plagioclase. Hjelmqvist (1943, p. 17) has described similar recrystallization in the soda granite.

The contact type of schist (Fig. 33) contains some small, roundish patches with coarser grain, in which the light minerals are enriched.

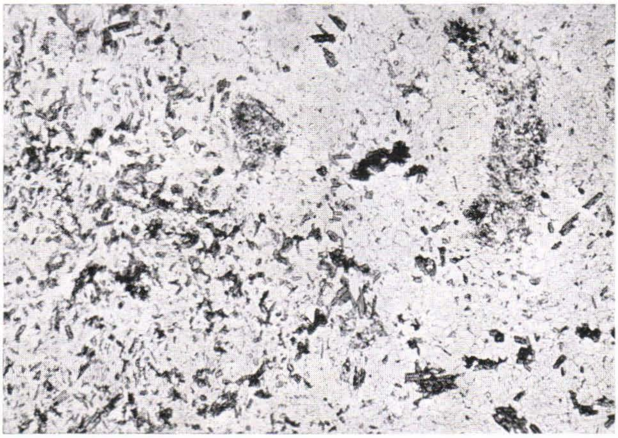

Fig. 32. Contact between »soda granite» and xenolith. N.W. of Lake Kutemajärvi, Orivesi. Nic. ||, magn. 16 ×.

Certain patches contain larger, round grains of quartz, and in places abundant small, quartz-rich accumulations are seen close to the veins cutting the schist. It seems as if there were a certain evolutionary stage of secondary »quartz porphyritic» texture in question.

In his description of this rock Sederholm has already paid attention to certain feldspar-quartz intergrowths in its ground-mass, which he considered to be a primary micrographic texture (1897, p. 120). Such a texture is not very common, and the most typical one does not occur in the contact zone proper. It has always resulted from the intergrowth of quartz and plagioclase, potash feldspar being not necessarily present, but other evidence of additional materials, such as muscovite, is well observed. Mainly the new, clear plagioclase partakes in this process, but in the well-developed formations quartz forms intergrowths with the phenocrysts of older, altered plagioclase as well. A »belt» of quartz inclusions with the same optic orientation within a particular phenocryst can

Fig. 33. Recrystallized schist with laths of plagioclase near the contact of »soda granite». N. of Lake Kutemajärvi, Orivesi. Nic. +, magn. 16 ×.

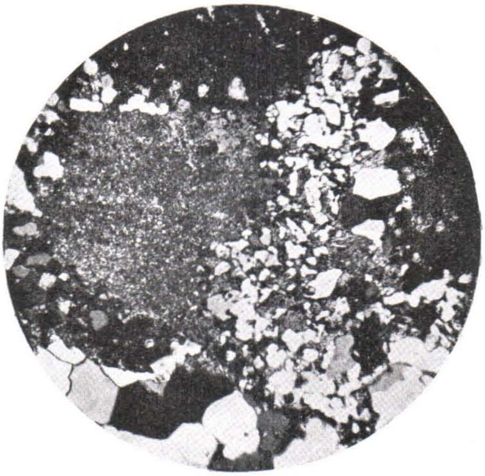

Fig. 34. Quartz inclusions in plagioclase crystals in »soda granite» (see text). E.S.E. of Lake Pukalanselkä, Orivesi. Nic. +, magn. 40 ×.

continue outside the host mineral and is found to form a similar intergrowth with another feldspar grain (Fig. 34). The quartz does not possess the same orientation throughout the belt, however.

Many petrographers have discussed the »graphic» texture in granites and related rocks. According to certain newer proposals, distinction should be made between the concepts »graphic» (or »micrographic») and »granophyric», the latter of which would be a more general definition of intergrowths (cf. Hjelmqvist, op. cit., p. 19); the rather irregular texture described above would be referred to as granophyric and the rock itself as granophyre. Hjelmqvist holds that many of the granophyres may be of secondary origin, yet different interpretations would be possible in different cases. Erdmannsdörffer (1943, 1948) concludes that the quartz-feldspar intergrowths have resulted from corrosion of feldspar by quartz during a later, »endometasomatic» stage of crystallization after a previous magmatic one. Drescher-Kaden (1948) does not accept any magmatic crystallization. According to him (op. cit., p. 239), the silica released by epidotization and sericitization of plagioclase replaces feldspars and thus builds up the granophyric or graphic texture.

Some comments on the *chemical composition* are worthy of note. The composition of the plagioclase in the xenoliths is identical with that in their immediate surroundings where the anorthite percentage is thus comparatively high (An_{25-30}). In the pure soda granite with a few xenoliths the plagioclase is distinctly poorer in anorthite (An_{12-17}). Furthermore, the surroundings of the xenoliths are richer in hornblende and biotite than the rock farther outwards. Especially when small diffuse veins penetrate the basic country rock, the veins also are fairly basic. The soda granite containing abundant schist inclusions is more basic throughout than usual. Hornblende and biotite, although diminishing in quantity, are present in the intrusive in approximately the same relative amounts as they are in the bounding schist. The pale colour of the mafic minerals, especially that of the hornblende, which is most striking in the rock poorest in these constituents, gives an idea of their richness in magnesia. This is also indicated by the number of *mg* unexpectedly high for such an acid rock. The same feature was observed, for instance, by Sundius (1926, p. 35 and 39) in some plagioclase-extreme aplite granites.

The soda-rich margins of granodioritic and related massifs may have aroused more speculation than all other intrusive rocks except microcline granite. Before the general discussion (p. 70) of the intrusives treated above, therefore, some of the different interpretations will be quoted.

Magnusson (1937, p. 529) considers the soda-rich marginal facies to be a differentiation product of the so-called urgranite (= primordial granite). According to Sundius (1926) there is differentiation of a granitic magma in question, through which part of the resulting rock becomes soda extreme, or direct differentiation of a magma originally poorer in potash (granodioritic). But when there is a soda granite bordering soda-extreme leptite, he is inclined to explain it as having resulted from the melting up of the country rock. Sederholm who first described this rock in the Tampere area (1897; 1913) may not have paid attention to its richness in soda, and was mainly interested in its textural features. He regarded it as having crystallized from the chilled outer part of the intruding magma, and the fine grain and the porphyritic as well as the granophyric texture would be due to the rapid consolidation. Many objections can be raised against this explanation. The transitions between the intrusive and the basic country rock, and the recrystallization phenomena in the latter are to be noted, for example, and the strong contact influence of the small veins could hardly be understood in the case of a rapidly-cooling acid magma. Suggestions of the secondary nature of the granophyric texture were quoted above. According to Eskola (1932 c), the late-magmatic addition of soda (soda-autolyse) accounts for the composition of the border variety, and a similar idea has been expressed by Geijer (1929). However, this does not sufficiently explain the fusion phenomena of the country rock. Hjelmqvist (1943) regards the soda granite as an original soda-rich leptite gradually granitized by the urgranite. Such an explanation may better correspond to the observations in the Tampere area, if applied to the cases of more basic country rock. In the opinion of Backlund (1938, p. 192) the marginal variety has originated from any kind of rock in the border zone through alkali metasomatism, but Backlund holds that even the urgranite has resulted from a similar introduction of »alkali emanations» (op. cit.). Reynolds (1944) maintains that trondhjemitic rocks may represent an intermediate stage in the transformation of hornfels into granodiorite by Na, Ca, Si metasomatism and that the formation of oligoclase porphyroblasts is characteristic of that stage of transformation (op. cit., p. 233). Lastly, Dunn (1942, p. 235) believes that aqueous solutions migrating outwards from the main zone of granitization may give rise to soda granite, if soda is sufficiently available in the permeated rocks.

MICROCLINE GRANITE, APLITE, PEGMATITE

All deeply eroded districts offer plenty of evidence of granitization, that is to say, of metasomatic transformation of older rocks into granite. This is also true of the Tampere area, especially of the north side of the schist belt. But as in all plutonic terrains, one may also see granites that behave quite intrusively in the strict sense of the word. There are thus »granites and granites» in the sense of Read (1944, 1948 a). The last-mentioned category is the subject of the present chapter, whilst the metasomatic granites, as well as the whole concept of »granite», are preferably discussed in another connection, however unwise such a dualism may be. Some comments on the nature of granitic intrusions will be added.

The occurrences of this microcline granite are scattered in the area W. of Lake Pukalanselkä. The bosses are never more than 200—300 m. in diameter and usually irregularly shaped or roundish, or there are large dikes cutting the older rocks in different directions. A slight foliation is sometimes seen, probably due to later cataclasis, and the texture is more or less typically granoblastic. An analysis is presented in Table V, N:o 15.

Quartz is often unevenly distributed forming irregular patches of larger grains.

Microcline occurs as small grains between other minerals as well as abundant larger ones which may show some crystal shape. It is unaltered, usually distinctly cross-hatched, and sometimes contains thin perthite streaks.

Plagioclase forms xenomorphic grains whose boundaries against microcline are often corroded, while well-developed myrmekite has been formed. The composition of the plagioclase is An_{15-17} ($\beta \approx$ N of Canada Balsam and the max. ext. angle $= 4°$).

Biotite is fairly subordinate. Epidote, sphene, and iron ore are present as accessory constituents.

Many occurrences are still poorer in mafic components and sometimes rather coarse-grained. In that case, microcline becomes more and more predominant, plagioclase is albite or albite-oligoclase, and the micas are quite subordinate. Almandite and allanite may occur as accessories. The more the microcline is enriched, the larger and better-shaped are its crystals, whereas the plagioclase grains are more and more corroded and destroyed (Fig. 35). The plagioclase crystals enclosed by microcline are often completely myrmekitized. It seems evident that the microcline replaces the plagioclase.

Certain dikes of more fine-grained aplite proper are muscovite-bearing, and do not display replacement phenomena nor myrmekite. They may have crystallized at a lower temperature.

Besides the microcline-rich aplitic varieties there are also dikes and small bosses of aplite rich in oligoclase (An_{15-20}). Microcline is often quite subordinate to oligoclase and quartz, whereas biotite has somewhat increased. Transitional forms between both varieties are also observed.

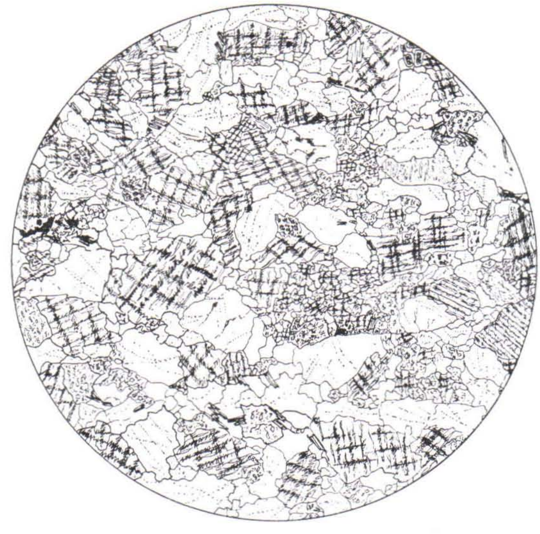

Fig. 35. Coarse-grained microcline granite with myrmekitized plagioclase. W. end of Lake Pukalanselkä, Orivesi. Magn. 6 ×.

At the western end of Lake Pukalanselkä there is a large stock of coarse-grained pegmatite. It is a simple pegmatite, mainly composed of large crystals of microcline (up to 6 cm. in diameter) with some muscovite. Certain parts are rich in quartz and may pass over into pure quartz. The pegmatite is situated in a crush zone parallel to the east-west strike, and it penetrates an associated microcline aplite with sharp boundaries. It thus apparently represents the last stage of intrusion in the area.

More or less granitized walls are characteristic of most of the intrusive granites and aplites, and distinction between »intrusive» and »metasomatic» is not always easy.

An ardent disputation is going on about the causality of the processes of intrusion and soaking. The rather reasonable conception of granite magma causing granitization needs no commentaries in this place. But several modern petrographers hold that soaking by granitizing liquids or emanations under favourable physical conditions is the primary process, and that the intrusive stocks of granite are but an effect. Dunn (1942) suggests that a complete fluidity can be achieved secondarily and that the resulting material has all the properties of a magma proper. Radioactivity would be the source of the energy required. Wegmann (1931, p. 58) believes that soaking may give the soaked mass the power of movement, and an intrusion may result if that occurs with resistant walls. Read (1948 a, p. 16) does not propose »magma» but instead some mashes of crystals and liquid. Wegmann (l. c.) considers the pegmatite dikes to represent that part of the granitizing solutions which crystallizes in opened spaces arising in the permeated mass; furthermore, Read (1944, p. 90) admits that some s m a l l granites may have crystallized from migma, some others even from magma. On the other hand, some of the advocates of igneous magma have also modified its definition as a completely fluid melt (e. g., Shand 1948, p. 138; Erdmannsdörffer 1948, p. 245). Shand says that the magma is a three-phase emulsion consisting of crystals and two liquids one of which is an alkaline solution. Infiltration and forceful injection may thus proceed hand in hand. We shall return to these subjects later on.

The intrusive granites in the area concerned, of whatever origin they may be, are in rather close connection with the metasomatic granites and do not seem to be essentially different in age. Thus all the granites are probably of one connected origin in any case.

DISCUSSION

The chemical compositions of the intrusive rocks analyzed are presented graphically by means of Niggli diagrams in Fig. 36. The result is rather irregular and unusual. Only *c* and *alk* show a normal development, though *c* decreases only slightly with increasing *si*. The values of *al* and *fm* are fairly variable at the basic end, and *fm* is somewhat abnormal in other respects also. The curves of *k* and *mg* are most irregular, although the steep rise of *k* against the value of *si* = 220 may be ascribed to the granitization of the rock concerned (p. 59). The figures of *mg* are highest in the most acid rocks with considerable or abundant free silica. On the other hand, certain representatives of the diorite class show unexpectedly low values of *mg*, and the poverty in magnesia in most of the diorites and gabbros is also distinctly indicated by the calculated compositions of the hornblende (Table VI) and the biotite (p. 58). As well known, the ratio [FeO] : [MgO] in the above minerals in such rocks, if they are magmatic differentiates, should be less than 1 : 1 on the average, so the deviations observed are remarkable. A high

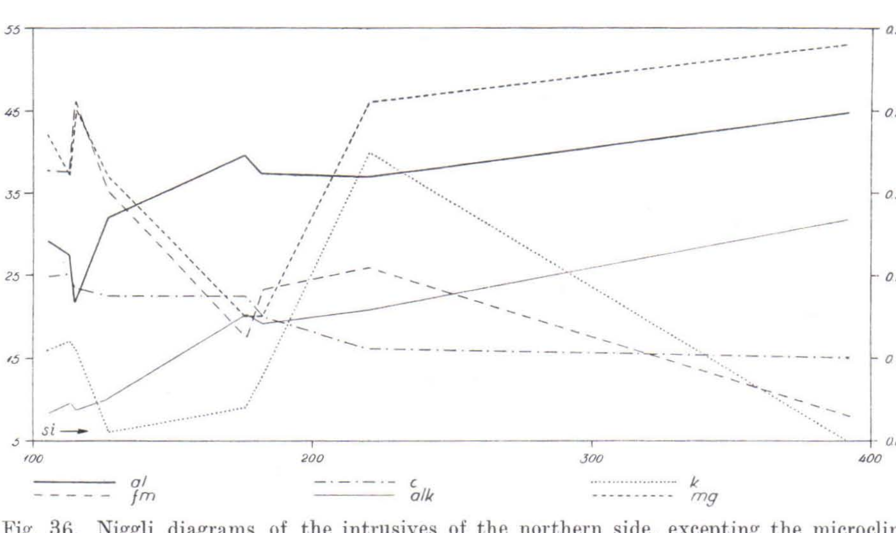

Fig. 36. Niggli diagrams of the intrusives of the northern side, excepting the microcline granite.

content of Al replacing Si in hornblende does not seem to influence essentially the refractive indices, as, for instance, the analysis in Table VII shows the same ratio [FeO] : [MgO] as can be estimated from the refraction according to Winchell's diagram (1933).

It is difficult to see any model example of crystal differentiation in the above diagram. A further significant fact may be presented, namely, the ratio quartz: feldspar as compared with the amount of the dark minerals in the series from plagioclase-rich diorite to granodiorite (Table V, N:os 11—13). The more there is quartz in relation to feldspar the higher is the percentage of hornblende and biotite, i. e., the colour index, whilst the relation should be the reverse in an ordinary series of differentiation (cf. Rudolf Wager 1937, p. 14).

The contact relations, especially those of gabbro and diorite, show that materials of the country rocks have been mobile and modified the intrusive part, and that mobilization and thorough recrystallization of the schists have produced gabbroic rocks not distinguishable from igneous ones. Several points in the foregoing chapters suggest that distinction between »intrusive rocks» and »metamorphic» or »metasomatic rocks» is not at all obvious. In this contact zone we are apparently dealing with an ultrametamorphism the effects of which may be very significant as to the evolution and composition of all the intrusive rocks considered.

There are several descriptions of similar phenomena in the geological literature. The modern German school frequently emphasizes the convergence of magmatic and metamorphic. The so-called transformists who allow little or no significance to the magma do see in all igneous rocks a result of mere rock transformation. If there is magma, it is but secondary. »They hold in common that regional metamorphism and 'igneous' activity are genetically related» (Read 1948 b, p. 196).

In Finland attention seems to have been paid rather scantily to these subjects. Judging from the old explanation to the map sheet of Tampere (Sederholm 1913, pp. 91—93), however, the phenomena concerned are quite general along the northern boundary of the whole Tampere schist belt. Sederholm has noted assimilation, recrystallization of the basic schist into dioritic rocks often with coarse grain and lath-shaped hornblende, and formation of plagioclase porphyroblasts. Mäkinen (1916, pp. 57 and 90—91) describes certain phenomena of contamination in more detail. Hietanen (1947, p. 1070) mentions that intense recrystallization of porphyrites and leptites may give rise to rocks like gabbro, trondhjemite, or granite. After the recent revision of the Tampere area by the Geological Survey of Finland transitions from plagioclase porphyrite into quartz diorite are recorded in the explanation to the map sheet of Ikaalinen (in print). In these and other descriptions, however, the question is seldom discussed in detail.

Let us cite some foreign papers.

Around a massif of quartz diorite in Idaho, Johnson (1947) observed various gneisses similar to plutonic rocks in composition and texture but evidently of sedimentary origin. He concluded that the sediments have been altered by the hydrothermal solutions from the igneous quartz diorite.

Drescher-Kaden (1936) suggests that supracrustal rocks metamorphosed at great depths become plutonic-looking by recrystallization and associated migration phenomena, or give materials to new true magmas through assimilation. The primary heterogeneities of rocks, as well as those due to tectonic agents, would involve metamorphic differentiation at deep levels. Drescher-Kaden describes diorite veins which have apparently been squeezed out from their country rock. He says that all the marks of primary-magmatic crystallization are often seen in the recrystallized portions of schist, but the sequence of crystallization of the main minerals can be variable indicating irregular variability in the available constituents, a feature unusual in the consolidation of a magma.

The idea of the mobilization of non-magmatic bodies suggested by Drescher-Kaden is similar to the opinion of certain transformists concerning the nature of intrusive granites (p. 69). Some migration of materials and favourable physical conditions would be required to render the rocks mobile. Joplin (1939, pp. 101—02) seems to think somewhat similarly in certain particular cases, but it must be emphasized that she does not at all propose the idea of such a rheomorphism in general. According to her, amphibolite may be recrystallized into coarse diorite-like rock by volatile-rich soda-silica solutions in a state of tension. The presence of volatiles would involve a coalescence of hornblende into large crystals.

Erdmannsdörffer has published several excellent studies on the ultrametamorphic evolution of intrusive rocks. He interprets migmatic diorites as follows (1947, pp. 81—84): The migmatite consists of a mash of crystals and liquid the chief part of which is external and magmatic, and of more or less solid materials from basic walls. The formation of mixed rock is advanced by penetrative movements between resistant walls. The inclusions change into spots and schlieren of hornblende, but there may also be sharp fragments which indicate the migmatite to behave like a magma (op. cit., p. 73 and 78). Cf. also a study of granite (Erdmannsdörffer 1948, pp. 221—23, Figs. 3—5 and 11). If »thermic or tectonic energy» is added, the migmatite passes into a homogeneous intrusive mass (1947, p. 84), and the texture approaches more and more that of magmatic rocks. (Reynolds, in describing her igneous-like transformed rocks, suggests that true magmas may result in the same way »if sufficient energy is available» — 1944, p. 238. The source of this energy is not considered.) But, Erdmannsdörffer goes on, diorite can certainly be formed also *in situ* from amphibolite or hornfels, though only locally.

Smulikowski (1946, p. 262 sqq.) writes: Close to palingenic granite masses, the basic parts of older rocks also begin to show indications of granitization and migmatization (recrystallization; mineral or structural transformation by the action of heat and of the remolten medium; veins, injections, and »nests»). Smulikowski calls the rearranged country rocks »lipotectites», and the process is »an ultrametamorphic reconstruction in the solid state». The most altered lipotectites, termed »metatectites», nearly correspond to Scheumann's (1936) »metatexites». The deeper the level, the more completely disappears the primary structure of the lipotectites; these become more and more basic, and the adjacent palingenic rock (»palingenite») increases and is more and more enriched in cafemic constituents. This highly contaminated rock is called »diachyte». The contamination is not due to melting of those constituents (cf. Bowen's theory of assimilation) but to diffusion in solid and mechanical dispersion of loose crystals (cf. Nockolds 1933). The stage of anatexis may be followed by differentiation of the resulting palingenic magma or crystal suspension by squeezing, etc., which may give rise to various series of intrusive rocks.

Koch, in his investigation of metatexites (1939), describes processes comparable with the formation of diachyte suggested by Smulikowski. He notes that plagioclase in the dispersed remainders of amphibolite is considerably enriched in anorthite.

The geologists, when speaking about »intrusion», always meet with the problem of the space required by their intrusions. The discussion of granite is the main milieu for dispute about the space problem, but this is of general significance as well. When the transformists use it as argument against the magmatists, it may be said with Bowen that »material pushed up chemically occupies just as much room as the same material pushed up mechanically» (1948, p. 88). Many intrusions may be explained by assuming some »opened spaces», but if one supposes extensive intrusives to exist, such an explanation is hardly applicable. Drescher-Kaden (1936) offers a rather reasonable solution of the problem: the parts of the crust pushed aside during intrusions can rise upwards only to a limited extent, so they must sink downwards into zones where they are subjected to thorough rearrangement, and new magmas are formed at their expence.

Many petrographers have described the formation of plagioclase porphyroblasts during ultrametamorphism, metasomatism, or metamorphic differentiation (McCallien 1934, Cheng 1944, Reynolds 1944, Smulikowski 1946, Erdmannsdörffer 1947, etc.). It may be ascribed to different reasons in different cases: to the coalescence of existing constituents according to Eskola's (1932 a) concretion principle (McCallien); to the introduction of Na, with or without Ca (Cheng, Reynolds). Reynolds (op. cit., p. 233) suggests that the formation of porphyroblasts is characteristic of all rock transformation under its initial stage.

The classical studies of veined gneiss by Sederholm and Holmquist are well-known. They represent the two main principles of interpretation: according to Holmquist (1907), the veins are exclusively »venitic», i. e., products of segregation; Sederholm (1907) considered the veins due to magmatic injection and introduced the term »arterite». Nowadays, such a contradistinction looks rather academic, because both types may exist as well. In 1926, Sederholm himself admitted that the principles are not very far from each other (op. cit., p. 137). Both speak about palingenic vein material, but Holmquist holds that it is *in situ*, Sederholm that it is not. Most modern petrologists, indeed, appear to prefer the theory of segregation to that of injection. In addition, Holmquist's primary conception of merely pegmatitic and aplitic veins has been much enlarged.

In interpreting the venites, several investigators have applied Eskola's theories of differential anatexis (1933) and metamorphic differentiation (1932 a; 1939, p. 405). Holmquist early premised the conception of differential anatexis in his »pegmatite palingenesis» (1920, 1921), and later it has been supported especially by the modern Germans (Wager 1937 and 1938 a—c, Erdmannsdörffer 1938 and 1947, Wimmenauer 1950). Erdmannsdörffer suggests, too, that migration of material according to Eskola's »principle of solution» may be of significance (1938, p. 20). The German authors, and several others, frequently accentuate p e n e t r a t i v e m o v e m e n t s as an important advancer of segregation. Kranck (1931, p. 93) and Walter Schmidt (1932, p. 182) have suggested that the mechanical sorting is the only essential factor in the formation of banded gneisses: the regroupment of material into different bands would be due to the different capacities of translation of minerals under deformation. The heterogeneities caused mechanically may be further increased by concomitant magmatic injections along the planes of differential movements (Wenk 1937, p. 87), or by pore fluids drawn into the zones of high shearing stress (Turner 1941, p. 14). Also Eskola (1939) accepts the mechanical sorting as a factor in the process of metamorphic differentiation. We might summarize, according to the above-cited authors in common: the formation of veined or banded gneiss and the metamorphic differentiation are inseparably associated with each other; the segregation due to differential anatexis is an essentially similar process; the introduction of material (and the corresponding extraction of other) only accents the heterogeneities caused by internal operations.

Many geologists of to-day may support quiet diffusion as the mechanism of veined structure, because older structural features may have been preserved in fairly heterogeneous gneisses. Obviously, that is not always the case. The vein material may acquire more or less »magmatic» properties, whether this is due to internal or external fluids, or to tectonic agents, or to both (the above-cited works of Wager, Erdmannsdörffer, and Wimmenauer; Wegmann 1931, Drescher-Kaden 1936, etc.).

The composition of the segregations, of course, depends on that of the parent rock to a considerable degree. For instance, anatectic segregations (»ectects» of the Germans) from biotite-plagioclase schist (Erdmannsdörffer 1947, p. 68) were found to be quartz dioritic, whilst those from amphibolite (Koch 1939) may approach an anorthositic composition.

Last, let us look into the theory of Kennedy and Anderson (1938) with some applications to the suggestions of anatexis and ultrametamorphism quoted in the foregoing. Thereafter we may proceed to some tentative thoughts in the present matter.

Kennedy and Anderson set forth as to the origin of the plutonic rocks that there is a universal granodioritic parent magma which has resulted from the remelting of the sialic crust. Contamination of this magma during its slow rise is of importance in forming different derivatives from it.

It seems evident that local differences in the composition of the crust may give rise to local variations in the resulting palingenic magma (cf. Dunn 1942, p. 237). Smulikowski's (1946) »palingenites», when developed in an environment basic enough, may be, e. g., tonalitic in composition, and they are suggested to become still more basic at deeper levels. Erdmannsdörffer has once wondered: »Ist aller Diorit nur verwandeltes Altmaterial?» (1947, p. 84); he also appears to have considered certain syenites to be palingenic (cf. Wager 1938 b, p. 42). Koch (1939) suggests that primarily acid magmas contaminated by basic material at greater depths may have been pushed up as dioritic intrusions.

It seems to the present author that the intrusive rocks considered in the preceding chapters have originated from pre-existing solid material parts of which have been mobilized anatectically. In general, the palingenic material is probably not *in situ*, but the small dioritic patches and »impregnations», at least, prove that an anatexis may have taken place also at this level. The »palingenite», to use Smulikowski's term, may have been modified by contamination, and various kinds of rock have thus been produced.

As to the composition of the primary uncontaminated palingenic material, the author would like to suggest that it may not be very far from that of the plagioclase-rich diorite (Table V, N:o 11). Thus it would have contained alkalies (predominantly Na), Ca, Si, Al, and Fe (with a little Mg), a composition quite possible according to the suggestions of partial anatexis cited in the foregoing, as well as to the author's own observations of veined gneiss and venitic patches. A rather basic ancestry is to be supposed. The mobilization of considerable amounts of Al is often denied (cf. Lapadu-Hargues 1945, p. 306). However: the »ectects» containing sillimanite, disthene, almandite, and cordierite (Wager 1937, pp. 7—8, and 1938 a, p. 31; Erdmannsdörffer 1938, p. 19), the disthene-muscovite pegmatites (Karpoff 1946), the many well-known granites with garnet or cordierite in the Svecofennides, etc., indicate that Al is well able to migrate, in whatever way this may happen.

The plagioclase-porphyritic contact variety of schist enriched in biotite and quartz might be explained by an influx of K, Si, and some Na; the striking poverty in K of the feldspar-rich dioritic intrusives might be ascribed to the removal of this constituent. The ratio [FeO] : [MgO] is distinctly in favour of [FeO] in the plagioclase-porphyritic variety (Table VI, N:o 6), whilst the relation is the reverse in the gabbroic rocks explained as being recrystallized basic schists (Table VI, N:os 1 and 7). It thus seems as if Mg would have been removed farther from the contact for some distance. A part of Ca which has been released from biotitized hornblende has, perhaps, migrated together with Mg and caused some enrichment in hornblende in the respective »gabbros». Thus there would be certain »basic fronts» in question, and the gabbroic central parts of the inclusions (p. 56) would be in a sense comparable with the »basified cores» suggested by Reynolds (1946, p. 434).

The primary »palingenite», having been contaminated by material of the plagioclase-porphyritic contact modification, may pass over into quartz diorite. If unchanged basic schist material is added, too, more and more basic rocks may result which would correspond to the homogenized dioritic and gabbro-dioritic migmatites of Koch (1939) and Erdmannsdörffer (1947). By later introduction of potash and silica (advanced by rather strong penetrative movements) these would have been changed into granodiorite. It is worth noting that the granodiorite is the most gneissose of all the intrusives concerned.

Obviously, many points would still require additional field explorations and much chemical investigation.

The veins of the veined gneiss are no doubt to be regarded as venitic segregations, and the formation of veined gneiss may be subsequent to that of the above-treated rock complexes. During the development and contamination of the intrusives, penetrative movements have been, in general, of no considerable significance, whereas the distinct foliation and parallel arrangement of the components of veined gneiss indicate different conditions; the richness in biotite suggests a preceding introduction of potash, too. Holmquist early held (1907) that magmatic assimilation and associated phenomena would be of older age than the segregation of veins. However, different processes may partly overlap each other.

As regards the soda granite, many correspondences to the rocks N. of Lake Paarlahti may be noted as to the composition as well as to the contact relations. Yet there is a fundamental difference, namely, the high figure of *mg*. For the present, the significance of this difference cannot be explained.

THE VÄRMÄLÄ GRANODIORITE AND ASSOCIATED INTRUSIVES

A fairly large, roundish intrusive massif, about 8 km. in diameter, extends across the boundary between the parishes of Teisko and Aitolahti. It consists mainly of granodiorite and granite, with subordinate basic rocks, a part of which occurs as small separate massifs. The rocks are by far more homogeneous in structure than are those of the northern side.

THE VÄRMÄLÄ GRANODIORITE

Almost the whole of the massif consists of granodiorite, although considerable parts of it have been influenced by granitization. The rock is usually very slightly foliated, with the exception of the border zones, especially in the west. Dark, rounded, biotite-rich inclusions are encountered, most often in the vicinity of the contact.

Large areas in the northern and eastern parts of the stock are very homogeneous showing the following mineral composition and textural features:

The texture is hypidiomorphic and somewhat porphyritic. No parallel texture is visible under the microscope.

Plagioclase forms well-shaped, distinctly zoned crystals. The composition varies between An_{25} and An_{10} (by comparing the refractive indices to those of Canada Balsam and quartz).

Quartz tends to occur as a granulated mass between the other minerals, and as larger accumulations in places.

Microcline is not very abundant and usually occupies an interstitial position as small crystals. Some much larger, xenomorphic grains are observed, and in connection with these replacement of plagioclase is seen. A slight formation of myrmekite can be found in a few cases.

Biotite is often partly chloritized, and appreciable amounts of epidote are met with in association with it, as well as a very few small crystals of hornblende.

The chemical composition of the rock is presented in Table VIII, N:o 17.

The rock in the shore cliffs of Lake Pulasjärvi has been fairly strongly deformed, obviously representing a crush zone. Biotite has been entirely chloritized, and in the interspaces and abundant cracks are considerable amounts of chlorite, calcite, and epidote. The analysis of the rock (Table VIII, N:o 18) shows a slightly more basic composition than that of the main type.

Table VIII. Analyses of the intrusives of the Värmälä and southern massifs.

	17		18		19		20		21	
	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.
SiO_2	70.12	11 675	69.26	11 532	55.76	9 284	67.82	11 292	73.14	12 178
TiO_2	0.33	41	0.39	49	1.00	125	0.43	54	0.15	19
Al_2O_3	14.95	1 467	14.24	1 397	17.91	1 757	16.21	1 590	13.89	1 363
Fe_2O_3	0.70	44	0.56	35	1.73	108	0.91	57	0.88	55
FeO	2.23	310	2.66	370	7.04	980	2.87	400	1.22	170
MnO	0.07	10	0.02	3	0.12	17	0.05	7	0.02	3
MgO	0.90	223	1.23	305	1.91	474	1.08	268	0.52	129
CaO	2.29	408	2.28	407	7.08	1 262	1.76	314	1.36	243
Na_2O	3.81	615	4.16	671	2.66	429	2.90	468	3.35	540
K_2O	3.17	337	2.90	308	1.75	186	5.06	537	4.99	530
P_2O_5	0.07	5	0.19	13	0.18	13	0.19	13	0.07	5
H_2O+	1.58		1.66		2.18		0.64		0.53	
H_2O-	0.13		0.12		0.16		0.16		0.09	
	100.35		99.67		99.48		100.08		100.21	
Niggli numbers										
si		338		327		174		305		394
ti		1.2		1.4		2.3		1.5		0.6
al		42.4		39.6		33.0		43.0		44.1
fm		18.3		21.2		31.7		21.3		13.3
c		11.8		11.5		23.7		8.5		7.9
alk		27.5		27.7		11.6		27.2		34.7
k		0.35		0.31		0.30		0.53		0.50
mg		0.35		0.41		0.28		0.34		0.31
c/fm		0.65		0.54		0.75		0.40		0.59
Mineral composition										
Plagioclase	An_{25-10}	52.5	An_{14-20}	43.9	An_{35-40}	47.2	An_{25}	29.7	An_{20}	26.7
Quartz		24.0		28.5		15.5		33.2		35.0
Microcline		14.3		16.9		—		15.8		28.2
Biotite		8.8		—		12.2		17.1		6.3
Hornblende		—		—		21.6		—		—
Muscovite		—		—		—		3.6		3.0
Chlorite		—		9.7		1.8		—		0.7
Accessories		0.4		1.0		1.7		0.6		0.1
		100.0		100.0		100.0		100.0		100.0

17. Granodiorite. E. end of Lake Sisällyspohja, Teisko. Analyst M. Mäntynen.
18. Granodiorite. E. shore of Lake Pulasjärvi, Teisko. Analyst V. Leppänen. (P_2O_5 has been determined by M. Mäntynen.)
19. Diorite. 2 km. N. of the south-eastern end of Lake Pulasjärvi, Teisko. Analyst M. Mäntynen.
20. Porphyritic granite. 2.2 km. E. of the southern end of Lake Kutemajärvi, Orivesi. Analyst M. Mäntynen.
21. Granite. S. of Lake Peurnajärvi, at the boundary between the parishes of Kangasala and Aitolahti. Analyst J. Seitsaari.

The chemical composition of the Värmälä granodiorite is almost similar to those of two granodiorites in the Aulanko area (Simonen 1948, N:os 7 and 11 in Table II, pp. 22—25). N:o 11 of Simonen represents a gneissose variety of the »Aulanko granodiorite» which is a similar roundish and for the most part very slightly foliated massif. Neuvonen describes a granite greatly resembling the Värmälä granodiorite in his unpublished study (1946) of the area immediately W. of Lake Näsijärvi. The composition of this rock differs from that of the Värmälä granodiorite only in the considerably higher content of potash, through which it has become granitic.

Southwestwards the Värmälä massif gradually becomes slightly more basic, as indicated by the increasing amount of hornblende and of anorthite in the plagioclase. The following compositions were determined for the plagioclase in a specimen E. of Lake Iso Lumajärvi: the kernel up to An_{34}; the shell An_{20-24}. The increasing basicity, however, has been largely eliminated by granitization which increases westwards. Local granitization is also observed in the immediate vicinity of the contact N. W. of Lake Pulasjärvi, where crushing of the rock has afforded opportunities for it, but in the western part of the massif it is quite general. More and more abundant porphyroblasts of microcline appear, and an increasing replacement of plagioclase has been caused by the increase of potash. The granitization seems to be in connection with a more distinct foliation of the rock. In the western border area there is true microcline granite. The altered rock sometimes contains appreciable amounts of allanite. The allanite crystals mostly display a metamictic decomposition.

At the boundaries, especially in the S. W. and S., a reddish aplitic variety is frequently met with, often forming a zone more than 100 m. in breadth and sometimes grading into pegmatite. Farther from the contact the aplite seems to pass over into the granitized main rock.

Subordinate, fairly fine-grained and more distinctly porphyritic marginal modifications are encountered in the southwestern border of the massif. S. E. of Lake Iso Lumajärvi such a rock forms a small lens situated between gabbro and phyllite. It does not differ very greatly from the granitized main type of this part of the massif, excepting in grain size and a few definite phenocrysts of plagioclase. The other occurrences are veins in »leptitic phyllite», or in fine-grained »arkose gneiss», fragments of which are encountered in the veins, and gradual transition into the wall-rock is sometimes in evidence. Plagioclase phenocrysts (An_{20}), several mm. in length and showing no zonal texture, lie in a fine-grained (0.10—0.15 mm.), granoblastic ground-mass. Only thin »impregnations» of microcline are observed, whereas muscovite is present in abundance. Granophyric intergrowth of plagioclase and quartz is sometimes seen, and tourmaline is met as an accessory constituent. The mineral composition greatly resembles that of the bordering »arkose gneiss», and, on the other hand, many of the textural features are similar to those of the soda-rich marginal variety of the northern massif.

On its northeastern side the roundish stock of the Värmälä granodiorite penetrates the country rock transverse to the bedding and schistosity. There are no apophyses and no schist xenoliths. Other boundaries are rather concordant, and the occurrence of xenoliths and even large apophyses is especially common in the southwestern corner. Noticeable contact influence was only ascertained in the phyllite S. E. and S. of the massif, where sericitized pseudomorphs (probably after andalusite) are found, occasionally more than 100 m. away from the contact.

DIORITE AND GABBRO

The largest mass of basic igneous rocks is situated immediately south of the Värmälä granodiorite, between this and the schists. The occurrence forms an elongated lens, 2.5—3 km. in length and about 600 m. in breadth.

The gradual basification of the granodiorite in its southwestern part does not directly lead to these more basic rocks. When visible, the boundary between the granodiorite and the gabbro and diorite is distinct, and the latter rocks are often penetrated by veins of granodiorite. The southern and western parts of the lens are the most basic, though irregular variations in composition are also observed. In general, the rock is fine-grained, mostly somewhat porphyritic with hornblende phenocrysts, and heterogeneous in structure to some degree. The southern part especially is very strongly foliated. »Typical» gabbro or diorite are rather rare.

The best-developed gabbro is rather ophitic in texture.

Hornblende is pale greyish green and most often polysynthetically twinned according to the augite law. The extinction angle $\gamma \wedge c$ is $17° \pm 2°$, and $\alpha' = 1.654$, $\gamma' = 1.673$.

Plagioclase is idiomorphic and distinctly twinned. The composition is about An_{50} ($\alpha' \geq \varepsilon$ of quartz, and the max. ext. angle = 28°).

Oxidic ore is abundant, and most of the biotite of the rock has crystallized around the ore grains.

Some quartz occurs in the interspaces of other minerals, and apatite is present in considerable amounts.

East of Lake Pulasjärvi is another lens-shaped occurrence, about 1 km. in length, and consisting of diorite. The rock is fairly homogeneous, excepting certain zones parallel to the foliation, in which a strong deformation, perhaps, has produced heterogeneity.

The plagioclase crystals are idiomorphic in relation to the dark minerals, usually weakly zoned, and largely sericitized and epidotized. The composition varies between An_{35} and An_{40} approximately.

Hornblende is often rather brown-coloured. The kernels of certain grains have recrystallized into a mass of small, lath-shaped crystals, and contain some prehnite. In a few cases lighter-coloured kernels are observed.

Biotite is partly chloritized. In association with it are grains of titaniferous iron ore with leucoxene rims, and sagenite needles.

Considerable quantities of quartz occur between the other constituents, and apatite and a little garnet are accessory.

The chemical analysis of the rock is presented in Table VIII, N:o 19. The composition is similar to that of the peleeitic magma type according to Niggli (1923), though *k* is too high and *mg* too low. In comparison with the rocks of the northern massif, this diorite is somewhat related to the cummingtonite-bearing gabbro-diorite (Table V, N:o 10).

In the western part of the parish of Aitolahti there are some very small basic bosses (some tens of metres in diameter as a rule), the farthest of which is situated about 4 km. S. W. of the Värmälä massif.

Certain phenomena at the boundaries of the above-described rocks suggest that they might have originated in part through the mobilization of the materials of their wall-rocks. Their mode of occurrence in association with and as continuations of intermediate and basic schist beds also supports such an idea. In the only locality where a contact between the diorite E. of Lake Pulasjärvi and its walls is seen, a basic plagioclase-porphyritic schist passes quite gradually into diorite. Amphibolite occurring close to granodiorite W. of Lake Pulasjärvi is also found to pass into rock similar to diorite or gabbro, whilst further transition into granodiorite is not observed. In the southern marginal part of the basic lens S. of the Värmälä granodiorite the rock resembles schist in appearance, and among others banded structure can be seen. It seems rather probable that the ultrametamorphic processes discussed in the last chapter of the previous division (pp. 70—77) have also been acting here, but the homogenization of rocks is still less complete and the similarity to true »igneous» rocks is often slight. As regards the small basic stocks S. W. of the main massif, they do not show any genetical relation to their argillaceous or arenaceous wall-rocks, and usually penetrate the latter quite transversely. They are no doubt real intrusives.

THE SOUTHERN MASSIF

GRANITES

South of the schist complex *porphyritic granite* is by far the most widely distributed rock and extends from Lake Pappilanselkä to the northwestern border of the parish of Kangasala. In addition, in the southern part of Aitolahti, between the areas of mica schist and veined gneiss, there is another occurrence of similar granite forming a narrow lens, about 7 km. in length.

The chemical and mineralogical composition of this granite is presented in Table VIII, N:o 20. They are not in close agreement with those of a typical granite. The high excess of alumina is especially conspicuous and the content of silica is comparatively low. On the basis of the great amount of potash, the relative quantities of alkalies, and $fm/alk < 1$, the rock is to be linked to the granites. Neuvonen, in his unpublished investigation (1946), has described a fairly similar but granodioritic rock occurring as a roundish massif within the schist complex N. W. of

Tampere. Its main components are as follows: SiO_2 62.57, Al_2O_3 16.18, Fe_2O_3 0.81, FeO 5.65, MgO 2.15, CaO 3.50, Na_2O 3.06, and K_2O 3.23. Of these two rocks the granitic one is closely related to an »impure» granite presented by Erdmannsdörffer (1948, p. 239). Erdmannsdörffer holds that sedimentary material has partaken in the formation of such a granite.

The rock is fairly coarse-grained. The size of the feldspar phenocrysts varies from 1 × 2 cm. to 2 × 4 cm. approximately. The foliation is weakly developed, but mechanical deformation is common near the boundaries.

The plagioclase crystals, the smaller ones as well as the phenocrysts, are rather idiomorphic and weakly zoned as a rule. The composition varies in different specimens from An_{20} to An_{28} (by comparing the refraction to that of Canada Balsam and quartz).

Abundant quartz tends to occur as accumulations.

Large crystals of microcline sometimes enclose plagioclase and well-developed myrmekite is frequently observed in association with it. However, a myrmekite rim is found around certain larger plagioclase crystals, in which microcline is almost lacking.

Biotite occurs as large flakes containing zircon inclusions in appreciable amounts. Some muscovite is associated with biotite.

Apatite is comparatively abundant.

In the granite lens of Aitolahti the feldspar phenocrysts are fairly small (7—20 mm. in length). The rock is often like augengneiss, or quartz and microcline form stripes parallel to the foliation, owing to the strong deformation of the rock.

The contact against the schist is mostly simple and undisturbed. Taken as a whole, the granite cuts the country rock more or less across the strata, but more conformable relations are seen on a small scale. In certain cases veined gneiss has been formed, whilst transverse apophyses are seldom observed. Xenoliths of the wall-rock are rather uncommon, except in the neighbourhood of Lakes Matalajärvi (in Northern Kangasala) and Pappilanselkä.

The porphyritic granite is not always in immediate contact with the schist, however, but between these is often a more or less aplitic variety of granite. On both sides of Lake Kutemajärvi such a rock forms a zone 4 km. in length and in places 1 km. in breadth. The transition from the porphyritic granite is gradual and begins with an increase of muscovite and microcline, and the porphyritic texture soon disappears. In this stage, biotite still remains as large, interspersed flakes. The composition of the plagioclase varies between An_{12} and An_{22}. When proceeding towards the schist, biotite entirely disappears and the grain size diminishes. Rather thick perthite is sometimes observed in microcline, but myrmekite, common in the transitional form, is rare. The anorthite percentage of the plagioclase has further decreased (An_{12-15}). Near the schist contact the aplite contains abundant pegmatitic parts often comprising more than half the rock. Tourmaline and almandite are found in both aplite and pegmatite, the quartz-rich portions of which, moreover, occasionally contain arsenopyrite.

Certain xenoliths of mica schist in the porphyritic granite are surrounded by an aureole of aplite-pegmatite.

The transition is not always as regular as described above, but patches of the porphyritic granite are encountered within the even-grained, muscovite-bearing granite. In a few cases such portions have rather sharp boundaries, and certain small patches are surrounded by a weak rim of biotite.

Pegmatite-aplite has most often intruded into the schist as conformable veins and lenses, occasionally some hundreds of metres in length. Certain aplite lenses are parallel to the secondary flow cleavage, while some others form irregular stocks. The contacts are quite sharp as a rule. East of Lake Paalijärvi the porphyritic granite in a hill has been jointed parallel to the surface, the joints being filled by pegmatite which thus forms approximately horizontal veins, 10—15 cm. in thickness. At the contacts is a rim of muscovite which also extends into the porphyritic granite for some distance.

The pegmatites, containing tourmaline and arsenopyrite, are so-called complex pegmatites (in the sense of Landes). The gradual transition between the granite types suggests that the porphyritic granite has been soaked by liquids rich in potash and silica and thereby changed towards aplite. The occurrence of abundant myrmekite in the transitional zone may afford further evidence of such a development, if myrmekite is assumed to be the result of a replacement of plagioclase by microcline (see later p. 93). Thus the same materials which have finally crystallized as pegmatite may have effected the changes in the porphyritic granite. The pegmatite is probably closely related to the granite.

Somewhat different granites are encountered in the eastern part of Aitolahti, as well as in places in the isolated granite lens of this parish. They are fairly fine-grained, the grain size of the ground-mass being about 0.5 mm. and the feldspar phenocrysts measuring only 3—5 mm. In comparison with the coarse porphyritic granite, microcline has considerably increased, while biotite has decreased. A specimen taken near the boundary between Aitolahti and Kangasala was analyzed (Table VIII, N:o 21). In this rock the composition of the plagioclase is about An_{20}, the microcline is somewhat perthitic, and myrmekite is common. In the corresponding rock in Southwestern Aitolahti the plagioclase is poorer in anorthite (An_{12-14}), and perthite as well as myrmekite is almost lacking. Here a transition into coarser-grained porphyritic granite can be seen, and the composition of the analyzed rock also shows a certain relationship to that of the porphyritic granite proper, representing a more acid derivative of it. Thus these granites are probably varieties of the porphyritic granite, but owing to their typical granitic composition, the designation of microcline granite is used on the map.

In places, this rock is penetrated by veins of tourmaline-rich, almandite-bearing aplite with diffuse boundaries. In contact with mica schist the granite forms sharp veins parallel to the foliation.

OTHER INTRUSIVES

Near the contact of the porphyritic granite, or the associated aplite and pegmatite, there are some occurrences of granodiorite within the schist. They are lens-shaped with the longitudinal direction parallel to the general strike, and usually very small, excepting the largest one situated 2 km. W. of Lake Pappilanselkä in Orivesi. This massif is more than 1 km. long and isolated from the granite by a narrow belt of schist, in places only 10 m. broad but never absent. The borders of the lens are often considerably foliated, but for the most part the rock hardly shows any parallel arrangement. According to a determination on the integration stage, the mineral composition is as follows:

Plagioclase	50.6
Quartz	23.4
Microcline	12.4
Biotite	12.4
Chlorite	1.1
Apatite	0.1
	100.0

This composition shows a distinct similarity to that of the Värmälä granodiorite (Table VIII, N:o 17). A difference appears in the composition and properties of plagioclase. It forms very well-shaped crystals with an extremely well-developed zonal texture. In the extreme case, the determination in a section parallel to 010 gave the following results: the kernel, $\alpha \wedge 001 = -17^\circ$ (An_{50-51}); the shell, $\alpha \wedge 001 = +10^\circ$ (An_{16-17}).

Apophyses from the massif are quite uncommon. Xenoliths are encountered, but seldom in abundance. In certain cases they have been largely assimilated. Near the boundaries the rock is richer in biotite and sometimes tends towards biotite-quartz diorite. Westwards, the grain size diminishes, and in the westernmost corner of the massif the rock is rather a biotite-rich, fine-grained diorite.

A similar transition into diorite is seen in a small lens E. of Lake Paalijärvi. In addition, there are several vein-like occurrences of a rock dioritic or gabbro-dioritic in composition, usually in the immediate vicinity of the aplitic granite. These formations are parallel to the schist layers and 5—10 m. in breadth. The rocks are characterized by abundant pale-coloured hornblende, rather idiomorphic and distinctly zoned plagioclase, and a very weakly developed foliation. They often contain irregular patches of schistose rock, and are sometimes banded with more and less basic stripes. Gradual transition into the adjacent schist is also observed. Since some hornblende-rich beds are found in the schists in the same tract, the above-treated formations rather suggest thoroughly recrystallized portions of the supracrustal rocks.

THE VEINED GNEISS IN SOUTHERN AITOLAHTI

The southernmost part of the area investigated, in Aitolahti, consists of veined gneiss, extending beyond the limit of the area. Gradation from the neighbouring mica schist is clearly observed. The layering of the original schist has still remained in the transitional zone, but farther south, all the primary features soon disappear and a heterogeneous mica gneiss results. The alternate darker and lighter stripes are often highly contorted and the rock has obviously been in a very plastic state.

The veins, tiny stripes in a better-preserved mica gneiss as well as larger veins in the veined gneiss proper, are of two different types. One of the two types is fairly rich in plagioclase and quartz, with microcline in various amounts and some biotite as other constituents. The plagioclase (An_{24-26}) may sometimes be quite predominant. The other type mainly consists of quartz. The latter are distinctly sharper and may irregularly penetrate the former, though both are mostly parallel. The quartzose veins contain apatite and tourmaline, the apatite occurring even as large accumulations in certain stripes of quartz (Fig. 37).

In places the veins have been enlarged into patches and lenses, sometimes 20—25 m. broad, and often showing very indistinct boundaries against the wall-rock. They are rather granodioritic in composition and consist of plagioclase (An_{26-30}), quartz, mica, and microcline. Plagioclase is usually more or less idiomorphic. The borders of the patches are weakly porphyritic with small, interspersed plagioclase phenocrysts, and considerably foliated, and contain largely assimilated remnants of schist. These xenoliths are muscovite-bear-

Fig. 37. Apatite accumulations in a fragmentary quartz vein in the veined gneiss. N. of the Aitolahti Gulf, Aitolahti. Nic. ‖, magn. 20 ×.

ing, whereas this mineral is absent in the adjacent granodiorite. The centre is even-grained and slightly foliated. It is richer in quartz and also contains muscovite, even in predominance over biotite; although microcline is rather sparse and does not form larger crystals, abundant myrmekite is associated with it. Tourmaline and apatite are entirely lacking.

Dikes of pegmatite and microcline granite are common in the zones of stronger mechanical deformation.

The general features of the formation concerned are similar to those of the veined gneiss north of Lake Paarlahti. The predominant calcic oligoclase in general, as well as the abundant mica in the granodioritic patches, must involve a rather high content of alumina, and especially in the granodiorite richer in muscovite a fair excess of alumina must also exist. Both the mode of occurrence and the composition of the veins are thus suggestive of venites segregated from an argillaceous parent rock. As to the mobilization of Al, the author wishes to refer, again, to Wager's, Erdmannsdörffer's and Karpoff's observations of this subject (see p. 76). According to Wager (1938 a, p. 31), the apatite often abundant in the »ectects» may be due to a migration of P and F from the parent rock. Such an explanation seems valid also in this case.

Inasmuch as the ancestry of the highly metamorphosed veined gneiss is not recognizable, it is difficult to decide whether there has also been an introduction of material. Na and Ca, perhaps, are required to build up the granodioritic bosses.

ON THE AGE RELATIONS OF THE INTRUSIVES

Sederholm (1897, 1913, 1932) divided the intrusives of the Tampere region into two age groups, and regarded the southern porphyritic granites and granodiorites as older, and both the northern and Värmälä massif as younger. He even considered the porphyritic granite to be the basement rock for the schist formation. Later, however, this idea was abandoned (Mäkinen 1915; see p. 8), and it seems to the present writer that Sederholm's classification should also be corrected in other respects. Some data for estimation will be repeated in the following.

Considering the intrusive rocks of the area from the intrusion-tectonical point of view (a point discussed by Saksela 1936 and Wahl 1936), we find them to represent two different types in their relations to the country rocks. The northern contact zone is fairly complicated for the greater part, and peculiar migmatites with contamination phenomena are common. Especially N. of Lake Paarlahti the rocks seem to have been in a rather plastic state, as all the components conform to one another, and a parallel structure is usually apparent. On the other hand, the Värmälä granodiorite and the southern granite often transversely penetrate the schists, with the exception of the small-scale features, and notable contact aureoles of intermixed rocks have not in general been formed; the foliation is weak. These features suggest that the northern intrusives have originated at greater depth, and hence they must be older in age. The author does not wish to dispute the character of the Central granite as »younger granite», but he wishes to point out that the primary infracrustal rock which has bordered the deep-seated schists has been something other than this microcline granite. Among others, Wahl (op. cit.) has paid attention to the occurrence of even large portions of older rocks, both infracrustal and supracrustal, within the huge Central massif, and later this has been frequently noted by several investigators.

Wahl (op. cit.) believed that the material of the Central granite has been squeezed out from the primary zone of migmatization of the Svecofennian mountain chain. Magnusson (1937, p. 546) considers the migmatite zones with the rising granitic masses to be huge reservoirs of magmas, even for those of the synkinematic group, as well as the scene of a large-scale transportation of materials. This view is, in fact, not so far from the ideas of Kennedy and Anderson (1938), and Drescher-Kaden (1936). See »Discussion», p. 70. Concerning the area treated, we may presume that most of the rocks on the northern side, complicated and largely contaminated, belong to a deep migmatite zone, whereas the other stocks, more discordant (»more intrusive») in character, represent a higher level situated over their respective migmatites. Microcline granites may have been introduced into even higher horizons of the crust, but probably represent the latest phase in the same continuous development, and being exposed at the present surface are of course the youngest infracrustal rocks. Hence there would be no essential »hiatus» between the different stages of processes, as is also set forth by Wahl (op. cit., p. 496).

The mutual relations of the Värmälä and southern massif are uncertain. The small occurrences of granodiorite near the southern granite contact (p. 84) seem to be closely related to the Värmälä granodiorite, but even they do not come into contact with the porphyritic granite. It is peculiar that W. of Lake Näsijärvi there is a similar, very narrow but uninterrupted belt of schist between the corresponding rocks (Neuvonen 1946). Some xenoliths of granodiorite are found in the aplite-pegmatite generally occurring at the boundary of the porphyritic granite, but this may be of no importance, because the aplite is, in any case, also younger than the porphyritic granite.

The porphyritic granite does not seem to be related to the veined gneiss in S. Aitolahti, probably excepting the »Aitolahti lens» which shows certain transitions into the granodioritic and other rocks forming venites.

DIKE ROCKS

METAMORPHIC DIKES

Some single *greenstone dikes* are encountered here and there in the northern part of the schist complex. Their breadth varies from a few centimetres to 1.5 m., and they trend either quite parallel to the general strike or at a small angle to it. The dikes consist of well-foliated amphibolite, excepting two or three W. of Lake Iso Teerijärvi in Orivesi, which are even more basic consisting mainly of hornblende with minor plagioclase and accessories. Hornblende forms rather shapeless crystals, but plagioclase occasionally displays the form of indistinct laths. These are largely saussuritized and have often recrystallized into a fine-grained aggregate, and the composition cannot be determined. It is probable that these dikes are connected with the formation of the supracrustal deposits.

An amphibolitic dike S. of Lake Hankajärvi shows an exceptional trend by cutting the strike nearly at right angles. Yet its foliation is parallel to the general strike. Its mode of occurrence is similar to that of the numerous greenstone dikes in the coastal region of Southern Finland.

An *acid dike* is situated 0.5 km. S. E. of Lake Peräjärvi, near the western boundary of Orivesi. The dike is 30—50 cm. broad and quite straight forming an angle of about 5° to the general strike. Its visible end is sharp with a somewhat convex boundary. The dike can be followed for about 100 m. It has been interrupted by several faults, as well as opened fractures filled by quartz.

The rock consists of quartz, alkali feldspar, muscovite, and a little oxidic iron ore. The texture is granoblastic and a foliation can be seen. The grain size is 0.015—0.020 mm. A few small phenocrysts of quartz and plagioclase are observed. Certain irregular grains of quartz near one another seem to have similarly oriented themselves in many places, and are, perhaps, relics of a micrographic or »skeleton» texture.

Both feldspars are present, but the relative amounts cannot be decided. The plagioclase is albite, An_{5-10} ($\gamma' \lesseqgtr$ N of Canada Balsam, and the max. ext. angle about 12—13°).

The amount of muscovite varies in different zones parallel to the foliation.

OLIVINE DIABASE

In Orivesi, immediately W. of Lake Pappilanselkä, there is a rather broad, fragmentary dike of quite non-metamorphosed olivine diabase. Its broadest parts are 15—20 m. in breadth. The dike usually cuts the schist beds, and can be followed for about 2.5 km.

The texture is distinctly ophitic, and the most idiomorphic constituent is plagioclase, followed by olivine and titaniferous augite.

The plagioclase laths are up to 4 mm. in length and sometimes slightly saussuritized. The maximum extinction angle in the symmetrical zone is 35°, so the composition is An_{62}.

Olivine is only slightly serpentinized and augite is quite unaltered.

Ore, probably ilmenite, and apatite as long needles are fairly abundant. The ore grains are often surrounded by biotite as a reaction product of the latest potash-rich pore liquids. Some individual flakes of biotite are also observed.

The centre of the dike is somewhat coarser than the borders and shows a reddish tint. Some potash feldspar is found there as very small xenomorphic grains in the interspaces of the plagioclase laths, as well as within them in some cases.

On the shore of Lake Pappilanselkä the dike is never more than 3 m. in breadth and ends with narrow »tails». Minor dikes are encountered on both sides of the main one. Here the dikes are approximately parallel to the strike of the country rock, and the greatest one bends the schist layers in accordance with its own trend. The rock is very fine-grained, probably even glassy in part, and porphyritic. In the ground-mass can be seen tiny plagioclase laths and a few grains probably of olivine. Pigmental iron ore is abundant. Very large (up to 5 cm. in diameter), nearly square-shaped phenocrysts of transparent plagioclase (An_{56-59}) are interspersed here and there, certain phenocrysts being somewhat corroded.

The main type of this rock is entirely similar to the Jotnian olivine diabase in Satakunta, about 100 km. W. of Tampere, and the dike concerned is no doubt of the same age.

METASOMATISM

GRANITIZATION

The widespread occurrence of granitization in the area is conspicuous, especially on the northern side which has hardly anywhere been completely preserved from it. The final »ideal granite», however, has seldom been achieved.

The advance of the granitization process can be well followed in the widely distributed granodioritic and related rocks. The first sign is a reddish colour occurring as interspersed spots, or sometimes a thin tissue of red stripes. This colouring becomes more and more general, and porphyroblasts of microcline begin to appear, sometimes at a rather early stage in the rocks comparatively poor in potash. The porphyroblasts increase in number and grow larger, being finally up to 2—3 cm. in diameter. They are usually unevenly distributed, and patches of the original rock are seen here and there.

In other instances the granitization is hardly visible, and is only indicated by a greyish pink colour and decreasing amount of the dark constituents, though microcline is already present in remarkable quantities. Where porphyroblasts are observed, we already have a microcline granite proper.

The formation of microcline (or orthoclase) »augen» at granite contacts and in granitized rocks has frequently been noted and discussed in literature. Some recent works may be mentioned: Wegmann 1938; Cheng 1944, p. 143; Read 1944, p. 74 and 1948 a, p. 12 (both with numerous further references); Barth 1947; Erdmannsdörffer 1948, p. 235; Edelman 1949. Erdmannsdörffer appears mainly to emphasize an immediate influence of granite magma on loosened xenoliths in it or on its walls, whereas in the Tampere area this is certainly not the case. Wegmann, Barth, and Edelman suggest that brecciation or other crushing may have advanced the formation of porphyroblasts. Although the present author has found the porphyroblasts to be somewhat commoner where the rock is deformed, such an explanation does not seem to be generally applicable. The augen of potash feldspar are more probably an ordinary stage in the evolution towards a metasomatic granite (cf. Read, l. c.).

Granite derived from an earlier intrusive rock often contains basic xenoliths primarily enclosed by this. Only occasionally have the xenoliths been considerably granitized and in that case carry microcline porphyroblasts but, in general, no further change has taken place. However, in certain cases, probably due to a high concentration of the agents of granitization (cf. later p. 93), the schist has been changed rather directly into granite and is thoroughly soaked by these materials, resulting in a vein-like body. The primary foliation is seen to the last, showing that there is no true vein in question.

In the microscopical study, the following features may be observed in connection with typical granitization:

(1) Microcline forms porphyroblasts, some millimetres in diameter. The porphyroblasts mostly contain thin perthite, sometimes rather well-developed. Towards the borders of the crystals the perthite decreases and finally dies out as a rule. Two porphyroblasts developed near each other seem to have united themselves into one single crystal in certain cases.

(2) Plagioclase has mostly been corroded by the younger microcline, or entirely enclosed by it. In the latter case isolated grains of the original plagioclase are seen within a microcline porphyroblast, and the grains show a simultaneous extinction indicating that they have been inherited from one single crystal (Fig. 38). One may infer from this that, for instance, a poikilitic texture is unlikely. The borders of the inclusions are often more albitic than the inner part, but no primary zonal texture can be in question, since quite shapeless grains also have such a shell (Fig. 39). When plagioclase is only in partial contact with microcline, indistinct stripes of albitic plagioclase may be found to intrude from the contact inwards into the plagioclase crystal.

Fig. 38. Remnants of one plagioclase crystal within a porphyroblast of microcline. Microcline granite N. of Lake Paarlahti, Teisko. Nic.+, magn. 20 ×.

Fig. 39. Shapeless grain of plagioclase with an albitic rim, enclosed by microcline. Microcline granite N. of Lake Paarlahti, Teisko. Nic.+, magn. 40 ×.

(3) Myrmekitic plagioclase is in close association with the microcline porphyroblasts which are sometimes completely surrounded by a myrmekite rim. The formation of rims usually increases with the growth of porphyroblasts. The plagioclase grains entirely enclosed by microcline, however, have rather seldom been largely myrmekitized. In the initial stage of the process the well-known, vermicular inclusions of quartz appear at the border of a plagioclase crystal, and later this border has been granulated into several, small myrmekite grains. From the refraction it may be deduced in some cases that the myrmekitized plagioclase is somewhat richer in anorthite than the unchanged plagioclase. In other cases, between large porphyroblasts which build the greater part of the rock only narrow rims of granulated mass, sometimes with biotite, are found. The myrmekitic texture is in that case often very fine, even difficult to see under the microscope. It was observed that such a »rim» may have been introduced into a microcline porphyroblast (Fig. 40). This type of myrmekite is rather analogous to the »postmicroclinic myrmekite» of Drescher-Kaden (1948, p. 80) or the »intergranular symplectite» of Erdmannsdörffer (1949, pp. 6—9).

(4) Plagioclase is rarely altered very strongly. The degree of alteration, of course, depends upon the primary composition and, where this has been rather basic, the granitization means a greater change and alteration products are more abundant. The myrmekitic plagioclase also can be largely sericitized.

(5) The composition of the plagioclase also depends upon the origin of the granitized rock, as well as the degree of granitization. In the rocks studied (originally varying from granodiorite to gabbro) the composition does not vary very greatly and is usually between An_{16} and An_{26}.

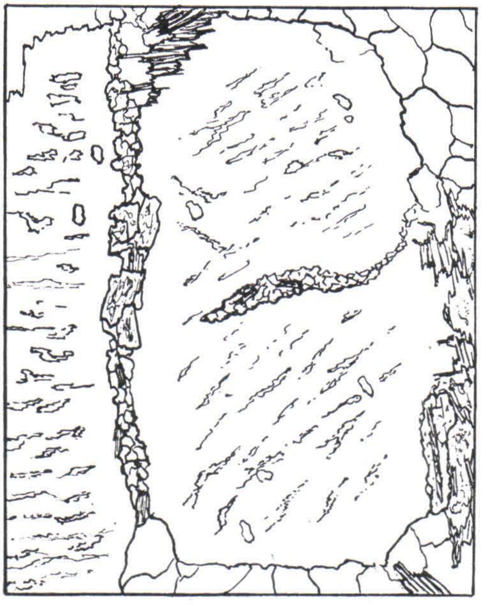

Fig. 40. Crack infilling of fine-grained myrmekite and biotite in microcline. Microcline granite in the western part of the Värmälä massif, Teisko. Magn. 16 ×.

(6) Some hornblende is often preserved. It is mostly very dark-coloured and turbid. Considerable amounts of epidote and sphene are sometimes observed in association with the dark minerals. The sphene might have originated from the titanium originally contained in hornblende and biotite, and leached away at lower temperatures. This alteration chiefly belongs to a later stage, however. In certain rocks allanite is encountered as kernels of the epidote, as well as independent grains. Very small spots of fluorite are incidentally met with as inclusions in plagioclase.

A typical product of advanced granitization of granodiorite was analyzed (Table V, N:o 16). Such a rock is fairly common N. of Lake Paarlahti.

The rocks concerned may have been rather strongly foliated, but in the very shear zones the granitization process is of somewhat different character. In these rocks biotite has been considerably chloritized and occurs as long streaks associated with some muscovite. Quartz and microcline form stripes between the biotite-chlorite streaks parallel to the foliation (Fig. 41). These features indicate that a strong movement has taken place along closely-spaced shear planes, and the granitizing fluids appear to have utilized these planes as channels (cf. Wegmann 1931, p. 62, and Cheng 1944, p. 145). Microcline often forms porphyroblasts in this case also, but the formation of myrmekite is rather slight or lacking. The composition of the plagioclase is usually An_5—An_{15}, and it has been very strongly saussuritized. Some epidote is seen throughout the rock and calcite is also met. The mineral composition indicates an alteration under the conditions of the epidote-amphibolite facies, or even the greenschist facies. The author has called these rocks »microcline gneiss». The soda granite at Lake Pukalanselkä has often been altered in such a way.

More or less diffuse veins of granitic material are observed in many rocks, and in certain intermediate and acid intrusives they can be enlarged even into larger areas. These contain very indistinct remainders of the country rocks. The granitic material sometimes appears to have

Fig. 41. »Microcline gneiss». S. shore of Lake Pukalanselkä, Orivesi. The discontinuous white stripes are microcline. Nic. ||, magn. 20 ×.

used the contact between two rocks as a channel, as for instance between granodiorite and a schist xenolith, producing a rim rich in microcline and quartz. In certain cases such portions become quite homogeneous aplitic granite which granitizes the country rocks. These formations might be presumed to represent an »enrichment of ichor». The granite material has also streamed along the veins originally poor in potash, e. g., in veined gneiss, and forms microcline-quartz stripes parallel to the veins or is restricted to the contact between the vein and wall-rock (Fig. 42). All these occurrences carry microcline porphyroblasts, and their plagioclase is corroded and myrmekitized. Also the »most intrusive», sharp veins showing no apparent connection with the creep of granitization are characterized by a strong myrmekitization and corrosion of the plagioclase (Fig. 35, p. 69).

Myrmekite and the replacement of plagioclase. Two fundamentally different explanations of the genesis of myrmekite exist, namely, (1) that myrmekite is produced in con-

Fig. 42. Stripe of microcline and quartz at the contact between a vein of »soda granite» and its wall-rock. S. of Lake Pukalanselkä, Orivesi. Nic. ||, magn. 5 ×.

nection with a replacement of potash feldspar by plagioclase, and (2) that it is built up at the expence of plagioclase in connection with the formation of younger microcline. The first explanation was presented by Becke (1908). It was accepted by Sederholm (1916) and recently, e. g., by Joplin (1942, pp. 188—89) and Cheng (1944, p. 140). The alternative explanation has been especially elaborated by Drescher-Kaden in his detailed works (1940, 1948), and it has also obtained several supporters: Johnson 1947, p. 501; Strand 1949, p. 21; Edelman 1949 and others. Drescher-Kaden, indeed, describes a type of myrmekite which he calls »post-microclinic», but this would be formed by the influence on plagioclase of fluids which originate from re-solution of the pre-existing microcline (1948, p. 80 sqq.). In the »intergranular symplectite» of Erdmannsdörffer (1949, pp. 6—9) the myrmekite would be an independent constituent, formed at the expence of both feldspars as well.

The interpretation of Edmondson Spencer (1945) deviates from all the other explanations. He suggests that exsolution and rearrangement of albite and a hypothetical lime feldspar $Ca(AlSi_3O_8)_2$ formerly held in solid solution in the potash feldspar would produce myrmekitic plagioclase (the lime feldspar $\rightarrow$ anorthite + quartz).

Independent of the myrmekite theories, there are many observations of the replacement of plagioclase by microcline. Thus Cheng (l. c.) admits it (it would happen both before and after the reverse process of myrmekitization!); Erdmannsdörffer's works afford several suggestions of it (1938, p. 21; 1943).

The present author accepts Drescher-Kaden's principle of myrmekitization. The replacement of plagioclase appears to be an obvious fact. It is mostly the largest microcline crystals which are surrounded by the broadest continuous rims of myrmekite. When such microcline crystals are found, e. g., in gabbro, they are certainly secondary. In the plagioclase grains entirely enclosed by microcline the myrmekite texture is not always absent though rare. The author wishes to make reference to Edelman's idea (1949) that the constituents of the decomposed plagioclase migrate *outwards* like a zone around the microcline porphyroblast. Because more Na than Ca can be retained by microcline, an »anorthite-quartz metasomatism» attacks the plagioclase in this zone. In consequence, the plagioclase about to be myrmekitized may be somewhat enriched in anorthite, as observed in some cases. The albitic rims and stripes of the plagioclase in contact with microcline indicate that the constituents of anorthite have been leached away. But myrmekite quartz can be also observed *inside* the rim and is found to occur in the enclosed plagioclase grains in a similar manner. (Unfortunately, such textures were too fine to be photographed.)

An excess of silica must be assumed in the process of myrmekitization, but it is difficult to decide to what degree this is due to an introduction of silica, to a decomposition of silicates and removal of cations, or, perhaps, to primary quartz, and this may depend upon the relative quantities of constituents in every individual case.

As regards the temperature during myrmekitization, the author, contrary to Edelman (op. cit.), holds that it has not in general been very low. In the rocks containing considerable amounts of chlorite, muscovite, epidote, etc., myrmekite is sparse and weak in comparison with that in the products of »normal» granitization, although abundant potash has been introduced.

The supporters of Becke's theory quoted above, in general, hold that the participant feldspars are of one connected origin, e. g., they originate from the same crystallizing magma. By the supporters of Drescher-Kaden myrmekitization is mostly recorded from true potash-metasomatic rocks. On the basis of the present author's observations presented in several connections (p. 68, 83, 93), it may be suggested that the time interval between the consolidation of plagioclase and microcline is not always very long, and thus the length of time may not be essential in the formation of myrmekite.

In a previous chapter the present author quoted Read's saying »there are granites and granites». These two granites were the metasomatic and the intrusive one.

One could list dozens of petrographers who have expressed a similar idea. Nobody may like to dispute the close connection of these different granites with each other, but the opinions on the relative quantitative significance of each granite are by far more divergent, and the origin of granite on the whole is still more controversial. One group of speculators, the magmatists, hold that most of the granites have been formed by crystallization of an intrusive liquid magma. Yet almost all magmatists do admit granitization which is effected by magmatic fluids, though some of them prefer »gneissification» to »granitization». The other group, the transformists etc., believe that most of the granites, if not all, are products of a metasomatic replacement. Furthermore, within the first group there is divergence of opinion as to how the granitic magma came into being. Some magmatists support the differentiation of a basaltic parent magma, contaminated or not (Bowen, Niggli). According to Eskola (1932 b, 1933), both differentiation (by squeezing) and partial re-fusion of older deep-seated rocks (differential anatexis) may produce granitic magmas. The latter way would be of the greatest significance, if not unique, in the large granitic areas of the Archaean. Daly (1933) agrees with Eskola as to the Archaean granites; Grout (1948) supports differential anatexis above all.

Eskola holds that the granitic magmas produced by differential anatexis may rise upwards as pore fluids causing granitization. The idea of such fluids was earlier proposed by Sederholm who called them »ichor» (1926). Both these eminent petrologists, though certainly magmatists, consider granitization to be of great quantitative significance. The primary cause is of course the granite magma. That is what the transformists do not recognize — if there is magma, it is but secondary.

Are the opposing camps as far apart as they would believe themselves to be?

It seems to the present author that the principle of differential anatexis is well acceptable. But what will happen when a part of the earth's crust is sinking downwards during orogeny? A sudden melting-up may be unlikely. It may be supposed that increasing amounts of the most mobile constituents will be gradually made to migrate, the migration increasing with increasing depth. Last, there will be a nearly ubiquitous »cloud» of these constituents migrating upwards within the deep-seated rock mass — i. e., the granitic pore fluids have been realized. Coalescence into magma masses does not seem to be necessary. Yet one may consider these migratory granitizing fluids to be pore m a g m a s; on the other hand, such an explanation may satisfy many of the transformists who have often ignored the source of the agents of granitization. Provided that a liquid transfer is not denied, the two opinions may not be quite incompatible.

The author is thus inclined to agree with the transformists as to the most part of granites being replacement products. As regards the intrusive granites, many of the conformable ones, as well as the dike-like bodies, may represent »enrichments of the ichor» which have crystallized in opened spaces (cf. Wegmann 1931, pp. 58—59). The mobilization of the »wetted» rocks should be also taken into consideration (Wegmann, l. c.). Sosman's interesting observations (1948, p. 116) may further testify to such a mobilization.

As the structures of the granitized rocks can be preserved to the last and as the process of granitization is thus obviously quite gradual and slow, the question of the mechanism of this process has been inseparably connected with the general controversy of granite. Wegmann (1935) introduced the concept of intergranular film as the passage for ichor and as the scene of reaction. A particular group of transformists proceed still further and like to explain all the metasomatism and granitization, etc., as being due to an ion- or atom-disperse phase without any liquid or solution as carrier. Greenly (1903) long ago suggested the idea of solid diffusion; nowadays, several supporters of it can be listed: Perrin and Roubault (1939, 1945, etc.); Bugge (1945); Ramberg (1946); Backlund (1946); Holmes and Reynolds (1947); Barth (1947); Lapadu-Hargues (1945) is inclined to this opinion. Barth (op. cit., p. 181) explains »granites and granites» as follows: the granitic stocks and patches in a granitized terrain are due to the crystallization of a »cloud of ichor» (= ions and atoms) itself, while their adjacent rocks are granitized by such an ichor.

In 1948, Eskola returned to the subject and said definitely: the granitizing pore fluids are equal to granite magma. He pointed out that under the liquidus limit of granitic magma the metasomatism leads to more heterogeneous end products, regionally as well as in the range of composition. — Also in the Tampere area other kinds of potash metasomatism were ascertained, indeed, and they have all taken place under conditions different from those of granitization and evidently at lower temperatures without exception. Some data will be discussed in the following.

POTASH AND ASSOCIATED METASOMATISM IN THE PAARLAHTI—ISO TEERIJÄRVI ZONE

Lake Paarlahti and its continuation eastwards through several small lakes as far as the eastern edge of the area represent a large-scale shear zone in which materials have been mobile and metasomatic changes of several kinds have taken place. Besides the almost uninterrupted main zone there are subordinate ones parallel to it.

Rapid variations in both the nature and degree of metasomatism and the mineral facies are characteristic of the zone. Yet a low-temperature facies is by far the commonest. In all probability the primary rock has mostly been a more or less basic schist. Since an introduction of potash and/or silica always seems to have been connected with the alteration, it is quite possible that some schists situated in the vicinity of this zone and designated as »intermediate» or »acid» on the map, have also been primarily basic, but later changed metasomatically.

On the shores of the eastern part of Lake Paarlahti and farther E. for about 10 km., a metasomatism producing potash feldspar and some muscovite is characteristic. The formation of »microcline gneiss» (p. 92) represents a transitional form between the granitization and this process. These rocks are distinctly finer-grained than the gneiss mentioned. The grain size is about 0.04—0.05 mm. on the average, but very strongly sheared rocks are even finer. The porphyritic texture of the original schists with rather shapeless plagioclase phenocrysts can still be seen.

The main minerals, in the order of their usual relative abundance are quartz, plagioclase, microcline, chlorite (biotite), and muscovite. Calcite is often met with. Close, narrow bands of different compositions are characteristic (Fig. 43).

The darker bands mainly consist of plagioclase and chlorite (biotite), although they are also intermingled with quartz and microcline. Some epidote may be present, but never in great abundance. In the strongly sheared rocks containing

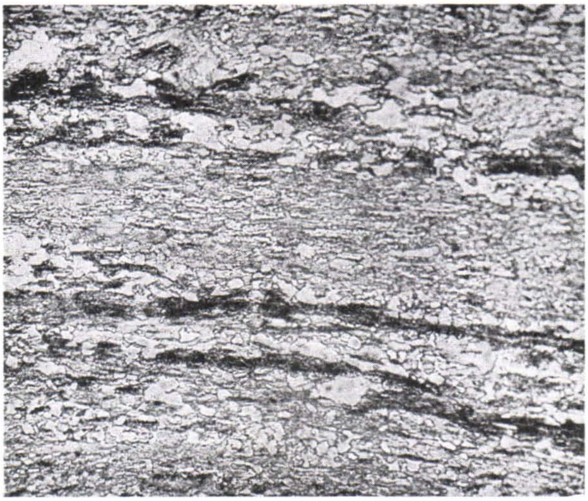

Fig. 43. Fine-grained metasomatic schist with parallel stripes of quartz and microcline (light). E. end of Lake Paarlahti, Teisko. Nic. ||, magn. 40 ×.

larger amounts of muscovite, the biotite is chloritized but otherwise it can be rather well-preserved.

Plagioclase occurs as shapeless, altered grains. Its composition, determined by comparing the refraction to that of Canada Balsam, is An_{5-10}, or occasionally sodic oligoclase. It has often been largely replaced by microcline (on this replacement see further below).

Most of the light stripes are composed of quartz and microcline, sometimes associated with a little calcite and muscovite. Certain stripes consist of quartz and calcite, some others mainly of muscovite, and small lenses of pure quartz are common. The stripes vary in breadth, and a lenticular structure has resulted in certain cases. All these minerals also fill cracks and other pressure minima. In the infillings of these, tiny grains of microcline often occur in the interspaces of the quartz crystals, so that microcline seems to have crystallized last in these cases.

Magnetite grains are sometimes surrounded by a rim of hematite. Sulphides, mainly pyrite, are met with in the rocks richest in quartz, and pyrite was found to follow the quartz stripes. It also can be rimmed by hematite.

Small accumulations of apatite are seen in the quartz-rich rocks.

From the light stripes microcline is distributed into the surroundings and then commonly replaces plagioclase. The best preserved crystals only contain sparse, tiny spots of microcline, but with advanced destruction the plagioclase is soon filled by a complicated impregnation of microcline (Fig. 44). With further replacement the microcline impregnations are united into a few larger, irregular crystals, finally forming one single crystal which contains remainders of plagioclase. The end result is a pseudomorph of microcline after plagioclase, and no further growth of the microcline crystal has taken place. Myrmekite has not been observed.

Fig. 44. Plagioclase partly replaced by microcline. Altered »soda granite» near Lake Iso Teerijärvi, Orivesi. Nic. ||, magn. 40 ×.

In many places there are abundant patches and indefinite veins of epidote. The epidote was found to be associated with microcline, some calcite, and incidentally a little fluorite. The constituents of the epidote may have been inherited from the original rocks and accumulated owing to their mobility which is probably increased by volatiles. These and other materials can also produce so-called helsinkites, as will be described later on.

The relative amounts of microcline and muscovite sometimes vary greatly in a rather limited area, and microcline can be almost lacking. An increase of muscovite (sericite) and quartz and a decrease of feldspars leads gradually to sericite schist.

Sericite schist. In the main zone of metasomatism, sericite schist forms a fairly large, lens-shaped area N. W. of Lake Kutemajärvi in Orivesi. The »soda granite» has also been attacked by sericite-quartz metasomatism.

The sericite schist is an almost white rock with perfect foliation and cleavage.

The mica flakes measure up to 1 mm. in length, so that the mineral may be termed muscovite rather than sericite. The optical properties have not been determined. The amount of quartz is somewhat greater than that of muscovite.

The other constituents are quite subordinate. A few small »augen» of residual feldspar were observed. Rutile is found as small aggregates, often associated with apatite. Sparse grains of clinozoisite are present too. The main occurrence only occasionally contains sulphides, but in the other localities some pyrite is encountered.

Though silica has obviously increased in general, an absolute increase of it may not always be very considerable, as for instance in the alteration of a soda granite. Lime, soda, and especially magnesia have been leached away almost entirely; even the iron oxide has not usually been retained, since only a little or no sulphides have been formed. Thus an increase of sulphur may not be essential in the formation of sericite, but seems to be mostly connected with a larger invasion of silica, as was also set forth by Saksela (1923, 1933). According to Schmedemann (1938), sericitization of certain minerals is advanced in the presence of H_2F_2 as catalyst. The ordinary occurrence of apatite in the sericite schist discussed above also proves that fluorine (and chlorine too, perhaps) has been mobile, though fluorite is not met with.

At the northern border of the sericite schist lens N. W. of Lake Kutemajärvi, in soda granite, appreciable amounts of hornblende as aggregates of small prisms have recrystallized here and there. A little farther N. where various kinds of potash metasomatism have taken place, epidote patches with a centre of hornblende are frequently found, and basic xenoliths in the sericitized and silicified soda granite have been strongly epidotized. These phenomena point to a mobility of the mafic components in connection with the metasomatic processes mentioned.

When the increase of silica has been dominant, *silicified schists* have been produced. They are especially seen in the neighbourhood of Lake Iso Teerijärvi in Orivesi, where the rocks are strongly sheared often showing narrow undulating zones of slickensiding. The alteration of the rocks is not at all homogeneous, however, but the products of metasomatism of many different kinds closely alternate with one another. Less altered schists containing considerable quantities of biotite and plagioclase are always microcline-bearing and approach the rock type described

Fig. 45. Silicified schist with pyrite. Turbid spots are plagioclase. W. of Lake Iso Teerijärvi, Orivesi. Nic. ||, magn. 16 ×.

on pp. 97—99. All the processes considered in this chapter obviously have close relations to each other.

A microphotograph of the silicified schist is seen in Fig. 45. The mineral composition may not be very typical, since plagioclase and some biotite are present.

Fig. 46. A detail of Fig. 45. Pyrite grains with a rim of hematite. Nic. ||, magn. 40 ×.

Plagioclase phenocrysts, even nearly idiomorphic, are present and are usually only slightly sericitized. The anorthite percentage is remarkably high, up to 27. It is possible that these grains have recrystallized. In certain specimens, however, largely saussuritized plagioclase is also observed.

The ground-mass consists almost entirely of fine-grained quartz.

Greenish biotite forms thin streaks and is also distributed in the ground-mass. Chloritization is rather rare.

Abundant pyrite may be present, and also a little chalcopyrite is seen in the zones of the strongest alteration. Pyrite grains are often surrounded by a hematite rim (Fig. 46), and films of hematite may extend farther away from the grains.

Fluorite-filled tiny cracks are sometimes observed.

The most basic rocks have usually escaped alteration, but evidence of a certain mobility of their constituents can be observed. An almost hornblenditic dike (p. 88), obviously older than the introduction of silica, has been preserved among its silicified surroundings, but on both sides of the dike there are considerable amounts of recrystallized hornblende as idiomorphic prisms (Fig. 47). This rim also contains pyrite which encloses hornblende crystals and its therefore younger.

The rocks situated along the borders of the altered zone are fairly heterogeneous containing patches of epidote or hornblende between which there is mainly quartz. Sulphide and hematite are also found in the patches. In one thin section, cavities filled by fluorite were observed in a hornblende patch, and epidote and hematite were associated with this mineral.

Such heterogeneities, as well as the similar phenomena observed in connection with sericitization, have obviously arisen by a mobilization of Ca, Al, Mg, and Fe, which has taken place in advance of metasomatism. A certain kind of »basic front» may result, if greater amounts of mafic constituents are set in motion.

Cross-cutting fractures, often with tiny faults, are common in these formations. The fractures are filled by calcite and epidote, or calcite and potash feldspar, or pure potash feldspar. No younger cracks are observed, except some thin ones filled by hematite. In other fractures approximately parallel to the former ones pyrite has crystallized. On

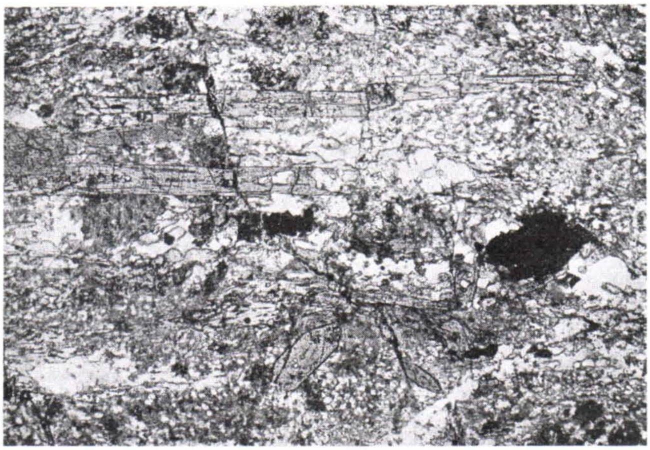

Fig. 47. Idiomorphic prisms of hornblende at the boundary between an ultrabasic dike and its silicified surroundings. Black = pyrite. S.W. shore of Lake Iso Teerijärvi, Orivesi. Nic. ||, magn. 20 ×.

the other hand, abundant pyrite is evenly distributed and disconnected with the pyrite-bearing crack infillings, and in the products of »microcline-quartz-muscovite metasomatism» in the western part of the zone under treatment there are often interspersed grains of pyrite. In these rocks microcline was found to surround idiomorphic crystals of pyrite in some cases.

The features described in the foregoing show that there are two phases in both the ore and microcline formation. The earlier crystallization of pyrite seems to be chiefly connected with the introduction of silica, and the consolidation of microcline forming impregnations and causing replacement of plagioclase may be even earlier, yet continuing over a rather long period of time. The second generations of both, as fissure infillings, may be nearly contemporaneous with each other. One of the latest events is probably the oxidation of pyrite into hematite, and the presence of carbon dioxide may account for this phenomenon. Certain experiments (Dreibrodt 1912) have shown that a far-reaching oxidation of ferrous iron (in biotite) is easily attained by treating this mineral with water containing carbonic acid at only 30° C. A related alteration occurs under low-temperature hydrothermal conditions (Eskola 1949, p. 115). In the silicified schists, as well as in some other rocks metamorphosed at low temperatures, calcite frequently occurs in the youngest cracks, indicating a considerable concentration of CO_2. The occurrence of fluorite as an infilling of cavities and cracks proves that the circulation of fluorine also belongs chiefly to the last stage of the processes.

The formation of sericite (muscovite) is in such a close connection with the microcline impregnation that what is produced probably only depends upon different mechanical factors, i. e., the power of the shear movements. A difference in age may be of minor importance. On the other hand, the typical sulphide-bearing silicified schists contain neither microcline nor muscovite, excepting the young crack infillings. The unaltered biotite and basic oligoclase may prove that the temperature cannot have been very low during the invasion of silica.

ALBITE-EPIDOTE ROCKS

These rocks are encountered mainly around Lake Hankajärvi in Eastern Teisko. They occur in crush zones parallel to the strike, which have been formed in basic, uralite-plagioclase porphyritic or amphibolitic schists. The contacts against the wall-rock are usually sharp and often etched out by weathering. Both rocks sometimes have angular projections into each other, which may indicate a brecciation.

The microscopic data of the usual type are as follows:

Albite, containing at the most 5 % An (by comparing the refraction to that of Canada Balsam), forms a completely recrystallized, clear, granoblastic mass. A slightly undulatory extinction is often observed.

Epidote occurs as elongated accumulations, or long streaks together with chlorite, by which a distinct parallel texture is created. Judging from the high interference colours and sometimes yellow colour and pleochroism, it is fairly rich in pistacite. The crystals may be well-shaped and are usually filled by a turbid-brown pigment, obviously hematite.

Chlorite, in addition, is evenly distributed as small flakes, but not in abundance.

Oxidic iron ore, often hematite, is associated with epidote and chlorite. Films of hematite are sometimes observed. Sphene is commonly present.

The rock is ruptured by numerous cracks, both parallel to the foliation and transverse to it, and filled by epidote. Repeated small faults seem to have taken place in both directions. Coarser-grained albite also fills ruptures parallel to the foliation.

In many places the adjacent basic schist has been bleached, and microscopical study reveals addition of silica and potash producing quartz and microcline. The plagioclase is albitized and replacement by microcline is observed. Dark constituents have decreased greatly and are represented by chlorite, some yellowish epidote, and a little biotite. This alteration is apparently related to the potash-silica metasomatism discussed on pp. 97—99.

Certain occurrences of albite-epidote rock are also encountered in the Paarlahti shear zone, near Lake Paarlahti, where the potash-silica metasomatism is otherwise predominant. Lighter schlieren of albite and microcline, with some epidote, chlorite and quartz, are observed in these occurrences (Fig. 48).

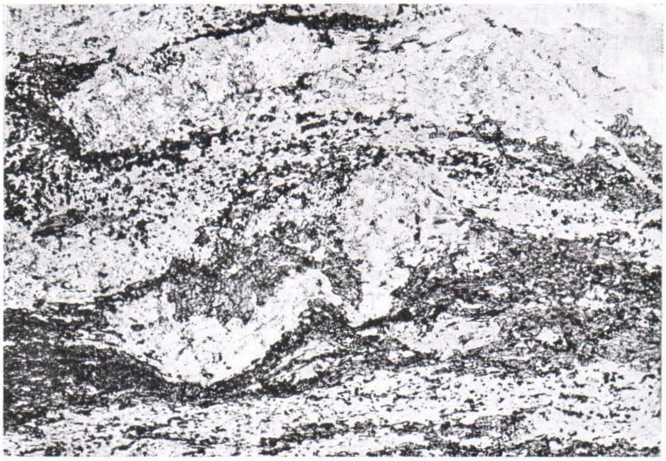

Fig. 48. Feldspathic schlieren in helsinkite. E. end of Lake Paarlahti, Teisko. Nic. ||, magn. 20 ×.

There are other rocks characterized by albite and epidote which differ from the ones described above as to their mode of occurrence. They form rather definite veins, or occur as small indistinct areas in connection with microcline granite. Moreover, microcline is an essential mineral, and the texture is often quite hypidiomorphic. The veins especially, show a micro-breccia structure. A microphotograph of a vein rock in a fairly well-preserved amphibolite between Lakes Hankajärvi and Pukalanselkä is presented in Fig. 49, and its mineral composition, determined by means of the integration stage, in Table IX, N:o 1. The vein is about 3 m. in breadth.

Albite occurs as larger, fairly well-shaped crystals, as well as being the main mineral in the finer mass between the larger grains. It is usually unaltered, and a well-developed twinning of the idiomorphic crystals is not uncommon.

Table IX. Mineral compositions of microcline helsinkites.

	1	2
Albite	40.7	30.9
Microcline	37.8	52.3
Epidote	10.9	5.8
Chlorite	9.2	4.6
Quartz	1.1	6.4
Oxidic iron ore	0.3	—
	100.0	100.0

1. Helsinkite. Between Lakes Pukalanselkä and Hankajärvi, Orivesi.
2. Microcline-rich helsinkite. 1 km. W.S.W. of Lake Savonjärvi, Teisko.

Fig. 49. Brecciated helsinkite. Between Lakes Pukalanselkä and Hankajärvi, Orivesi. Nic.+, magn. 20 ×.

Microcline grains, though often large, hardly show any crystal shape. The central parts of the grains are distinctly perthitic. Microcline is considerably turbid on account of hematite pigment.

The finer »mortar» and the crack infillings of the larger feldspar grains consist of albite, or albite and microcline, with idiomorphic epidote crystals and some chlorite. Hematite is a common accessory.

Some indistinct portions within the vein suggest highly altered inclusions. All the plagioclase is completely sericitized and epidotized, and does not give such an impression of recrystallization as does the vein rock. Larger microcline crystals are often fairly well-shaped and enclose grains of altered plagioclase. Myrmekite is observed. Quartz is abundant, whereas epidote is subordinate and does not form well-developed crystals. These features rather give the impression of granitization.

The contacts of the vein are mostly indistinct and epidote is found to have been mobile along the boundaries. The borders are distinctly foliated and composed mainly of albite and epidote, but microcline has entirely disappeared. Towards the wall-rock chlorite increases, and larger, epidotized grains of older plagioclase appear. Also pale green hornblende is soon present. On the whole, the rock corresponds to the albitization and epidotization previously described. A microphotograph of the contact is seen in Fig. 50.

The rock in association with microcline granite is a transitional form between this granite and the above-treated vein rock, and deviates from the granite by containing only a little quartz, but appreciable amounts of epidote and chlorite. The rock passes gradually into the surrounding

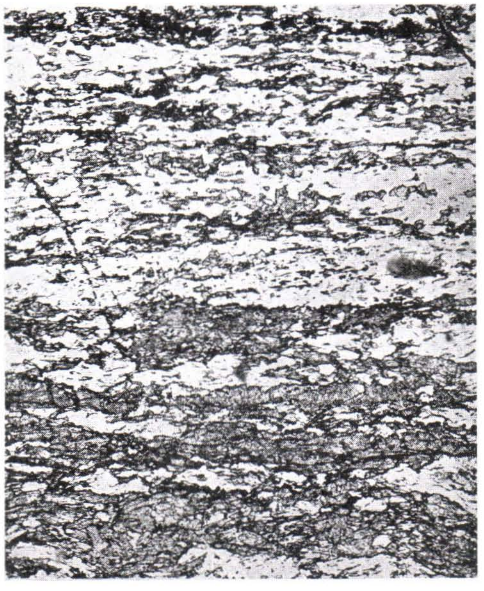

Fig. 50. The contact of the rock presented in Fig. 49 (see text). Nic. ||, magn. 16 ×.

granite. The mineral composition, determined on the integration stage, appears in Table IX, N:o 2.

Microcline forms some porphyroblasts which contain rather thick streaks of perthite and enclose grains of plagioclase. Its cracks may be filled by younger mobilized albite together with epidote.

Albite (An_5) is quite fresh.

Yellowish epidote is always idiomorphic and may occur as inclusions in microcline and quartz.

Judging from its mode of occurrence, this formation may represent a special case of granitization that took place at a fairly low temperature.

Albite-epidote rocks have been discussed by many investigators, especially in Fennoscandia, and the name »helsinkite», proposed by Laitakari (1918), has been adopted by most of the geologists. Mäkinen (calling these rocks »syenite»; 1916, p. 73), Asklund (1925, p. 74), and Wilkman (using the name »unakite», according to the Americans; 1928) believed them to be of magmatic origin, crystallized from a water-rich magma at low temperatures. Kranck (1931, p. 98) paid attention to helsinkites occurring in connection with migmatite granite and associated pegmatites, and regarded them as products of an autometasomatism of these, due to late- or post-magmatic solutions. He did not consider the older rocks (the intrusives of the »first group» and the supracrustal series) to owe their epidotization to the same cause, since, according to him, the formation of epidote in these rocks would have been destroyed by the intrusion of younger granite. Mellis, in his study of helsinkite boulders with special reference to textural features (1932), is rather inclined to agree with Kranck's interpretation, but considers these rocks to be any acid igneous rocks that have been affected by a post-magmatic autometasomatism initiated and advanced by brecciation. Furthermore, he does not regard as quite impossible an influence of outside pneumatolytic or hydrothermal agencies.

In the present author's opinion, in the area under treatment most of the helsinkites might be explained by a uniform cause, and just the outside factors would be the *primus motor* of the processes. The formation of »microcline gneiss» (p. 92) is obviously related to granitization, but, on the other hand, represents a transitional form towards the crush-zone alterations which include albitization and epidotization. All those phenomena are associated with each other, for instance, the surroundings of the albite-epidote zones have been affected by a potash-silica metasomatism. The replacement of plagioclase, and the veins and schlieren of helsinkite or albite in a potash-metasomatic environment point to a secondary mobilization of the constituents of plagioclase, and it seems that the potash metasomatism having influenced these and neighbouring rocks has caused their migration. The migration of Na, Ca, and Al, considered to have involved myrmekitization at higher temperatures (p. 94), cannot have led to such a result at low temperatures, because the conditions have not been favourable for a recrystallization of anorthite. Furthermore, any appreciable quantities of Na have not been retained by microcline at low temperatures. Instead of myrmekitic plagioclase, albite and epidote have thus been produced, and the materials have also migrated farther away from their primary environment. Turner (1941, p. 14) suggests that solutions may be drawn into the zones of shearing stress and crushing. The occurrence of the great amounts of ferric iron contained by pistacite, as well as that in the shape of hematite, might be due to the presence of carbon dioxide characteristic of most of the low-temperature processes (cf. p. 102, and Turner 1948, p. 96). In addition, CO_2 may act as the carrier of materials (Turner, l. c.).

The microcline-bearing, more or less hypidiomorphic helsinkites in association with granitized rocks probably indicate a different course of events. Kranck (op. cit.) regarded their albite as inherited *in situ* from the plagioclase of the original rock, and in part, this must also be true. In any case, the fresh albite indicates a complete recrystallization, and the albite-filled cracks in microcline, especially, show that a part of the albite has been mobile and consolidated later than microcline. Mellis (op. cit.) also considered a younger generation of albite to be probable. Simonen (1948, pp. 53—54), having ascertained the close connection of albitization with granitization also in the Aulanko area, believed that a fractionization of alkalies has taken place in the solutions causing metasomatism. Perhaps, also in this case some mobilization of the constituents of plagioclase might have happened within the rock itself.

Epidote has certainly received Ca and Al, in addition to iron, from mafic minerals as well, since these have also been destroyed in the advance of metasomatism. Furthermore, the mobilization of their constituents is indicated by abundant recrystallization of chlorite, hematite, magnetite, and sphene in the feldspathic and quartzo-feldspathic veins. Some of these veins correspond to the epidote-albite-hematite pegmatite in Fersmann's classification of granite pegmatites (1931). If the concept »pegmatite» is to be applied to them, they may be termed rather »contact pegmatite», as the circulating solutions have obviously been contaminated by materials of the wall-rock.

The nature of the resulting rocks in the genesis of helsinkite must essentially depend upon the composition of the parent rock in every individual case. This also causes the great variability in the composition of helsinkites. For instance, neither albite nor epidote are necessarily present (Mellis 1932).

The interpretation the author sets forth is not applicable to all the cases of the helsinkite genesis. When the primary composition has been suitable, a helsinkitization can have been caused by purely autohydrothermal alteration, as shown by Eskola (1934) of the porphyries of the Baltic. These rocks are different in character, and the changes have taken place without co-operant tectonic factors.

In some cases *prehnite* is observed in association with other low-temperature minerals. It seems to be accompanied by more abundant calcite. Judging from the mutual relations of the filled cracks, it is usually younger than chlorite and epidote. It is encountered in the rocks that have been most brecciated, for instance, in the crush zone cross-cutting the schist belt, in which Lake Pulasjärvi is situated. Albite-epidote rocks are also met there, but a chemical equilibrium seems to have seldom been attained at the alteration, since hornblende can be preserved in rocks intensely brecciated by prehnite, epidote, calcite, and quartz. These formations represent the last stage of the chemical changes in the rocks.

SUMMARY AND DISCUSSION

The processes considered in this division represent a series of events that is usually characterized by an absolute increase of potash and silica in the rock complex. The mode of appearance of the potash metasomatism varies with the temperature and shearing stress. Excepting the granitization, most of these phenomena have taken place at low temperatures corresponding to the conditions of the greenschist facies, as may be deduced from the mineral associations. In the rocks with microcline, chlorite, and micas both the biotite-chlorite and muscovite-chlorite subfacies (Turner 1948, pp. 94—96) are realized, and such an assemblage also indicates an excess of alumina, increasing when proceeding towards the muscovite-chlorite subfacies. The increase of muscovite, especially striking in the sericite (muscovite) schist, may indicate the lowest temperature, but can also be ascribed to a strong shear favouring the formation of muscovite. The predominant type of silicified schists with oligoclase and biotite, again, must be due to a higher temperature, unless there is an disequilibrium in question. In any case, S. Gavelin (1939) also has observed that mineral assemblages proving a higher grade of metamorphism are possible in such processes, for instance, plagioclase comparatively rich in anorthite in association with ore quartzites, and sulphide mineralization in the presence of hornblende.

Turner (op. cit., p. 96) emphasizes that favourable conditions for a low-grade metamorphism are not only created by a particular temperature and pressure (and most often a shearing stress too), i. e., by physical factors, but the chemical activity of hydrothermal solutions and carbon dioxide are quite essential. But when these are active, the rocks may be also affected materially by removal of some constituents and consolidation of others. It is well-known that, for instance, in many silicate rocks of the greenschist facies lime has decreased, because it has been carried away by CO_2 or other agencies. It is evident that a metamorphic differentiation can be involved in such a way. But if the mobility is high enough (it might be accelerated by intense deformation — Turner 1941, p. 14) and the materials migrate over long distances, we may call the altered rocks metasomatic as well. Moreover, as Eskola says (1932 a, and 1939, p. 405), the movement of material within the rock itself is due to internal or e x t e r n a l operations, the latter being the introduction or extraction of material and the general course of m e t a s o m a t i s m. The influx of external fluids is favoured by movement planes (Wegmann 1931, p. 62; Cheng 1944, p. 145; etc.), and those fluids may especially be drawn into the zones of high shearing stress or crushing (cf. Turner, l. c.).

It seems that all those processes have been of importance in the low-temperature metasomatism in the area under discussion, and especially striking in the genesis of helsinkite. The mobilization of material has been accelerated by shear movements, but probably initiated by the outside potassic and siliceous solutions which may have been called to the scene just by these movements. The gradual transition from microcline granite through »microcline gneiss» to the potash-metasomatic rocks of the lowest grades of metasomatism indicates that we are probably dealing with a direct continuation of granitization, and, in consequence, the agencies originate from the same source as do those of granitization.

This explanation of potash having caused many other kinds of metasomatism also at low temperatures somewhat contradicts the opinion of Reynolds and Holmes (Reynolds 1946, Holmes and Reynolds 1947). In the last-mentioned work (pp. 58—60) the authors, applying the ideas of migration presented by Lapadu-Hargues (1945), suggest as follows: K is no more active after granitization, but can only migrate with the »basic front» set in motion by K itself, and it is just K that migrates in advance of albitization, and not the reverse. In the opinion of the present author, however, the accumulations, schlieren, and veins of epidote, albite, and other minerals, that are associated with a large-scale introduction of potash into shear zones, as well as the replacement of plagioclase, indicate that the mobilization of the respective constituents must be ascribed to the main event, i. e., the potash metasomatism. In consequence, the relations would be the same as they are at granitization, according to Holmes and Reynolds. K having passed the range of its higher mobility and activity has been fixed, while many other elements have migrated. In the area investigated »basic fronts» of any nature are hardly observed elsewhere than in connection with low-temperature alterations caused by potash and/or silica metasomatism. Lastly, as regards the mobility of any particles, Turner (1948, p. 52) points out that »the concentration gradient set up between the moving and the immobile solutions, and within the latter itself» is a more important factor than their absolute velocities of diffusion for equal concentration gradients. Even though the circulating fluids were only »clouds of ions», their composition together with the solubility of solid materials in the pore solution is essential for the possibility of migration or consolidation. According to Bugge (1945), also external pressure, in addition to temperature and composition, is of importance.

The influence of the potash metasomatism would thus extend over a very long period of time and a host of phenomena, from granitization to helsinkitization. The primary source of granitization, again, is the large-scale mobilization of all the materials in the great depths of ultrametamorphism and palingenesis.

We have looked into the convergence of »metamorphic» and »metasomatic» in this chapter. Previously, we looked into the convergence of both those and »magmatic». It seems as if Read were not so wrong, as he emphasizes his »unity of plutonism»!

TECTONICS

Bedding and folding. The strike of the bedding appears from the petrological map. It usually has a rather constant trend, and the dip is steep or vertical with a few exceptions. Since parallel beds can be followed for long distances, it seems as if there has been in question a major folding with an almost horizontal axis. Inasmuch as no large syncline or anticline can be inferred from the map, we are probably dealing with the almost vertical limb of one large fold. However, it is evidently complicated by minor folding with the same axial direction, as is indicated here and there by the variations in the position of the base of the phyllite varves, and also directly seen in certain places. The axial plunge of these folds is usually 5—15°.

Disturbances in the strike are observed in the vicinity of the Värmälä massif. The beds are somewhat bent at the northeastern and southeastern contacts of this massif, but more intense disturbances, although local and on a small scale, are seen in the phyllite E. and S. of it. There flow folds have been created, the general appearance and attitude of which is presented in Fig. 51 a. The folds can be more than 100 m. in width, but are often only some metres wide. Southwest of Lake Paalijärvi, where such a folding is most abundant, the axial plane strikes in the direction N. 5—30° E. and the dip is practically vertical. The axis plunges at 45—70° to S. W. Minor shear folds have sometimes been formed on the eastern limb of the flow folds (Fig. 51 b). South

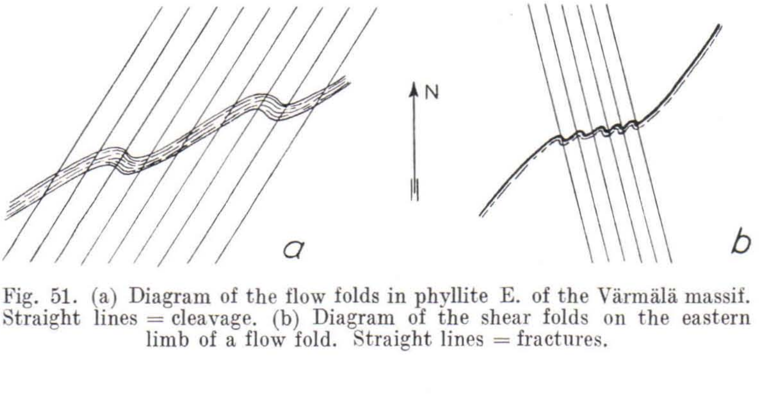

Fig. 51. (a) Diagram of the flow folds in phyllite E. of the Värmälä massif. Straight lines = cleavage. (b) Diagram of the shear folds on the eastern limb of a flow fold. Straight lines = fractures.

of the Värmälä massif the axial plane turns somewhat towards the E., and the axis does not plunge as regularly as it does farther E. In the western part of Aitolahti the beds, when deformed, are rather irregularly contorted, and a definite folding has seldom taken place. However, some beds with a northwest-southeast strike, having certain parts of them overturned even to N. 10° E., suggest that the deformation has been similar in character to that described above. The axis plunges steeply to the N. side.

Schistosity and cleavage. In a great part of the area, and almost always when the strike of the bedding is rather constant and straight, the schistosity is parallel to the bedding, or deviates from it by only 10—15°. Or, where two different cleavages are present, the more distinct one is as mentioned. Judging from the deviations, the schistosity is probably a secondary phenomenon independent of the bedding in general and might be a flow cleavage associated with the major folding. However, schistosity approximately parallel to bedding may be interpreted otherwise: it would have been developed on the primarily horizontal bedding by horizontal stretching (Roques 1941), or by forceful horizontal intrusion of magma (DeLury 1941).

An evident flow cleavage is connected with the steeply-plunging minor folds E. and S. of the Värmälä massif, since the plane of cleavage is identical with the axial plane (Fig. 51 a). This schistosity is seen very distinctly in phyllites (Fig. 7, p. 23). A fracture and shear cleavage that is observed here and there in the same contorted beds may be in close connection with the minor folds and flow cleavage. Southwest of Lake Paalijärvi it strikes in the direction N. 5° E.—N. 25° W., farther west N. 10—15° E., and in the western part of Aitolahti usually N. 35—45° E. The dip is always steep. In S. W. Aitolahti, another system of this fracture cleavage is occasionally observed, striking in the direction N. 70—90° W. The same direction of shear is also encountered at the southern granite contact farther E., in Orivesi, and is indicated, e. g., by an indistinct foliation in the granite.

The above-treated phenomena of folding and cleavage E., S., and S. W. of the Värmälä granodiorite stock might be explained by a nearly horizontal couple, in which the central part of the schist belt, including the Värmälä massif, has moved eastwards in relation to the granite and veined gneiss in the south. Thus the minor folds would be drag folds (Billings 1946), and the massifs would have played the rôle of competent beds. The fold axes plunge so steeply, and variably too, that they cannot be in harmony with a major folding.

Occasional shear or fracture cleavage occurs also elsewhere, but most often the directions of the maximum shearing stress are expressed by *joints* and small *faults* or flexures. These ruptures are inclined at roughly 45° to the strike of schistosity, and their dip is frequently practically

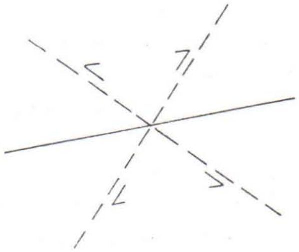

Fig. 52. The predominant trend of the faults in the area in relation to the general strike of the schistosity.

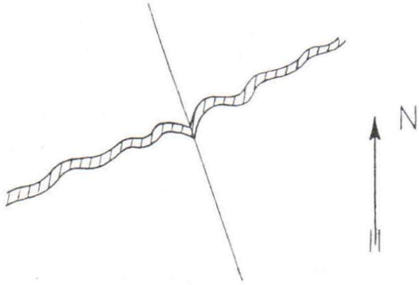

Fig. 53. Diagram of a contorted schist layer with shear fracture. The area between Lakes Pulasjärvi and Paalijärvi, Teisko—Kangasala.

vertical. The predominant trend of the faults, also deduced from the attitude of open *en échelon* fractures, is shown in Fig. 52. Both kinds can occur together. The slip is, however, quite insignificant, 1—10 cm. as a rule. East of Lake Pulasjärvi shear joints are sometimes found to be associated with a slight contortion of layers where incompetent beds are present (Fig. 53). The same phenomenon may also occur on a larger scale, since, for instance, at Lake Pulasjärvi the beds are bent in a similar manner, several cleavages varying in strike and strength can be seen, and a complicated net of well-developed joints is conspicuous. Thus this lake is probably situated in a large shear fracture. The crushed zone is continued for about 2 km. towards the N. W.

Judging by their attitude and rather equal distribution in both the N. E.—S. W. and N. W.—S. E. direction, these fractures may be ascribed to a compressive force that has operated in an approximately north-south direction. Consequently, it seems to be identical with that compression that has caused the main deformation of the whole area.

Joints perpendicular to the strike of the schistosity are as common as those described above, whilst in Aitolahti they are even largely predominant. Probably they are extension joints and in certain cases seem to be older than the shear fractures, as quartz-filled cross-joints are sometimes found to have been cut and displaced by shear slippage.

Distinct *lineation*, expressed, e. g., by the elongation of conglomerate pebbles, concretions, hornblende crystals, etc., plunges steeply with a few exceptions, but the plunge is quite variable over large areas. In Orivesi and the eastern part of Teisko the lineation tends to plunge in directions between N. E. and S. E. At Lake Paalijärvi and farther S. W., as well as S. W. and N. W. of the Värmälä massif the lineation plunges to the S. W. Some distinct lineations plunging E. are observed in the veined gneiss of Aitolahti and at its northern border. In this case, the plunge is usually rather gently inclined (35—45°).

In addition, a slight striation or contortion plunging gently can be also observed in the planes of the main schistosity, although only in a few cases. They are sometimes seen in the planes of local shear cleavage, too. In this case, the plunge is steeply inclined. In association with slickensides a further but horizontal striation is occasionally met with.

E. Cloos, in his review (1946), emphasizes that the nature and origin of linear structures is by no means uniform. The same conclusion can also be drawn from the area under discussion. Deformations of different age and character have taken place, causing different linear structures. In certain cases the cause is deducible. The weak gently-plunging lineation in the plane of the main schistosity is probably related to the primary b-axis of deformation, i. e., the axis of the primary major folds. Concerning the drag folding, a distinct lineation is identical with the fold axis. The case is thus what is regarded as normal, but there is quite a local and nearly vertical b-direction in question. The weak streaking of minerals in association with shear cleavage also suggests a lineation parallel to the local b-axis, when observed in similar crinkled beds with a steeply-plunging axis of the minor folds. The lineation has evolved parallel to the intersection of shear cleavage with the bedding or another cleavage. However, such striations, and especially those in slickensides proper can also be parallel to the movement of crust blocks past each other. Regardless of their origin, the interpretation of these sporadic traces of rather late movements may be mainly of local significance. The tectonics associated with the Värmälä stock, recently studied by Härme and Seitsaari (1950) and omitted in the present description, points to a further particular case of tectonic events in the area. On the basis of the lineation and foliation within the massif itself and the lineations in its immediate surroundings (see map), it was suggested that there is a tilted dome in question, the rise of which has influenced the neighbourhood to some extent. An example of such an influence is also suggested by Härme (1949, p. 44).

The most difficult problem is the origin of the distinct steeply-plunging lineation quite characteristic of the whole schist belt. According to Neuvonen and Matisto (1948), it would represent the direction of the tectonic a-axis, i. e., that of the movement of rock sheets past one another in the main folding. In the bibliography quoted and annotated by E. Cloos (op. cit.) examples are not lacking of phenomena that could be explained in a similar way. Recently, A. Mikkola (1949, p. 55) has ascertained that in some slates in the Karelian formations of Northern Finland a well-developed lineation perpendicular to the axis of the major folding has been formed in the bedding planes. In any case, the linear structure concerned is a fairly general feature in many areas of the Svecofennidic territory, and thus it may owe its origin to processes that are essential to folding. However, as appears also from the preceding discussion, one must be cautious of misinterpretations.

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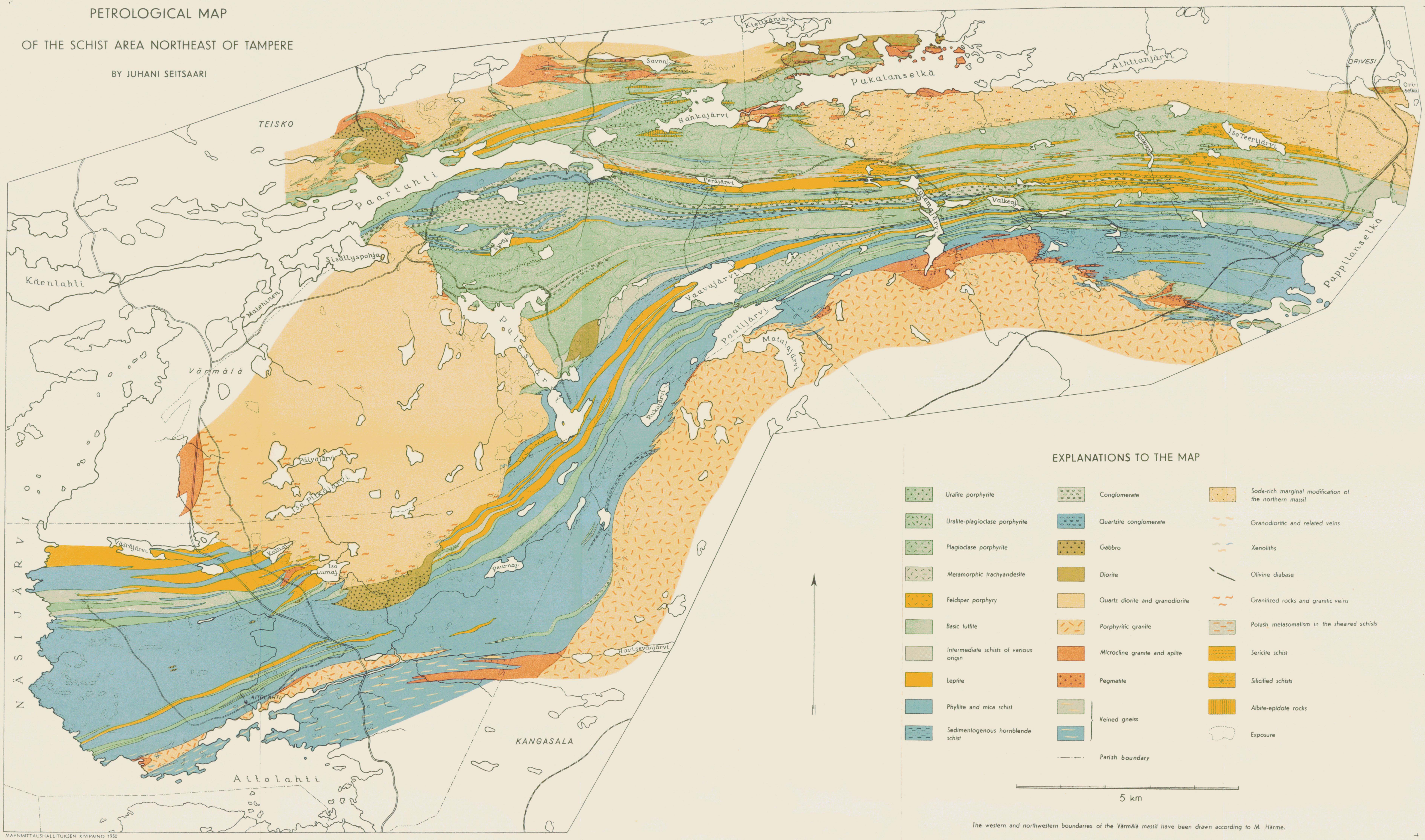
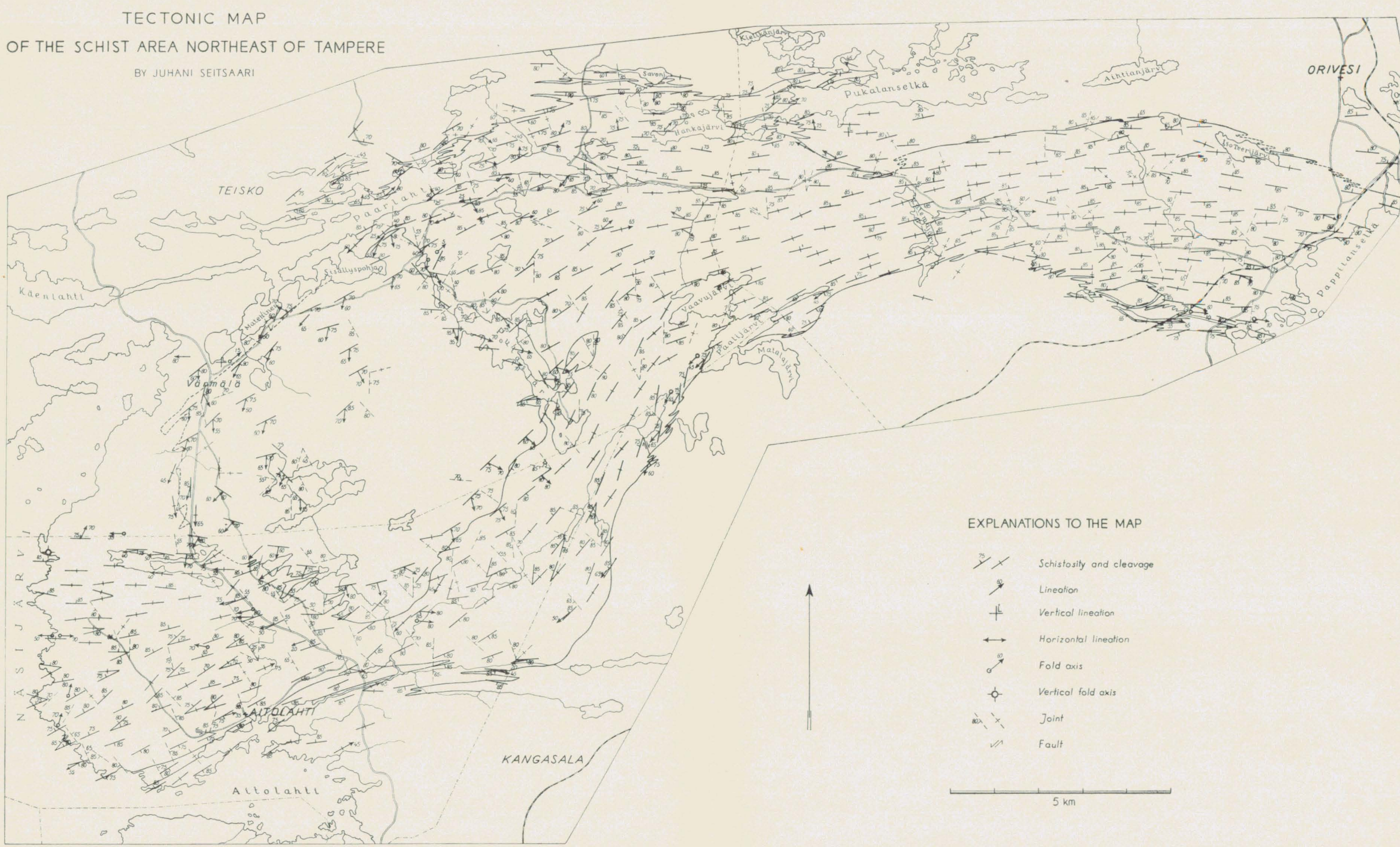
PETROLOGICAL MAP
OF THE SCHIST AREA NORTHEAST OF TAMPERE
BY JUHANI SEITSAARI




TECTONIC MAP
OF THE SCHIST AREA NORTHEAST OF TAMPERE
BY JUHANI SEITSAARI
ORIVESI
TEISKO
Pukalanselkä
Hankajärvi
Aihtianjärvi
Paarlahti
Käenlahti
Vaavujärvi
Paalijärvi
Näsijärvi
AITOLAHTI
Aitolahti
KANGASALA
Pappilanselkä
EXPLANATIONS TO THE MAP
Schistosity and cleavage
Lineation
Vertical lineation
Horizontal lineation
Fold axis
Vertical fold axis
Joint
Fault
5 km