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THE AGE OF THE SURROUNDING GABBRO-ANORTHOSITE COMPLEX AND THE CRYSTALLIZATION OF RAPAKIVI

BY

ANTTI SAVOLAHTI

WITH 22 FIGURES, 11 TABLES AND ONE MAP

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Helsinki 1957. Valtioneuvoston kirjapaino

PREFACE

I have the honor of being a pupil of Prof. Pentti Eskola, and it is from him that I learned geological thinking. Prof. Eskola spared no pains going through my manuscript and my material. He offered penetrating criticism, which I accepted with admiration and which caused me to collect additional material to support my conceptions.

Prof. Th. G. Sahama also deserves thanks for his help and advice.

For financial aid arranged in my behalf, I want to thank Prof. Aarne Laitakari, director of the Geological Survey of Finland, and Dr. Ahti Simonen, chief of department at the Geological Survey.

I further wish to acknowledge my debt of gratitude to the Emil Aaltonen Foundation and the Outokumpu Foundation for research grants.

Institute of Geology, University of Helsinki, December 8, 1956

Antti Savolahti.

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INTRODUCTION

The Ahvenisto massif [1]) is located in southern Finland on the NW side of the Viipuri rapakivi area between the church of the rural commune of Heinola and the parish center of Mäntyharju (Fig. 1, A). The outer edge of the massif is shaped like a horse-shoe and consists of basic rocks. The arch, or »horse-shoe», and the massif as a whole give a special character to the topography of this region. An almost continuous belt of lakes surrounds

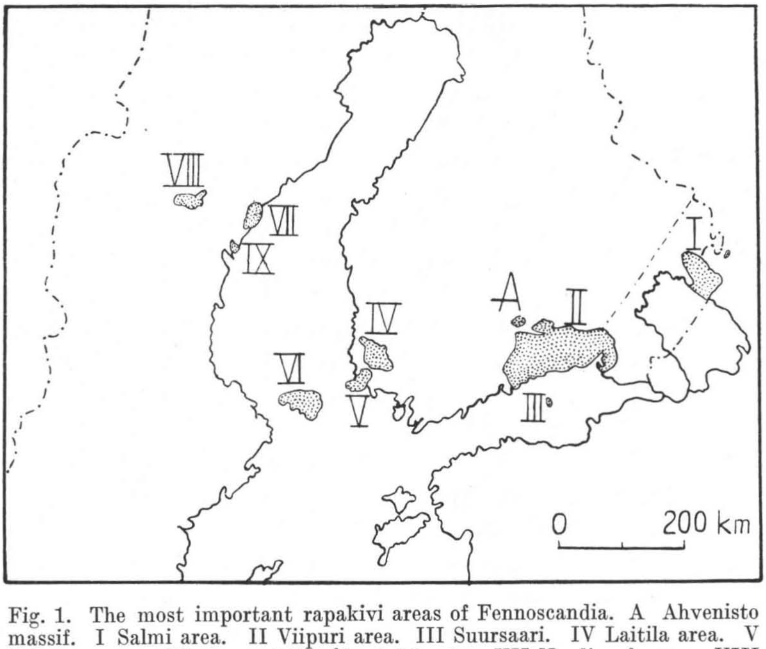

Fig. 1. The most important rapakivi areas of Fennoscandia. A Ahvenisto massif. I Salmi area. II Viipuri area. III Suursaari. IV Laitila area. V Vehmaa area. VI Area of the Åland Islands. VII Nordingrå area. VIII Ragunda area. IX Rödö area.

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[1]) Väyrynen (1954), in his work »Suomen kallioperä» (The Rock Foundation of Finland), used the designation »Ahvenisto massif», after the village of Ahvenisto, in lieu of the earlier »rapakivi-diabase area of Jaala—Heinola—Mäntyharju».

the whole massif. The lakes are situated in part a short distance from the massif, in part along its edge and in part cutting across it, especially the basic rocks. The arch rises up from the terrain to a somewhat greater height than the central part of the massif. Steep cliffs, which in many places rise more than 20 meters above the water-level, line the winding shores of the lakes. The entire arch is so full of exposures that it would be a hopeless task to mark down every individual outcrop on the map. Outcrops are abundant also in the northern, western and central parts of the rapakivi area. It is possible to walk for miles along continuous exposures. The SE and S parts of the rapakivi area adjacent to harder rocks is low-lying and to some extent swampy. The last-mentioned marginal zone is, to be sure, poorly exposed. On the other hand, the contacts of the Ahvenisto massif are well exposed on the W, N and E sides of the massif. On the S and SE sides the investigator is hampered in his work to a certain extent by the esker landscapes, where he can find no outcrops.

In age the Ahvenisto massif is, according to the prevailing view, post-Archaean and late pre-Cambrian. It is placed alongside the rapakivi rocks held to be sub-Jotnian. (As will be seen, the present investigation has led the author, however, to a different interpretation.) Figure 1 shows the most important rapakivi areas in Fenno-Scandia. I is the Salmi area (Trüstedt, 1907; Sahama, 1945), II the Viipuri area (Wahl, 1925; Popoff, 1928; Hackman, 1934), III Suursaari (Ramsay, 1890, 1896; Kranck, 1928, 1929), IV the Laitila area (Laitakari, 1928; Kahma, 1951), V the Vehmaa area (Kanerva, 1928), VI the area of the Åland Islands (Sederholm, 1890, 1934). North of the Åland Islands are the quartz porphyry and the graphophyre at the bottom of the Gulf of Bothnia (Eskola, 1928, 1934). VII is the Nordingrå area (Sobral, 1913, v. Eckermann, 1938), VIII the Ragunda area (Högbom, 1899, 1909), and IX the Rödö area (Holmquist, 1899; Högbom, 1909). SW of Rödö are the Dala porphyries (Looström, 1916) and the rapakivi in the Loos-Hamra region (v. Eckermann, 1936).

As early as last century, F. J. Wiik described in several publications minerals from the rocks of the Ahvenisto area (e. g. the diabases of Lautaniemi and Nöilöppijärvi), considering these two diabases petrographically different. Ramsay (1887) published a geological map of the northeastern part of the commune of Jaala. The map takes in the area between lakes Karijärvi and Vuohijärvi and extends in the north up as far as the northern shores of Salajärvi and Vuohijärvi. In this paper Ramsay describes the contact between the Lautaniemi diabase and microcline granite, and interprets the diabase as younger than the granite. This is the only contact between basic igneous rocks and microcline granite in the Ahvenisto area that has been described. Frosterus (1902) depended wholly on the degree of metamorphism in writing about the age relation of labradorfels to the microcline granite. Ramsay divided the rapakivi granites into two, petrographically different groups. One group consists of biotite rapakivi in the middle of the Ahvenisto massif and the rapakivi extending from the Viipuri area to the Ahvenisto area, while the other group consists of hornblende rapakivi at the southern and southeastern margin of the basic arch. The latter was termed syenite-granite by Ramsay (*cf.* Wahl, 1925, p. 71). Frosterus (1902, pp. 55—98) divided the rocks of the Ahvenisto massif into three groups, labradorfels, rapakivis and quartz porphyry dikes, and he drew up a separate map of the entire Ahvenisto area. In his description of the labradorfels Frosterus mentions practically all the rock types occurring in the area, though he does not classify them separately. The labradorfels is regarded by Frosterus as older than the rapakivi, though both of them are nearly the same age. The Ahvenisto rapakivis are supposed by him to be part of the rapakivi intrusion of the Viipuri area, to which connection had been cut off by erosion.

At the suggestion of Prof. P. Eskola, the present author investigated the area of Ahvenisto as a p r o - g r a d u project in the summers of 1949—1951. In the mapping work a basis was provided by aerial photographs of part of the massif (1: 20 000) and an economic map of the area as a whole (1: 100 000). In the summers of 1952—1953 the author continued his research by remapping the entire Ahvenisto massif. This time he sought to distinguish and mark down separately on the map the different rocks and to determine their contact and age relations. Aerial photographs (1: 10 000) of the entire arch of basic rocks and aerial photographs on a scale of 1: 20 000 of the other parts were available to help the author in his work.

The mineral components of the rocks have been presented in percentages of volume, and they have been determined with the Leitz integration stage, excepting for the biotite rapakivi and the granite-porphyry. In regard to the latter the volume percentage was measured with a ruler from specimens whose surface had first been polished. The optical properties of the minerals were determined with the Leitz universal stage in the Na-light. In determinations of refractive indices, a gelatine film was used in some cases while in others a cover glass was pressed tight against the mineral fragments, and the overflow of excess liquid dried with blotting paper, so that the chips could move upon tilting of the preparation. The possible error in the refractive indices is generally $\pm$ 0.002, and in feldspar and biotite even less, $\pm$ 0.001. The compositions of the plagioclases based on the refractive indices have been taken from Chayes' curves (1952). Otherwise, in the interpretation of the optical properties, Winchell's work (1951) has been consulted. The compositions of the plagioclases whose refractive indices are not reported are based on the extinction angle $\alpha' \wedge 010$ from sections $\perp$ 010 and 001. In the chemical analyses Groves (1937) has been followed wherever applicable.

THE ROCKS SURROUNDING THE AHVENISTO MASSIF

The rocks surrounding the Ahvenisto massif have been divided in this study into four groups:

— migmatites
— amphibolites
— quartz diorites and granodiorites
— microcline granites

MIGMATITES

Not only the typical migmatites but also the mica schists and mica gneisses occurring here and there and in places containing hornblende, garnet and cordierite have been marked on the map as migmatites. [1]) These rocks are often simultaneously cut by quartz diorites, granodiorites, and porphyritic granites as well as, on the other hand, microcline granites.

It is not easy to draw a boundary between the migmatites and the rocks cutting them — e. g. on the eastern side of Imjärvi as well as at Paistjärvi and Kuhaniemi abundant portions of migmatite are enclosed in the microcline granite.

The strike of the foliation of the migmatite in the N part of the Ahvenisto area is N 45°—90° E, its dip 45°—90° N and lineation 30°—50° N. On both sides of Lakes Ylä-Räävelinjärvi and Ala-Räävelinjärvi as well as around Lake Juolasvesi, the strike and dip of the foliation vary a great deal. Where this is the case, there is an abundance of penetrating rocks, particularly microcline granite.

Extensive continuous gneiss areas occur in the following places. Approximately five km N of the northern shore of Ala-Räävelinjärvi, fine-grained biotite-hornblende gneiss layers alternate with garnet-cordierite gneiss layers. In the latter there is an abundant content of quartz, plagioclase (An_{30}), and biotite with sphene and apatite as accessory minerals. The cordierite has partly altered into pinite. Biotite- hornblende gneiss contains considerable plagioclase (An_{35-40}) and quartz with a

[1]) Since at least part of the microcline granites are younger than the gabbro-anorthosite complex (see p. 34), it is sometimes necessary to distinguish between those migmatites cut by the microcline granite and the others. Whenever this is necessary the former is designated as younger migmatite and the latter older migmatite.

strongly undulatory extinction, while calcite, apatite, and zircon are accessory minerals. The relative amounts of hornblende and biotite vary. About 7 km northeast by east from Kuortti, near the shore of Lake Peruvesi, there are some small abandoned graphite quarries in graphite gneiss (Frosterus, 1902, p. 16). On the western shore of Juolasvesi, at the place where the strike of the foliation is north by south, there is a zone in the migmatite in which fine-grained garnet gneiss layers alternate with coarse-grained cordierite gneiss. The mineral assemblage of the garnet gneiss is plagioclase (An_{40-45}) 40.2 %, quartz 45.0 %, potash feldspar 0.5 %, biotite 13.0 % and garnet 1.1 %, while the cordierite gneiss contains plagioclase (An_{25}) 4.5 %, quartz 31.4 %, biotite 31.7 %, cordierite 30.3 % and ore 2.1 %, with pinite and sericite as subordinate constituents.

The migmatite often contains large grains of garnet and sometimes of cordierite. Between Ylä-Räävelinjärvi and Juolasvesi sillimanite is also present. In the mica gneisses met with between Lakes Kelesjärvi and Karijärvi there are in places eye-shaped microcline porphyroblasts measuring from 0.5 to 1 cm.

For the most part the migmatites are veined gneisses. Sederholm (1899, 1907, 1923, 1926, 1934) has described the veined gneisses of southern Finland and Holmquist (1921) those of Sweden. Hietanen (1943) has described intrusives forming migmatites as of two different ages from the Kalanti region. The migmatites of the Ahvenisto area, like those mentioned in the foregoing, vary greatly in structure and appearance.

Granite pegmatites are abundant in the migmatites. In structure they are in many instances graphic and contain garnet grains ($n = 1.817$). Black tourmaline ($\omega = 1.661$, $\varepsilon = 1.633$) occurs in the pegmatites WSW and ESE of Lake Pyhävesi.

AMPHIBOLITES

Amphibolites occur between Lakes Viilajärvi and Konnivesi as well as SW of Konnivesi. They are fine-grained, layered rocks. Layers rich in amphibole alternate with layers richer in mica. In the amphibolites near Viilajärvi there are thin carbonate-bearing layers (Frosterus, 1902, p. 17) and on the east side of the same lake pyroxene gneiss layers are also met with.

The mineral composition of the fine-grained, black-gray amphibolite on the east side of Viilajärvi is plagioclase (An_{42}; $\alpha = 1.550$) 62.7 %, hornblende 28.4 %, biotite 4.4 %, quartz 3.6 %, ore 0.5 % and apatite 0.6 %. In the darker layers there is less plagioclase. The mineral composition of the light-colored layers of a banded pyroxene gneiss a short distance to the south from the preceding site is: plagioclase (An_{53}; $\alpha = 1.556$) 67.6

%, quartz 14.9 %, pyroxene 12.9 %, biotite 1.9 %, ore 2.1 %, and apatite 0.6 %. The mineral composition of the dark bands is: plagioclase 64.0 %, quartz 0.4 %, pyroxene 13.7 %, amphibole 16.4 %, biotite 3.4 %, ore 1.7 % and apatite 0.4 %. The pyroxene is principally orthopyroxene. The axial angle $2V\alpha$ varies from 61° to 79°.

QUARTZ DIORITES AND GRANODIORITES

From the SW shore of Juolasvesi a quartz diorite area about 2 km broad extends to Pyhävesi. The rock is distinctly foliated in the direction N 40°—50° E, while the dip is 70°—75° S. The rock is light gray, of even grain from 2 to 3 millimeters in diameter. The mineral composition of the quartz diorite on the SW shore of Juolasvesi is shown in Table I, No. 1.

Table I. Modes of quartz diorites and granodiorites

	1	2	3
Plagioclase	51.3	45.5	42.8 %
Quartz	27.3	24.5	22.0 »
Potash feldspar	2.0	0.4	24.5 »
Biotite	18.9	24.6	10.4 »
Garnet	—	4.2	— »
Secondary minerals	0.3	—	0.2 »
Apatite	0.2	0.7	0.1 » (Apatite + Zircon)
Zircon	—	0.1	

The plagioclase (An_{36}; $\alpha = 1.546$, $\gamma = 1.554$) is euhedral, and has a narrow, more albitic margin (An_{15}). Sometimes the plagioclase is slightly sericitized. The quartz is xenomorphic. Potash feldspar (with quadrille structure) occurs in anhedral forms enclosed in the plagioclase; sometimes it is met with as independent grains. Biotite ($\gamma \sim \beta = 1.657$) encircles the plagioclase in bands. In places biotite is intergrown with quartz. Chlorite and pistacite occur at the edges of the biotite. Apatite is present mainly as inclusions in the biotite. In the quartz diorite on the northeast side of Juolasvesi there is also hornblende (γ = bluish green, β = greenish brown, α = yellowish brown, $c \wedge \gamma = 27°$); and in such cases there is a greater abundance of microcline in the rock than in those lacking in hornblende.

The quartz diorite between Vuohijärvi and Kelesjärvi also shows a distinct foliation. The foliation of the rock appears to run parallel to the contacts. This quartz diorite is coarser in grain than the foregoing. Between Lakes Lahnajärvi and Vuohijärvi the rock contains pale, eye-shaped plagioclase aggregates 0.5—1 cm in length. The mineral composition of the rock near the site (see p. 15) where microcline granite cuts the rock is given in Table I, No. 2. There are, in addition, slight amounts of chlorite in fissures in the garnet and of sericite in the plagioclase. The plagioclase (An_{32}; $\alpha = 1.544$, $\beta = 1.549$, $\gamma = 1.552$) is euhedral. The biotite ($\gamma \sim \beta = 1.648$) has folded around both the plagioclase and the quartz, and its margins are regularly black. Garnet occurs in small clusters of crystals containing quartz. Proceeding in a SW direction, the quartz diorite becomes coarser and porphyritic. In the vicinity of Lake Nöilöppijärvi there are angular microcline phenocrysts 2.7 cm long and 0.5—1 cm broad in rocks of the description in the foregoing. Microcline does not occur in the groundmass.

To the north and west of the parish church of Heinola there is an extensive area of medium-grained quartz diorite, which closely resembles the rock just described. The minerals present in the rock are: plagioclase (An_{30-35}), biotite, occasionally altered into chlorite, a small amount of potash feldspar, and apatite and zircon as accessories. In places there is an abundance of hornblende in the rock (Frosterus, 1902, p. 22).

About 4 km south of the parish center of Mäntyharju there is a zone of porphyritic granodiorite 1.5 km broad, which runs in the direction of N 80° E. The rock contains rounded phenocryst-like clusters from 2 to 6 cm in diameter consisting of plagioclase, quartz and potash feldspar crystals, with potash feldspar in some cases enveloping the others. The mineral composition of the rock is given in Table I, No. 3. The plagioclase (An_{25-30}) is euhedral and unaltered. In spots it has undergone sericitization, and to some extent potash feldspar appears to have replaced it. The biotite crystals ($\gamma \sim \beta = 1.662$) occur in bands encircling the quartz and plagioclase crystals. The biotite is dark brown and fresh, but in the neighborhood of the potash feldspar it is cloritized and contains separated ore grains; fluorite is generated in the same connection. The apatite occurs mainly in the potash feldspar.

Among these rocks there are also porphyritic granites, which contain even more microcline. They have been met with e. g. at Paistjärvi as dikes in the migmatite.

MICROCLINE GRANITES

The microcline granites are light reddish, sometimes light gray rocks ranging from one to five mm in grain size. Moreover, the microcline granite is in many instances coarse-grained, in some instances pegmatitic.

The structure of the microcline granites is xenomorphic-granular. The quartz and potash feldspar grains are not euhedral. The plagioclase grains are in some cases likely to exhibit idiomorphic characteristics to a slight extent. The plagioclase (An_{8-20}) is in part poikilitic, enveloping other plagioclase crystals. It is generally sericitized. At the margins of the microcline, the quartz and plagioclase form embayments. In spots the plagioclase appears to have been replaced by potash feldspar. Myrmekite also occurs. The potash feldspar is usually covered by a pale gray pigment. At times a beautiful quadrille texture is to be observed, mostly in the coarse-grained types. The quartz has a clearly undulating extinction, but in the central parts of the large, eastern microcline granite area this feature is not so conspicuous. The refractive index of the biotite ($\gamma \sim \beta = 1.658$—$1.665$) is appreciably smaller than that of the biotite of rapakivi rocks. To be sure, the former is dark but none the less much more nearly transparent under the microscope than the latter. Fluorite is generally lacking in microcline granites and the amount of zircon is slight.

The rocks often contain deep red or dark, eye-shaped garnet grains measuring 0.5—1.5 cm in length. The refractive index of the garnet varies between 1.811 and 1.817. Numerous anhedral quartz grains are enclosed in the garnet crystals. At the margin of the garnet, against the feldspars, there is often a narrow, dark green chlorite seam. In addition to the garnet, the granite may sometimes contain dark blue-gray cordierite grains of equal size ($\alpha = 1.545$, $\beta = 1.551$, $\gamma = 1.556$); in many cases they have altered to pinite. The garnet and cordierite together may comprise 4—5 vol. per cent of the rock. Garnet is much more general than cordierite, which is also likely to be lacking. When both garnet and cordierite are absent the amount of biotite is greater. The latter varieties are incidentally identical in structure to the former.

The mineral composition of the main mass of the garnet-bearing rock variety met with in the village of Nurmaa, 0.5 km SW of Lake Nurmaanjärvi, is as follows: microcline 47.1 %, quartz 29.1 %, plagioclase (An_{13-16}) 23.1 %, biotite 0.4 %, apatite 0.1 % as well as a small amount of zircon and ore.

These garnet- and cordierite-bearing microcline granites are petrographically comparable to the granite of Kakola (Hietanen, 1947, pp. 1073—1078). The difference is that our area lacks varieties containing only cordierite and no garnet, which do occur in the granite of Kakola.

INTERNAL CONTACT RELATIONS OF THE ROCKS SURROUNDING THE AHVENISTO MASSIF

The garnet-bearing microcline granite met with in the village of Paljakka about 0.5 km east of the northern shore of Lahnajärvi contains quartz diorite fragments with a diameter exceeding 10 m. Immediately to the S from this site quartz diorite exposures containing microcline granite veins are encountered. The quartz diorite fragments are generally angular and of the same description as the quartz diorite of the larger masses. They have small garnet porphyroblasts, like those of the nearby type, which is cut by microcline granite (see p. 13). A short distance to the NE from the south shore of Lahnajärvi there are microcline granite veins in the quartz diorite. Likewise, the microcline granite penetrates the quartz diorite at the west shore of Lahnajärvi.

Numerous veins or dikes of both microcline granite and coarse-grained, porphyritic granodiorite penetrate the migmatite between Kelesjärvi and Karijärvi.

The quartz diorite along the W shore of Juolasvesi appears to run in the banded gneiss as a vein parallel to the schistosity, and it is traversed by veins of microcline granite, which also in places includes garnet.

In the village of Paistjärvi there occur in the banded gneisses numerous porphyritic granodiorite veins or dikes of varying thickness, some of them measuring as much as approximately 100 m. Both the banded gneiss and the porphyritic granodiorite are cut abruptly by microcline granite veins of varying thickness, and they run a winding course both in the direction of the strike and transversally. One porphyritic granodiorite vein or dike about 50 m broad runs in the direction N 80° W along the NE shore of Lake Nuhjakkajärvi (this local name is not marked on the map) 2 km north of Lake Imjärvi. It is cut, together with the migmatite, by veins of fine-grained, light reddish microcline granite poor in garnet. From here northwards and from the isthmus between Ylä-Räävelinjärvi and Ala-Räävelinjärvi southwards the fine-grained, light reddish microcline granite becomes dominant, although it includes banded gneiss and porphyritic granodiorite. Also at the north end of Nuhjakkajärvi there is a broad dike of porthyritic granodiorite in the veined gneiss. Likewise along the west side of Lake Salmijärvi there runs in the direction of N 35°W a dike of porphyritic granodiorite, about 50 m wide, penetrated by microcline granite. In the vicinity of Lake Kalliolampi (this local name is not marked on the map), at a distance of over 2 km NE from Salmijärvi, porphyritic granodiorite is again intruded into the banded gneiss, and microcline granite penetrates both. From there the granodiorites continue in a N direction to the other side of Ylä-Räävelinjärvi.

In the southern part of the village of Paistjärvi, on the shore of Lake Kesiönjärvi, near the rapakivi contact, porphyritic granodiorite in veins or dikes of varying thickness occurs in the migmatite. Both are penetrated by light gray, fine-grained microcline granite poor in garnet. In addition, the microcline granite contains granodiorite fragments (Fig. 2). The biotite rapakivi, finally, cuts the microcline granite as a dike (see p. 54).

The amphibolites of the Ahvenisto area are older than the quartz diorite and microcline granite. E. g. on the northeastern side of Viilajärvi they are penetrated by both gray granodiorite rock and microcline granite. In the explanation to the map sheet of Mikkeli, Frosterus (1902, pp. 12—13) points out how numerous microcline granite veins cut these amphibolites and how in the gray granite situated on the E side of the town of Heinola, which he regards as an older Archaean granite (in the present study quartz diorite and granodiorite), amphibolites are met with as thick sheets. According to Frosterus, also the amphibolite on the SW side of Viilajärvi has altered in contact with gray granite.

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THE VIIPURI RAPAKIVI AREA

The NW corner of the Viipuri rapakivi area extends to the S border of the Ahvenisto area. Many detailed studies of the Viipuri rapakivi area are available. Wahl (1925) has thoroughly described the different types of rapakivi throughout the entire area, designating the chief types as viborgite and pyterlite. Hackman (1934) has carried out a careful investigation of the Lappeenranta area. Therefore, it is unnecessary to describe these rocks in the present study in detail. Suffice it to say that the part of the Viipuri rapakivi area extending into the Ahvenisto area consists chiefly of pyterlite and that varieties resembling the porphyry aplites of Ahvenisto also occur.

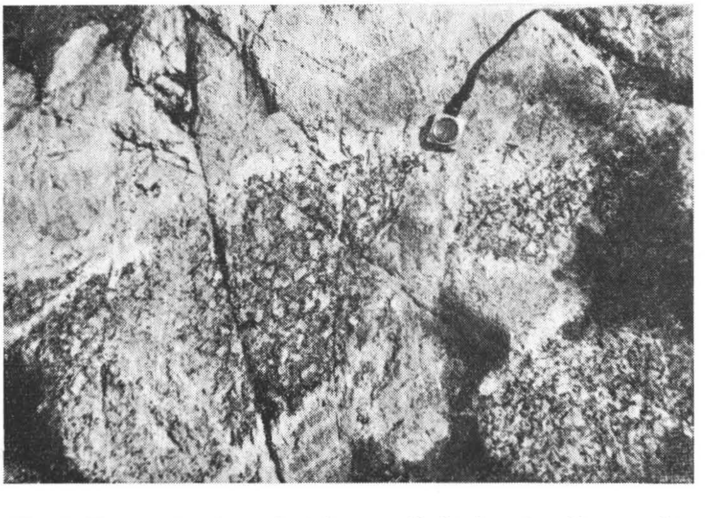

Fig. 2. Fragments of porphyritic granodiorite in microcline granite. About 100 m west of the rapakivi contact on the northern shore of Kesiönjärvi, south of Paistjärvi.

THE ROCKS OF THE AHVENISTO MASSIF

The Ahvenisto massif comprises the following igneous rocks:
— rocks of the gabbro-anorthosite complex
— quartz diabase
— biotite rapakivi and porphyry aplite
— olivine diabase
— hornblende rapakivi
— granite porphyry

THE ROCKS OF THE GABBRO-ANORTHOSITE COMPLEX

The designation »gabbro-anorthosite complex» is used in this study as a group term for all the different gabbro-anorthosite intrusions. This complex consists of eight different intrusions. One of these occurs separately on the shore of Nöilöppijärvi to the W of Vuohijärvi. The other seven surround the biotite rapakivi in an arch, with each intrusion retaining its separate character.

Common to all gabbro-anorthosite intrusions is the fact that their plagioclase, which generally contains 48—58 % anorthite, is labradorescent. Their principal mafic mineral is orthopyroxene, which contains 30—45 mol-% $FeSiO_3$. In certain varieties its place is taken by green hornblende or other amphiboles. To a slight extent quartz and orthoclase are always present in these rocks.

The various gabbro-anorthosite intrusions are very much alike in structure and composition. On the other hand, the same intrusion may contain closely related rocks that are quite different in texture and composition:

1. The intrusions always have a 5—50 m broad, fine-grained marginal zone rich in mafic minerals and containing plagioclase phenocrysts. The rocks of the marginal zone are gabbros (sometimes anorthositic gabbros) in composition and ophitic in texture; but there also occurs an ophitic texture with a sub-parallel arrangement of the plagioclase laths.

2. In all their parts the intrusions enclose anorthosites as small lenticules and in roundish shapes. The anorthosites are consistently smaller in grain than the gabbro-anorthosites.

3. The chief rocks represented in the intrusions are coarse-grained gabbro-anorthosites or anorthosite-gabbros, containing plagioclase phenocrysts of varying size.

4. In the central parts of the intrusions there are in places very coarse-grained anorthosite- and gabbro-pegmatoid parts, consisting mainly of plagioclase and hypersthene crystals up to one meter in length.

5. The last phase of the intrusions is represented by albite diabase dikes, etc. (See pp. 22, 27 and 29.)

MARGINAL ZONES OF THE GABBRO-ANORTHOSITE INTRUSIONS

The marginal zones of the gabbro-anorthosite intrusions evidently represent chilled contacts. They are invariably rather fine-grained and in texture ophitic, often with sub-parallel feldspar laths. The border always shows a gradual transition into coarse-grained anorthosite-gabbro. In some places, however, apophyses simultaneously run from the anorthosite-gabbro into the marginal zone. In addition, the entire marginal zone is cut by winding, coarse amphibole gabbro veins of varying thickness.

The NW side of the arch, 500 m from the shore of Ylä-Räävelinjärvi southward, the endomorphic contact phenomena are beautifully developed. Some 2—3 m from the contact the rock is a dark blue-gray gabbro with plagioclase phenocrysts. The plagioclase phenocrysts are 1—1.5 cm long and 5 mm thick, and the laths of plagioclase of the groundmass are 0.5 cm long and 1—2 mm thick. The groundmass of the rock is ophitic in texture. The mineral composition of the rocks is shown in Table II, No. 1. Plagioclase (An_{56}) is stained with a dark pigment. In places, particularly in the proximity of potash feldspar, the pigment is lacking, in which case the extinction of the plagioclase becomes undulatory and its refractive index drops. In these places it has also undergone sericitization. Also hornblende has grown in the form of thin needles and indefinite narrow particles inside the plagioclase, resulting in a weed texture (Unkraut-struktur; Eskola, 1946, p. 283). The potash feldspar, which is orthoclase, affects not only the plagioclase but also the pyroxene; it grows into the pyroxene, which remains there like the teeth of a comb. In these places in the potash feldspar there are spots and strings as fine as very thin hairs, which evidently are of quartz. There are also oxide ore grains in these places that have to all evidences been separated from the pyroxene. The quartz occurs, together with the potash feldspar, as wholly xenomorphic crystals in the interstices and as beady ribbons in the plagioclase. The pyroxene is mainly orthopyroxene ($2V\alpha = 60°$), but the rocks also contain a slight amount of clinopyroxene ($2V\alpha = 51°$, $c \wedge \gamma = 45°$). The pyroxenes are sometimes idiomorphic but in the interstices often xenomorphic, occurring as inclusions in the plagioclase as well as enveloping the olivine and the ore. In the last-mentioned instance, the pyroxene is non-homogenous and shows a patchy extinction. The olivine ($2V\alpha = 78°$) is present here and there in clusters of idiomorphic crystals. Whenever the pyroxene frame is lacking, it is enveloped by biotite. The cleavage cracks of the olivine are filled with ore, and in places the olivine is speckled with a dark green alteration product. Apatite occurs abundantly in the potash feldspar as large prisms running across the field of vision and at the points of alteration caused by the potash feldspar.

Towards the center of the mass the rock gradually grows coarser. About 20 m from the contact it is brownish blue gray and porphyritic. The plagioclase phenocrysts are 3 cm long and 1 cm thick, and the groundmass plagioclase laths are about 2 cm long and 1—3 mm thick. The mineral composition of the rock is given in Table II, No. 2. Part of the plagioclase (An_{56}) is grayish, unzoned, and with distinct twinning lamellae. The gray color is due to minute inclusions, which are arranged parallel to the 001-face of the plagioclase crystal. The other part of the plagioclase is bright, and appreciably richer in albite than the preceding. Its lamellar texture is indistinct. These two plagioclases always border on each other sharply. The plagioclase richer in albite is more often penetrated by hornblende — bringing about a weed texture — than that richer in anorthite. The potash feldspar is xenomorphic and occurs in conjunction with quartz in the interstices. Especially in these places there are small triangles in the potash feldspar as well as spots and strings of quartz as fine as hairs. Beside the plagioclase there is often myrmekite. The pyroxene is principally orthopyroxene ($2V\alpha = 64°$), but clinopyroxene is also met with. The clinopyroxene often occurs as lamellae or indefinite patches in the orthopyroxene. The pyroxene exists in large crystals in the interstices of the plagioclase grains and has grown around the olivine and idiomorphic ore. Anhedral grains of ore are present in the potash feldspar, particularly where the potash feldspar has replaced the pyroxene (see p. 23). The fissures in the olivine are filled with black ore. Furthermore, the olivine has in many instances undergone alteration. Amphibole occurs solely as an alteration product of pyroxene and with a weed texture. Also reddish brown biotite occurs chiefly at the margin of the pyroxene. Apatite occurs as small needles in the gray plagioclase as well as in the form of large crystals, principally in the potash feldspar and in the areas in the plagioclase characterized by a weed texture. It likewise is present in the pyroxene where the latter is replaced by potash feldspar. A large part of the apatite appears to have crystallized at a fairly late stage.

Still some distance farther away from the contact the rock grades over into coarse-grained anorthosite-gabbro containing labradorescent plagioclase phenocrysts. The transition takes place gradually over a short distance,

Table II. Modes of the rocks of the marginal zones of the gabbro-anorthosite intrusions

	1	2	3	4	5
Plagioclase	51.7	59.5	51.0	57.1	41.3 %
Potash feldspar	15.8	8.4	0.2	—	15.1 »
Quartz	2.5	0.9	3.0	—	1.1 »
Olivine	2.0	1.2	—	—	— »
Pyroxenes	18.6	21.4	—	30.0	28.0 »
Amphiboles	1.3	0.3	20.6	3.0 (Amphiboles + Biotite)	4.5 »
Biotite	1.8	2.6	16.7		0.3 »
Secondary minerals	0.2	0.9	2.2	—	— »
Ore	4.5	3.6	4.5	6.6	6.0 »
Apatite	1.6	1.2	1.8	3.3	3.8 »

but sometimes the anorthosite-gabbro intrudes as an apophysis for some distance into the fine-grained marginal zone.

The entire marginal zone described in the foregoing is cut here and there by a dark-colored amphibole gabbro. It winds in the shape of poorly defined veins ranging in thickness from 1 to 40 cm and appears to come from the center of the intrusion. The mineral composition of this amphibole gabbro is shown in Table II, No. 3. In addition the rock contains calcite, which is met with here and there in the form of rather large grains. The plagioclase, the composition of which, as determined from unaltered grains, is An_{55}, has largely undergone alteration to such an extent that the lamellae have disappeared and the grains are filled up with the alteration products (mainly epidote). The margins of the altered plagioclase crystals are often bright and their refractive indices smaller than those of quartz. There are two kinds of amphibole: pale amphibole and hornblende. The pale amphibole ($2V\gamma = 87°$, $c \wedge \gamma = 16°$, γ = pale green) is twinned on 100, giving it the appearance of plagioclase. Its margins often consist of green amphibole. Green amphibole ($2V\alpha = 74°$, $c \wedge \gamma = 21°$, γ = blue-green, β = brownish green, α = yellowish green) also occurs as independent grains and with a weed texture in the plagioclase. Sometimes pyroxene relics may be seen in the amphibole. Reddish brown biotite occurs as independent clusters of the crystals. The biotite has in many cases undergone chloritization. The ore grains are surrounded by pale-colored amphibole, followed by biotite and then green hornblende. A slight content of leucoxene is also present. Even independent biotite grains are sometimes seen to alter into green hornblende. There is quartz in the interstices and often also as small crystals within the biotite.

Since the composition of the plagioclase in unaltered parts is the same as that of the country rock and since the mafic minerals have, at least to some extent, formed from pyroxene and, moreover, since the veins have exceedingly indefinite boundaries, it appears evident that these veins have originated during the final stage of crystallization of the gabbro-anorthosite intrusion, after the marginal zone had already crystallized under the influence of residual solutions and volatile substances.

An example of a marginal type exhibiting an ophitic texture with subparallel plagioclase laths is to be seen at the N end of Lake Hietastenlampi N of the village of Nurmaa. It occurs against a migmatite portion in microcline granite. The rock is fine-grained and greenish. Its mineral composition is given in Table II, No. 4. The plagioclase (An_{53}) also appears as phenocrysts in the marginal zones of which pyroxene inclusions can be seen running parallel to the border. The pyroxene is largely orthopyroxene ($2V\alpha = 64° — 58°$). It encloses thin lamellae of clinopyroxene. The amphibole occurs as large poikilitic phenocrysts.

Farther from the contact the same rock grades over to become coarser, and the coarse variety to some extent penetrates the finer variety. Its mineral composition is shown in Table II, No. 5. The plagioclase is zoned ($An_{53\text{-}48}$). There is myrmekite along its border against the potash feldspar. The latter also replaces the pyroxene, whereupon pyroxene tongues have remained in the potash feldspar. Their extinction is contemporaneous with that of the neighboring pyroxene crystals. The pyroxene is mainly orthopyroxene ($2V\alpha = 67°$) and it contains clinopyroxene lamellae ($2V\,\gamma = 54°$). There is hornblende around the ore and in the plagioclase, forming a weed texture. The apatite appears as large idiomorphic crystals. This rock grades over into coarse anorthosite-gabbro, which in places borders abruptly against the former.

ANORTHOSITES

Anorthosites occur in all the gabbro-anorthosite intrusions as lenticules and round bodies with abrupt borders. They are likely to be met with in all parts of the intrusions. The length of the anorthosite occurrences varies between a few meters and some scores of meters, but generally they are not larger. In color these rocks are bluish gray, violet brownish gray, gray, or light gray. The grain size of the main mass of the anorthosites is generally small (2—5 mm), being regularly smaller than that of the anorthosite-gabbros (5—20 mm). Plagioclase phenocrysts 1 to 10 cm long often occur in the anorthosites. Mafic minerals (orthopyroxene, amphibole and biotite) constitute less than 10 % of the volume of these rocks, and the composition of the plagioclase is $An_{53\text{-}58}$. For the chemical composition of the anorthosites, see Table VIII, No. 1, p. 77.

Some 500 m N of Hietastenlampi an even-grained bluish gray anorthosite is met with. Its grain size is 2—3 mm and its mineral composition is given in Table III, No. 1. In the mafic minerals there have been measured chlorite,

Table III. Modes of anorthosites

	1	2	3
Plagioclase	92.5	86.9	93.0 %
Potash feldspar Quartz	3.7	5.8	4.1 »
Mafic minerals	3.1	—	2.8 »
Pyroxene	—	6.2	— »
Biotite	—	<0.1	— »
Ore	0.6	1.0	0.1 »
Carbonate	0.1	—	— »
Apatite	<0.1	<0.1	<0.1 »

biotite, epidote, remnants of hypersthene and muscovite. The plagioclase (An_{58}) grains are idiomorphic, and in places at their margins corroded. Within them there occur in places products of alteration, such as carbonate, muscovite and epidote. Bent lamellae may be observed in some of the plagioclase crystals. All the other minerals are xenomorphic in the interstices.

About 500 m S from the center of the S end of Lake Iso-Vehkajärvi there occurs a lens of violet brownish gray anorthosite. It has been crushed up and contains 2—10 cm long, labradorescent, eye-shaped plagioclase phenocrysts, and the grain size of the main mass varies between one and three millimeters. The mineral composition of the rock is shown in Table III, No. 2. The composition of the plagioclase of the main mass is An_{54} and that of the plagioclase phenocrysts An_{58} ($\alpha = 1.558$, $\gamma = 1.567$). The plagioclase grains are fresh, somewhat rounded and contain dark microlites which evidently give the rock its violet brown hue.

An abundance of myrmekite in narrow bands may be observed around the plagioclase. In places such bands run through plagioclase crystals. There is orthopyroxene ($2V\alpha = 58°$, γ = greenish, β = greenish brown, α = reddish brown) in the interstices. Biotite occurs around the ore, and in places also pyroxene has grown around idiomorphic ore grains.

East of Kuhaniemi in Ylä-Räävelinjärvi there are four islands, situated in a string, one after another, in an E-W direction. In the middle of the second island, as reckoned from Kuhaniemi, light gray, fine-grained (1—2 mm) anorthosite of parallel structure crops out. The rock contains sparse, small (0.5—1 cm long) plagioclase phenocrysts, whose lamellae are bent. The mineral composition of the rock is given in Table III, No. 3. The composition of the plagioclase is An_{55} ($\alpha = 1.557$, $\gamma = 1.565$). Myrmekite occurs along the margins of the plagioclase crystals and particularly at their ends. Often a myrmekite band penetrates plagioclase crystals. Alongside a myrmekite band the plagioclase is more albitic. In the mafic minerals there have been measured chlorite, chloritic biotite, green hornblende, orthopyroxene and epidote. The content of pyroxene is slight and that of epidote abundant, in association with either mafic minerals or plagioclase. The chemical analysis of this anorthosite is presented in Table VIII, No. 1. p. 77.

At the W end of the headland opposite Kuhaniemi in Ylä-Räävelinjärvi there occurs an anorthosite lens slightly coarser in grain than the ones referred to in the foregoing; it contains labradorescent plagioclase phenocrysts. The rock contains about 95 % plagioclase and slight amounts of myrmekite, orthopyroxene, clinopyroxene, ore, epidote and scales of serisite. The lamellae of the plagioclase (An_{57}, $\gamma = 1.566$) are bent, and every other lamella is broad and the one next to it narrow. Alongside the myrmekite the anorthite content of the plagioclase has diminished.

The other anorthosite lenses conform to the types herein described. Bending of the plagioclase lamellae and crushing up of the rock are by no means rare phenomena.

GABBRO-ANORTHOSITES AND ANORTHOSITE-GABBROS

The chief rocks of the under consideration intrusions are gabbro-anorthosites and anorthosite-gabbros. In color they are bluish gray, violet brownish gray, greenish gray or light gray. In texture the rocks are ophitic and the plagioclase laths of their main mass are 0.5—2 cm long. Often these rocks have sparse plagioclase phenocrysts, the length of which ranges from a few centimeters to several meters. The anorthite content of the plagioclase (An_{48-58}) is greater in the phenocryst plagioclases than in those of the main mass. Quartz and potash feldspar (orthoclase) are always present. The principal mafic minerals are hypersthene and amphiboles, as well as chlorite, biotite and a slight amount of clinopyroxene. The surface of the outcrop often exhibits grains of ore (titanomagnetite). Apatite is always present among the accessory minerals. The chemical analysis is given in Table VIII, No. 2. (p. 77). It probably represents the average composition of the gabbro-anorthosites.

Table IV. Modes of gabbro-anorthosites and anorthosite-gabbros

	1	2	3	4
Plagioclase	73.9	69.7	73.4	65.6 %
Potash feldspar	8.7	1.3	4.8	0.3 »
Quartz	4.2	0.3	2.4	2.8 »
Pyroxenes	6.4	8.2	—	— »
Amphiboles	2.0	—	11.1	22.1 »
Kelyphite rims	—	15.1	—	— »
Biotite	0.9	5.0	4.9	} 3.0 »
Chlorite	—	—	0.8	
Epidote	—	—	1.6	3.2 »
Ore	2.4	—	0.4	2.3 »
Apatite	1.5	0.3	0.6	0.7 »

Some 1.5 km N of the N end of Lake Siikajärvi, near the S end of Lake Iso-Salmellisenjärvi (this local name is not marked on the map), the gabbro-anorthosite contains dark bluish gray labradorescent plagioclase phenocrysts, 2—10 cm long. In texture the rock is ophitic and the plagioclase laths of its main mass are 0.5—2 cm long and 0.3—1 cm broad. The composition of the core of the idiomorphic plagioclase phenocrysts is An_{58} ($\alpha = 1.558$, $\beta = 1.562$, $\gamma = 1.567$). The composition of the core of the plagioclases of the main mass is An_{53} and that of their narrow marginal zone An_{48}. Potash feldspar and quartz occur as xenomorphic crystals. Myrmekite is present between the potash feldspar and plagioclase. The myrmekite forms a band separate from both crystals alongside the plagioclase crystals but connects unsharply with the plagioclase at the ends of the crystals. Most abundant among mafic minerals is orthopyroxene (Fs_{45}, $\alpha = 1.712$, $\gamma = 1.725$, $2V\alpha = 60°$). Clinopyroxene is sometimes present in the orthopyroxene as very narrow lamellae parallel to 111. Around the pyroxene there is often green hornblende. In addition the rock contains biotite, in many instances chloritized, ore, a little muscovite and epidote as alteration products of plagioclase, as well as rather large apatite crystals sparsely situated as an accessory mineral. A chemical analysis of this rock is given in Table VIII, No. 2. (p. 77).

About 1 km WSW of the square marked on the map at Kuhaniemi there occurs bluish gray, somewhat brownish gabbro-anorthosite with sparse, 3—7 cm long plagioclase phenocrysts. In texture its groundmass is ophitic and the length of the plagioclase laths of the main mass is 0.5—2 cm. The mineral composition of the groundmass is shown in Table IV, No. 1. The composition of the plagioclase phenocrysts is An_{55} ($\alpha = 1.556$, $\beta = 1.560$, $\gamma = 1.564$). The plagioclase crystals (An_{52}) of the groundmass are likewise idiomorphic and zoned only along their borders. The margins of the crystals are colorless in thin sections, but the middle parts are gray. The gray color results from very small needle-like inclusions. The border of the gray and colorless part is abrupt. In places the plagioclase reveals a weed texture. In such instances the lamellar structure disappears and the extinction becomes indefinite. This is the case especially in the proximity of the potash feldspar. The potash feldspar (orthoclase, $2V\alpha = 53°$) occurs as vague patches and tongues, which are small within the plagioclase but larger in the interspaces. Between the plagioclase and potash feldspar there is myrmekite. The quartz is wholly xenomorphic. The ore occurs in largish crystals and tiny spots in the pyroxene. There is orthopyroxene ($2V\alpha = 64°$) in the interspaces and it is zoned in its marginal parts. In places it contains some clinopyroxene as very thin lamellae. The margin of the pyroxene has in many cases altered into green amphibole ($2V\alpha = 64°$, $c \wedge \gamma = 12°$). There is biotite partly around the ore and partly around the pyroxene.

Between Nurmaanjärvi and Siikajärvi dark bluish gray, coarse-grained, ophitic anorthosite-gabbro contains plagioclase phenocrysts. The mineral composition of the rock is given in Table IV, No. 2. The plagioclase (An_{56}) is idiomorphic and forms rather broad laths. The interstices are filled with pyroxene, consisting mainly of orthopyroxene ($2V\alpha = 66°$). The axial angle of the pyroxene may in some instances be larger. The pyroxenes have a broad altered marginal zone, which in Table IV, No. 2 has been designated as a kelyphite rim. Starting from the hypersthene, it contains serpentine, pale amphibole, green hornblende and, as the outermost component, biotite. Two of the former may be lacking in the kelyphite rim, but the biotite is invariably outermost. The hornblende, furthermore, produces a weed texture and the potash feldspar causes the formation of myrmekite in conjunction with the plagioclase.

Orthopyroxene is often no longer present in the greenish gray, yellowish gray and, in some instances, dark products of alteration — or then only an »iron skeleton» of it is left. The mafic minerals are thereupon brown and green hornblende, pale amphiboles, which have in part developed multiple twinning, after the habit of plagioclase, and in part have a radial extinction, as well as chlorite and epidote. In such alterations there is often an abundance of apatite. Rocks of this kind occur W of Iso-Vehkajärvi, in the NE part of the village of Paistjärvi, on the E side of Lake Pankajärvi and E and N of Lake Enonvesi.

The mineral composition of a greenish gray, coarse gabbro-anorthosite occurring between hornblende rapakivi and migmatite on the W shore of Juolasvesi is shown in Table IV, No. 3. The rock contains no pyroxene. To what extent this type is autometamorphic, to what extent metamorphozed by later intrusions, I do not wish to venture a guess. (See p. 63.)

The gabbro-anorthosite intrusion on the W shore of Nöilöppijärvi is also of a greenish gray type. In the middle part of the intrusion the rock consists to an extent of more than a half of 1—5 cm long pale gray plagioclase phenocrysts (An_{53}, $\alpha = 1.556$, $\gamma = 1.564$). The interstices of the plagioclase crystals are green and contain quartz, amphiboles and biotite. To a slight extent the rock contains ore, apatite, epidote and sphene. The marginal part of the intrusion is fine-grained and the plagioclase phenocrysts in it are less than 1 cm long and distinctly zoned (An_{45-55}). The mineral composition of the rock about 1.5 m from the contact is given in Table IV, No. 4. The amphiboles are green hornblende, but a small amount of pale amphibole is also present. The amphiboles in many instances occur in conjunction with chlorite and twist about the idiomorphic plagioclase crystals and penetrate into them to produce a weed texture. The epidote generally occurs in association with plagioclase and — in a minor amount — the sphene often with chloritized biotite.

PEGMATOID GABBROS AND ANORTHOSITES

Coarse pegmatoid gabbros and anorthosites occur here and there in the middle parts of the gabbro-anorthosite intrusions. They consist chiefly of large, 1—20 cm long and even longer plagioclase crystals and hypersthene crystals measuring 1—20 cm. The plagioclase crystals are idiomorphic. The hypersthene again is xenomorphic and occurs in interspaces, in places enveloping plagioclase crystals. The respective proportion of hypersthene and plagioclase varies. In places the hypersthene is almost totally lacking, whereas in other places it comprises more than half of the entire rock. The transition between two extreme types may be gradual, but it is often abrupt. Both types occur frequently as meandering veins, which intersect each other. In addition to plagioclase and hypersthene, the rock contains a minor amount of small quartz grains, potash feldspar, chlorite, ore and apatite.

About 200 m N of the end of the bay on the NW side of Siikajärvi, there occurs pegmatoid gabbro (Fig. 3) resembling that described in the foregoing; in general, it borders abruptly on coarse pegmatoid anorthosite. The composition of the plagioclase crystals in the gabbro is An_{53} ($\alpha = 1.556$, $\beta = 1.560$, $\gamma = 1.563$) and in the anorthosite the same (An_{53}, $\alpha = 1.556$, $\gamma = 1.563$). A peculiar feature of this site is that the hypersthene crystals are zoned. The zoning is clearly visible on the very surface of the rock. The core of the crystals is blackish brown and the border of the crystals is brown over a breadth of about 0.5—1 cm. Also in thin section the boundary of the zones is sharp, and in the border area there occur olivine, plagioclase and ore as inclusions. The center appears at its margin to alter somewhat into hypersthene, like that of the border area. Both hypersthenes have grown together in such a way that their main vibration axes (α, β, and γ) are parallel. In the hypersthene of the center ($2V\alpha = 77°$, $\alpha = 1.692$, $\gamma = 1.705$) there may be seen very thin lamellae parallel to 100. The hypersthene of the border area ($2V\alpha = 57°$, $\alpha = 1.696$, $\gamma = 1.709$) is homogenous. The following optical properties were measured for the olivine crystals occurring as inclusions: $2V\alpha = 83°$, $\alpha = 1.716$, $\gamma = 1.756$.

The same kind of pegmatoid gabbro occurrence is met with near Lake Eerolampi in the NNE part of the village of Paistjärvi. This occurrence, which was described already by Wahl (1925, p. 17), differs from the preceding in the respect that the hypersthene and also the plagioclase appear as large phenocrysts in the finer-grained groundmass. Alongside this gabbro occurrence there are outcrops of pegmatoid anorthosite, but it has not been possible to obtain a precise conception of the way the rocks intersect. A chemical analysis of the large hypersthene crystals of this pegmatoid gabbro has been made by Lokka (1943, p. 29). According to this analysis the com-

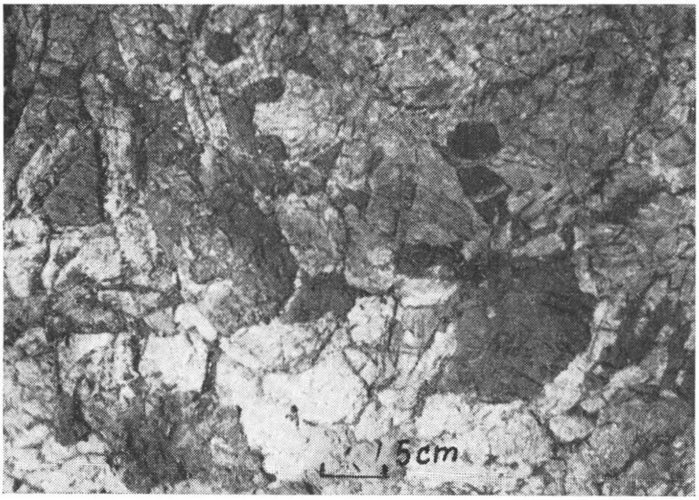

Fig. 3. Pegmatoid gabbro (hypersthene and plagioclase grains). About 200 m north of the end of the bay at the northwestern side of Siikajärvi, to the east of the rapakivi massif. (Photo by E. Viluksela.)

position of the hypersthene is as follows: 49.32 % SiO_2, 6.39 % Al_2O_3, 0.81 % TiO_2, 1.02 % Fe_2O_3, 16.40 % FeO, 0.26 % MnO, 23.52 % MgO, 2.02 % CaO, 0.00 % Alk., 0.03 % F, 0.37 % + H_2O, 0.08 % —H_2O. From the same specimen Sahama and Torgeson (1949, p. 9) have determined the optical constants of the hypersthene ($2V\alpha = 73°$, $\alpha = 1.698$, $\gamma = 1.711$) and investigated it thermochemically.

Similar pegmatoid gabbro areas are to be found e. g. NNE of Enonvesi and about 2 km NW of Pankajärvi. In the last-mentioned area the hypersthene grains have become transformed around their borders and fissures, or totally, into pale amphibole ($2V\,\gamma = 73°$, $c \wedge \gamma = 13°$, $b = \beta$, $\alpha = 1.643$, $\beta = 1.652$, $\gamma = 1.666$), and the pale amphibole rim is often surrounded, against the plagioclase, by a narrow biotite rim ($\gamma \sim \beta = 1.601$). The rock is penetrated by thin, pale veins measuring 0.1—0.5 cm in width and containing feldspar and quartz. The secondary nature of the pale amphibole is indicated by the fact that the veins intersect the hypersthene and plagioclase but not the pale amphibole and biotite.

ALBITE DIABASE DIKES

The albite diabase dikes consist of megaophitic rocks. Their plagioclase laths are of a pale green hue and measure over 10 cm in length and 2—5 cm in width. In composition the plagioclase is albite ($\gamma' <$ n Canada-balsam).

The interspaces of the plagioclase laths are dark green and contain green chlorite, pistacite, quartz, ore and a fair abundance of apatite. Potash feldspar is not present to any appreciable amount. Epidote is met with also as an alteration product of the plagioclase.

One such vein occurs on the W shore of Nurmaanjärvi, running in the direction N 20° W. Another is situated on the E shore of Iso-Vehkajärvi and runs in the direction N 60° E. Both veins border sharply on the gabbro-anorthosite.

CONTACTS OF THE GABBRO-ANORTHOSITE COMPLEX AGAINST OLDER ROCKS AND THE BOUNDARIES BETWEEN DIFFERENT GABBRO-ANORTHOSITE INTRUSIONS

The gabbro-anorthosite intrusions always have a chilled margin at the contacts against older rocks. (See p. 11.) In addition, the intrusions have had some effect on their country rock.

The gabbro-anorthosite intrusion of Nöilöppijärvi, about 7 km W of Vuohijärvi, is in contact with the porphyritic granodiorite at the S end of Nöilöppijärvi. At the contact the gabbro-anorthosite is fine-grained. Its plagioclase phenocrysts are less than 0.5 cm long. The rock gradually becomes coarser and its plagioclase phenocrysts reach a diameter of as much as 3—4 cm in the center of the intrusion. At the same time, the grain size of the groundmass grows from 1,5 mm at the contact to 5 mm in the center. The granodiorite has lost its characteristic texture over a width of several centimeters from the contact and altered into a fine-grained, brownish red rock, A short distance farther on the mafic minerals of the granodiorite have chloritized and its plagioclase sericitized.

Quite the same kind of contact is met with NE of Salmijärvi, about 100 m S of Ylä-Räävelinjärvi. On p. 20 there is a description of the transition of the gabbro-anorthosite into a coarser rock. Approximately 50 m N of the site described a high, extensive outcrop of porphyritic granodiorite occurs, at the foot of which I succeeded in exposing the contact for a length of a couple of meters. At the contact the gabbro-anorthosite is fine-grained, nearly aphanitic; and the porphyritic granodiorite there has melted and recrystallized into a dense rock, with an exceedingly micrographic texture. Somewhat farther on the porphyritic granodiorite has altered, assuming a reddish color, and its mafic minerals have chloritized. About 100 meters S the same kind of contact against migmatite is visible.

South of the aforesaid contact there are to be seen several contacts between the gabbro-anorthosite and, on the other hand, the migmatite, porphyritic granodiorite and gray porphyritic granite. They occur also at the N margin of the arch. All are like those described in the foregoing.

The gabbro-anorthosite arch around the rapakivi granite is not a single uniform intrusion but consists of many intrusions, as I have pointed out. I have not drawn the different gabbro-anorthosite intrusions on the map because their boundaries as weakness zones are not sufficiently exposed. On the other hand, I have marked with dotted lines those places where it appears to be quite clear that the boundary between two different intrusions is involved. The boundaries therein drawn divide the gabbro-anorthosite arch into seven different intrusions, which evidently intruded in succession at short intervals. Certain observations indicate that even more intrusions possibly exist.

W of the village of Paljakka on the S end of Lake Näätjärvi, there is a fine-grained marginal zone of the gabbro-anorthosite intrusion situated against the gabbro-anorthosite on the N and E sides. This fine-grained margin can be followed near the W shore of Näätjärvi in an easterly direction (see map) and from there about one km southward. On both sides of the turning point the fine-grained marginal variety can be observed bordering sharply on the gabbro-anorthosite on the N and E sides. The contact between them appears to be vertical. In the W and S directions the fine-grained margin grades over into normal gabbro-anorthosite (*cf.* description on pp. 20—22).

At the E end of Iso-Vehkajärvi such a fine-grained marginal transition can be followed for a considerable distance.

On the S shore of Pankajärvi there occur outcrops of fine-grained gabbro, which gradually becomes coarser as one proceeds E and N. The fine-grained border appears to run across the bay extending in a northerly direction from Siikajärvi, for fine-grained gabbro exposures continue also on the other side of the bay.

Opposite Kuhaniemi in Ylä-Räävelinjärvi there is a large headland. Along the shore of the cape the rock is fine-grained, growing coarser inland. This marginal variety continues eastward along the contact against the migmatites. In which direction the fine-grained margin extends on the S side of the cape has not been ascertained for sure; but possibly it runs from the end of the bay on the S side of the cape in an easterly direction.

East of the group of three Knuutinsaari islands (this local name is not marked on the map) situated at the W end of Ylä-Räävelinjärvi, the arch again breaks off. This is indicated by many observations: 1) The contact of the gabbro-anorthosite and migmatite on the N side of Ylä-Räävelin-

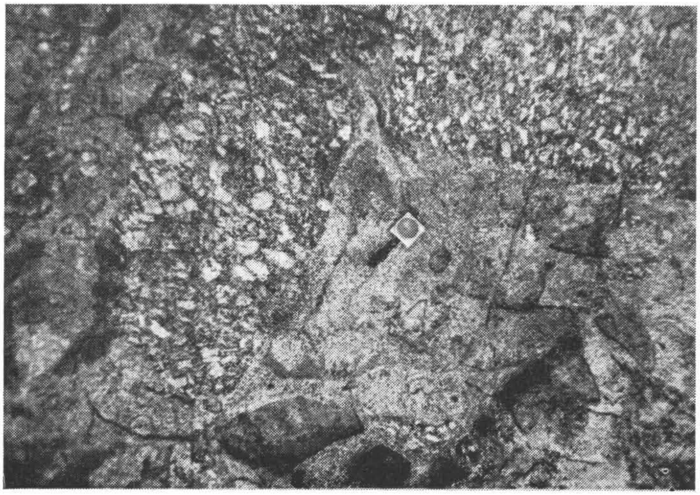

Fig. 4. Center of breccia zone. Porphyritic granodiorite fragment and gabbro-anorthosite fragments in microcline granite. North of Paistjärvi, east of Salmijärvi.

järvi arches in a southerly direction and does not run into the contact continuing on the S side of the lake. 2) The rock of the center of the easternmost island is migmatite. 3) In the E part of the microcline granite on the S side of Ylä-Räävelinjärvi fragments of fine-grained gabbro are found.

In the N part of the village of Paistjärvi E of Salmijärvi, light gray, fine-grained microcline granite runs into the gabbro-anorthosite (*cf.* p. 35) and forms a breccia zone, about 150 m broad, with porphyritic granodiorite and gabbro-anorthosite fragments (Figs. 4, 5). In the breccia zone attention is attracted to the circumstance that in the middle of it there are only porphyritic granodiorite fragments or scattered gabbro-anorthosite fragments and that toward the margins more and more gabbro-anorthosite fragments begin to be met with, while the porphyritic granodiorite fragments diminish in amount or, in places, disappear altogether. In the gabbro-anorthosite fragments situated in the central areas of the zone, the plagioclase phenocrysts measure 0.2—0.5 cm in length. In the gabbro-anorthosite fragments occurring in the marginal parts of the breccia, again, the plagioclase phenocrysts are 2 cm long. Furthermore, the porphyritic granodiorite fragments in the middle are likely to measure more than 10 m in diameter. My interpretation is that porphyritic granodiorite has remained between the gabbro-anorthosite intrusions. The

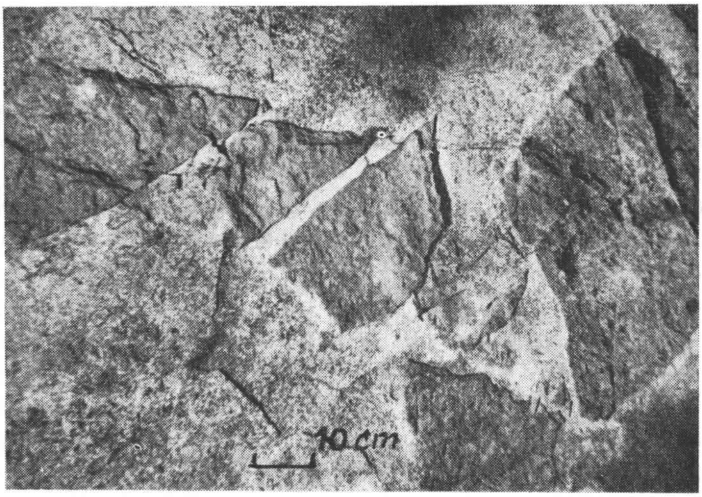

Fig. 5. Marginal part of breccia zone. Gabbro-anorthosite fragments (length 30—60 cm) in microcline granite. North of Paistjärvi, east of Salmijärvi.

microcline granite has then, at a later stage, brecciated the entire W part of the contact zone.

From this site about 1 km eastward a tongue of gabbro-anorthosite (marked on the map) extends in a southerly direction into the rapakivi. At the S end of the tongue there is a small exposure of fine-grained gabbro, which evidently represents the marginal zone of the gabbro-anorthosite at the N side continuing here from the preceding site. From here farther E there is a separate gabbro-anorthosite fragment of considerable size (marked on the map) in the rapakivi. Also at its S end the gabbro-anorthosite is finer-grained than usual, though not so fine-grained as in the aforementioned place.

In addition, the marginal zones of the different gabbro-anorthosite intrusions differ somewhat from each other. E. g. on the W shore of Juolasvesi and at the N end of Hietastenlampi the marginal zone possesses a fine-grained ophitic texture with a sub-parallel arrangement of the plagioclase laths, although it is generally elsewhere simply ophitic. Both types contain phenocrysts of plagioclase, the size of which varies. E. g. on the E side of Salmijärvi the ophitic groundmass contains labradorescent plagioclase phenocrysts exceeding 50 cm in length (An_{56}; $\alpha = 1.557$, $\gamma = 1.566$) and hypersthene phenocrysts about 20 cm long ($\alpha = 1.693$, $\beta = 1.703$, $\gamma = 1.706$) up to the very margin.

CONTACTS BETWEEN THE MICROCLINE GRANITE AND GABBRO-ANORTHOSITE INTRUSIONS

Microcline granite cuts the gabbro-anorthosites everywhere that the contacts between them are in evidence. It is hard even to imagine that all these cutting veins had originated as a consequence of partial remelting of the country rock caused by the gabbro-anorthosite intrusion. Such veins apparently do occur, to be sure, in places where the contact between gabbro-anorthosite and, on the other hand, migmatite, porphyritic granodiorite or porphyritic granite is to be seen (e. g. on the western and northern margins). These veins originating as a result of partial remelting of the country rock differ in texture, moreover, from the microcline granite. They regularly possess a micrographic texture (*cf.* Kahma, 1951, p. 34), are often meandering, and ordinarily also finer-grained than the microcline granite.

The basic rocks surrounding the rapakivi of the Ahvenisto massif in an arch have been regarded by Frosterus (1902) and Wahl (1925) as sub-Jotnian and associated with the rapakivis. (*Cf.* Sederholm, 1928, and Väyrynen, 1954.) A natural conclusion deriving from this is that the microcline granite dikes cutting the gabbro-anorthosite complex would be varieties of rapakivi and thus must be classified among rapakivi rocks. This conception is further supported by the fact that elsewhere as well basic rocks are associated with rapakivis. The microcline granite dikes cutting the gabbro-anorthosite complex as described in the following are, however, in both appearance and structure quite identical to the microcline granites and differ wholly from the rapakivis in appearance. In addition, the following differences between them may be remarked:

1. The quartz of rapakivis is idiomorphic and in many instances dark. In microcline granites it is generally pale and wholly lacking in independent form.

2. The potash feldspar in rapakivis is covered by a brown pigment, whereas in microcline granites, again, it is pale.

3. In rapakivis the potash feldspar is mainly orthoclase and partly microcline (Simonen and Kouvo, 1955, p. 62). In microcline granites, again, it is microcline.

4. The composition of the plagioclase in the rapakivi types of Ahvenisto is on the average $An_{20\text{-}30}$. In microcline granites it is $An_{8\text{-}20}$. Moreover, microcline granite veins contain relatively more plagioclase than rapakivi rocks.

5. The refractive index of the biotite of rapakivis ($\beta \sim \gamma = 1.670$—$1.695$) is considerably larger than that of the biotite of microcline granites ($\beta \sim \gamma = 1.658$—$1.665$).

6. The microcline granites cutting the gabbro-anorthosites also contain garnet, which is not met with in the rapakivi varieties of Ahvenisto. It has not been met with in any other rapakivi area either or in any rapakivi types, even in those cases where the rapakivi forms a breccia in Al-rich gneisses (see Hietanen, 1943, p. 64).

7. These microcline granites contain pegmatites in abundance, and part of the veins are coarse-grained pegmatitic. On the other hand, rapakivis contain little pegmatite.

8. Fluorite is generally lacking in these microcline granites, whereas, on the other hand, it is general met with in rapakivi rocks.

9. These microcline granites and different rapakivi types are never observed to pass gradually over from one to the other.

For these reasons the veins described can scarcely be regarded rapakivi dikes, while, furthermore, some of them may be observed to start directly from the microcline granite.

There is a peninsula named Kuhaniemi that juts into Ylä-Räävelinjärvi, and along the N side of it there is a boot-shaped bay. On the shores of this bay the contact between the microcline granite and the gabbro-anorthosite is plainly visible. A detailed map of this so-called Kuhaniemi contact is herein included (Fig. 6). The location of the area in question is marked on the large map. At point No. I in the figure the gabbro-anorthosite is in contact with the older migmatite. It is a fine-grained, ophitic gabbro with plagioclase phenocrysts at its contact. The gabbro is cut by narrow, fine-grained, reddish brown granite veins, which run in part along the contact. They have originated at least partly through the partial remelting of the country rock, even though in the vicinity the microcline granite penetrates the migmatite and tends also to cut the gabbro-anorthosite. On the S side of the same outcrop, at point II, where the gabbro-anorthosite has a coarser-grained groundmass, it is cut by the microcline granite. The dip of the contact is 60° S. This granite, even though it might be only as thick a dike as is visible in this exposure (about 10 m), could hardly be regarded any longer as palingenetic. Moreover, there is no reason to doubt that the microcline granite dike is at this point broader than is visible in the exposure, since identical microcline granite exposures, to be described in the following, occur in a southerly direction. At point III there is a steep gabbro-anorthosite cliff. About 2—3 m from its N side there is a microcline granite outcrop. In appearance and texture it is identical to the rock in the village of Nurmaa and E from it. In part it is fine-grained and in part coarse-grained, pegmatitic. The rock contains eye-shaped nodules of garnet (n = 1.817) and quartz measuring 0.5—1.5 cm in length and representing 4.5 % of the volume (see p. 15). It

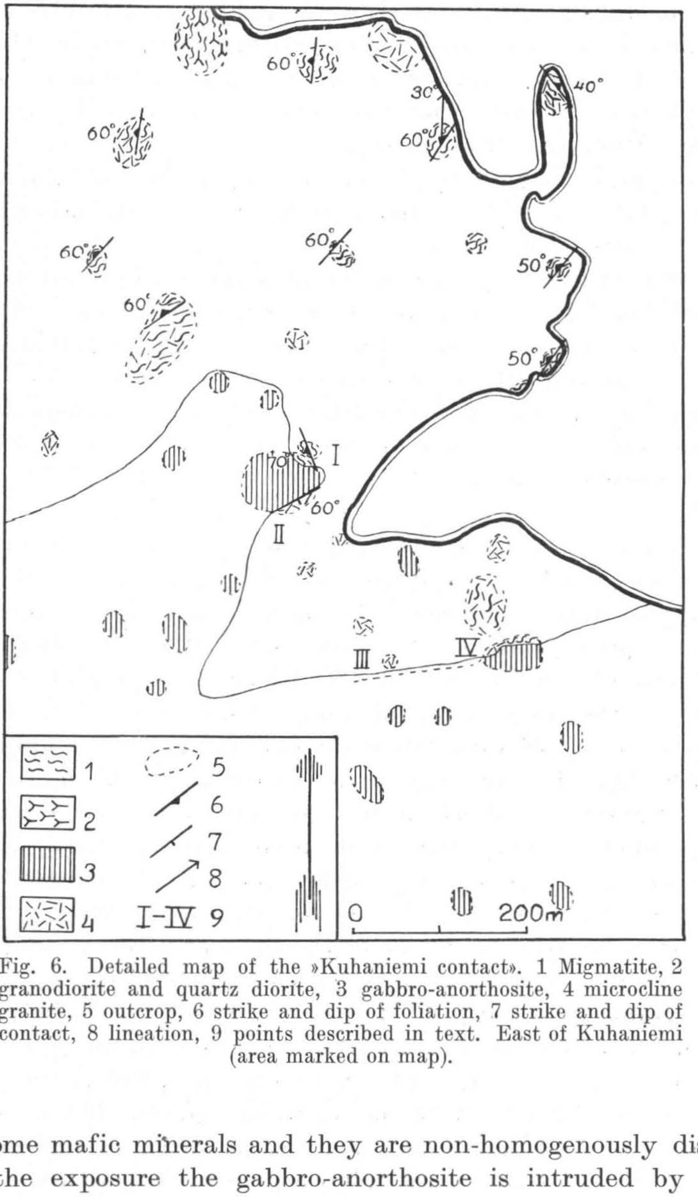

Fig. 6. Detailed map of the »Kuhaniemi contact». 1 Migmatite, 2 granodiorite and quartz diorite, 3 gabbro-anorthosite, 4 microcline granite, 5 outcrop, 6 strike and dip of foliation, 7 strike and dip of contact, 8 lineation, 9 points described in text. East of Kuhaniemi (area marked on map).

contains some mafic minerals and they are non-homogenously distributed. Opposite the exposure the gabbro-anorthosite is intruded by a similar microcline granite dike in a N 15° W direction and the dip of the dike is 50° W. I have succeeded in uncovering only one of the contacts of this dike. It should further be noted that the gabbro-anorthosite at this point is medium-grained and thus considerably coarser than on both sides of it near the contact. At point IV, about 100 m E, there is a group of exposures, where a coarse microcline granite is observed penetrating the

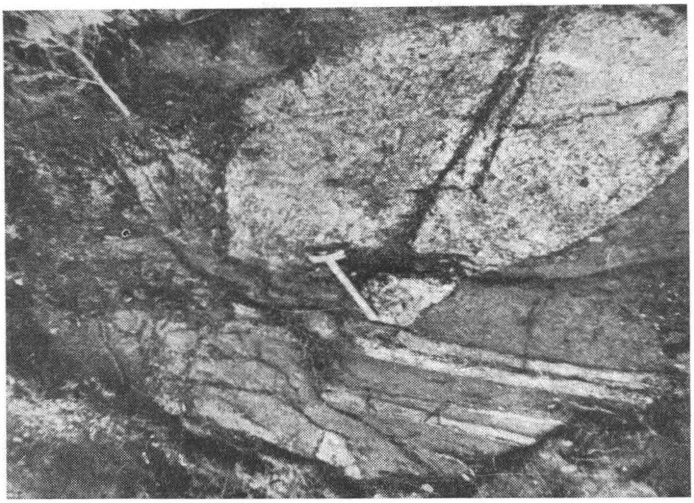

Fig. 7. Dikes branching out from the microcline granite into the gabbro-anorthosite. Point IV in Fig. 6.

gabbro-anorthosite in such a way that on proceeding along the contact in a NE direction the grain size of the groundmass of the gabbro-anorthosite diminishes. At the point where the line of contact forms an angle, three straight dikes starting from the microcline granite intrude into the gabbro-anorthosite (Fig. 7). The two dikes situated lower down in Fig. 7 also intersect each other. One of them is fine-grained and penetrates the microcline granite outside the contact, while the other is coarse-grained and starts from the microcline granite and cuts the fine-grained dike on the side of the gabbro-anorthosite. Less than a meter from the foregoing dikes in a northerly direction there is a third one of microcline granite, about 20 cm broad and coarse in grain. Some 10 m from these dikes to the NE there is a fourth one, about 15—20 cm broad, visibly starting from the microcline granite and cutting the gabbro-anorthosite. This dike can be followed in a straight line for about 20 m, after which it disappears under a moraine. Fig. 8 shows the end of the dike, where apophyses extending sideways can be observed. Further, ENE from the contact the microcline granite contains an abundance of older migmatite fragments and also some fine-grained gabbro-anorthosite fragments. Finally, from point IV in a NE direction near the lake shore there is a separate gabbro-anorthosite exposure surrounded by microcline granite outcrops. Evidently it is a large fragment.

After finding this contact in the summer of 1952 I became convinced that the gabbro-anorthosites are older than the microcline granite, inas-

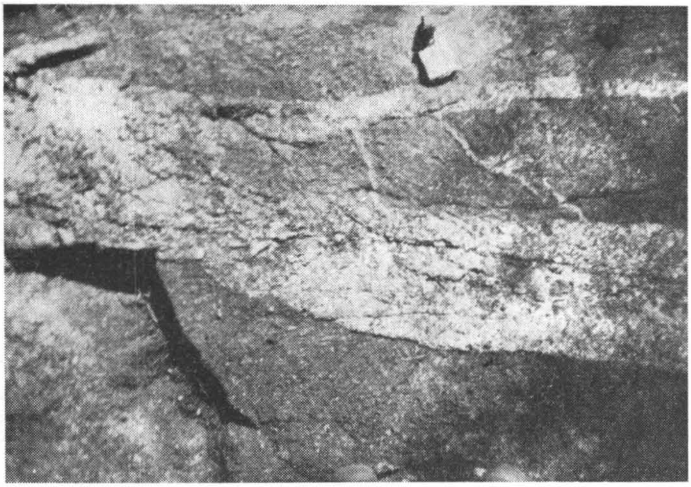

Fig. 8. Microcline granite dike in gabbro-anorthosite about 20 m from contact. Point IV in Fig. 6.

much as, on account of its large size, I could not regard the penetrating microcline granite as a product of partial remelting of the country rock caused by the intrusion of the gabbro-anorthosite, and because I could not believe either that the microcline granite containing an abundance of garnet belonged to the rapakivi complex. I am stili of the same opinion (cf. Savolahti, 1956, p. 47).

About 2 km W from the Kuhaniemi contact occurs the so-called Kauhkia breccia. (This local name is not indicated on the map.) A rapakivi dike measuring about 40 m in breadth runs approximately parallel to the contact between the gabbro-anorthosite and the younger migmatite and beautifully brecciates e. g. the gabbro-anorthosite (Fig. 9). The breccia zone is about 20 m broad and it also contains identical migmatite and coarse-grained microcline granite fragments. In the breccia are to be found gabbro-anorthosite fragments that contain migmatite inclusions. An important observation, however, is that the rapakivi contains a certain coarse-grained microcline granite fragment about 1 m long with two gabbro-anorthosite inclusions. One of the inclusions is about 20 cm and the other about 15 cm long. Around all the gabbro-anorthosite and migmatite fragments there is a transition zone a few mm broad, but these two inclusions situated in the microcline granite have been metamorphosed more, though they are still well recognizable. The plagioclase phenocrysts of the gabbro-anorthosite fragments are labradorescent, as in the gabbro-anorthosite in general. The composition of the plagioclase phenocrysts is An_{54} ($\alpha' \wedge 010 =$

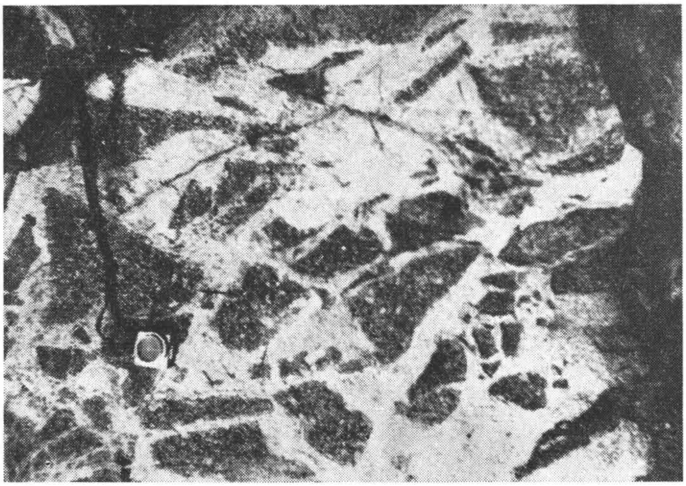

Fig. 9. »Kauhkia breccia». Gabbro-anorthosite fragments in rapakivi. Village of Kuhaniemi about 2 km west from the Kuhaniemi contact.

30° in a section ⊥ 010 and 001). The other minerals are hypersthene remnants whose axial angle could no longer be determined, greenish amphibole ($2V\alpha = 80°$, $c \wedge \gamma = 14°$), biotite, ore, potash feldspar and quartz, part of which is apparently secondary. These gabbro-anorthosite fragments contained in the microcline granite fragments cannot, as I understand it, be explained otherwise than that the gabbro-anorthosite is older than the microcline granite. It is inconceivable that such a coarse-grained pegmatitic part would have separated from the rapakivi magma before its main part crystallized, as presupposed by the appearance of the fragment in the rapakivi. The mineral composition of the gabbro-anorthosite itself, which here is a normal coarse-grained gabbro-anorthosite (Fig. 10), is as follows: plagioclase 74.2 %, potash feldspar 8.9 %, quartz 4.0 %, orthopyroxene 6.2 %, hornblende 1.7 %, biotite 0.8 %, ore 2.3 % and apatite 1.7 %. The composition of the plagioclase at the center of the phenocryst is An_{54} ($\alpha = 1.556$, $\beta = 1.560$, $\gamma = 1.564$, $\alpha' \wedge 010 = 30°$ from the section ⊥ 010 and 001). The potash feldspar ($2V\alpha = 53°$) is orthoclase. — Orthopyroxene: $2V\alpha = 64°$. — Amphibole: $2V\alpha = 64°$ and $c \wedge \gamma = 20°$. — About 20—30 m E from this breccia there is a point where the gabbro-anorthosite is in direct contact with the migmatite and the granite dikes cut both the gabbro-anorthosite and its country rock. Evidently, at least some of the dikes are microcline granite, although part may consist of granite deriving as a product of partial remelting of the country rock caused by the gabbro-anorthosite.

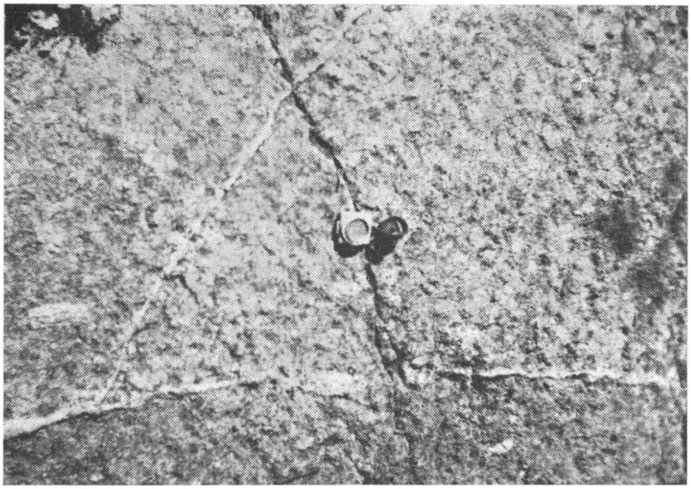

Fig. 10. Gabbro-anorthosite. Fifty m south of the »Kauhkia breccia».

Between the Kuhaniemi contact and the Kauhkia breccia, in addition, here and there far from the contact garnet-bearing microcline granite dikes occur in the gabbro-anorthosite.

On Kousaniemi on the S side of Ylä-Räävelinjärvi there is a considerable area of fine-grained, granoblastic, slightly foliated, garnet-poor microcline granite containing an abundance of pegmatites between the gabbro-anorthosite and biotite rapakivi. This microcline granite is marked on the map sheet of Mikkeli drawn by Frosterus and published in 1900, but it is missing from the detailed map of the »Ahvenisto area» included in the explanation to the map sheet, which was published by the same author in 1902. In this microcline granite there are gabbro-anorthosite fragments at numerous points, also on the southern margin of the granite, and, again, microcline granite dikes in the gabbro-anorthosite. One of the dikes is about 10 meters broad. The biotite rapakivi cuts the microcline granite at many points and they do not appear to grade over into each other anywhere (see p. 56).

At the E end of Ylä-Räävelinjärvi a long bay extends in a southerly direction. About 250 m S from the SW corner of this bay there is a contact between the gabbro-anorthosite and the microcline granite. The direction of the contact is W—E, and a short distance W from this spot it is N 60°E while its dip is about 60° S. Proceeding along the contact, the gabbro-anorthosite becomes coarser in grain toward the contact. No direct dike is visible in the gabbro-anorthosite, but the coarse grain of the gabbro-anorthosite at the contact indicates that it is an older rock. From this point about 2 km E a broad tongue of microcline granite penetrates the gabbro-anorthosite (see map). The contact against the coarse-grained gabbro-anorthosite is visible at the E margin of the tongue.

At the SW end of the gabbro-anorthosite arch in the NW corner of the small pond near Kelesjärvi, the microcline granite cuts in dikes and brecciates the gabbro-anorthosite. This granite does not appear to be rapakivi. The dikes, again, are so wide, often measuring several meters, that they cannot readily be regarded as products of a partial remelting of the country rock either.

QUARTS DIABASES

The quartz diabases are dark, either bluish or somewhat greenish, rocks with fine-grained, chilled contacts against the older rocks. In texture they are always ophitic — sometimes ophitic with a sub-parallel arrangement of the plagioclase laths — and contain plagioclase phenocrysts. The composition of the plagioclase of the quartz diabases is An_{45-62}. They invariably contain quartz, although this mineral may be almost lacking, but their analyses do not show normative olivine. The mafic minerals in these diabases are mainly pyroxene, amphiboles and biotite, which appreciably exceed those in gabbro-anorthosite in amount. The pyroxenes are in many cases of the clinopyroxene variety (often augite), but, especially in the marginal parts, orthopyroxene often prevails. The mafic minerals of the quartz diabases are, in addition, richer in Fe than those of other basic eruptive rocks in the Ahvenisto area. Two chemical analyses (3, 4) of the quartz diabases are presented (p. 77, Table VIII).

Quartz diabases occur as elongated, narrow intrusions all over the Ahvenisto area. The most extensive and coarsest quartz diabase occurs on Lautaniemi and Kuisaari, which jut into Vuohijärvi, as well as on the islands in between. The elongation of this 8 km long and over 1.5 km wide massif is N 70° W and its dip is 50°—80° N. Two smaller occurrences of quartz diabases are met with north of Kelesjärvi. The elongation of the diabase situated more to the south, containing small plagioclase phenocrysts, is N 70° W and it has a vertical dip. The diabase on the N side is coarser and runs in a W—E direction. On the E side of Siikajärvi there is a dark gray, small-grained quartz diabase dike about 2 km long, running in a N 20° W direction. Two rather small diabase areas are situated on the E side of Pankajärvi. The direction of the one to the S is N 45° W and its dip is 50° S, while the one to the N has a direction of N 30° W. On the N side of Pankajärvi there is a nearly triangular area of quartz diabase, ophitic in texture with a sub-parallel arrangement of the plagioclase laths.

In the islands to the E of Kuhaniemi in Ylä-Räävelinjärvi there are numerous vertical quartz diabase dikes running approximately W—E. In the gabbro-anorthosite of Kuhaniemi there is a quartz diabase intrusion shown on the map. About 1.5 km N 40° W from the N end of this quartz diabase dike another dike of quartz diabase, about 9 m wide, cuts the migmatite; this is not marked on the map. The strike of this dike is N 55° W and its dip 80° N. It can be followed near the gabbro-anorthosite, but then it vanishes.

Table V. Modes of quartz diabases

	1	2	3	4	5	6	7
Plagioclase	66.9	26.0	45.7	49.3	41.7	44.3	41.5 %
Potash feldspar	4.6	0.2	} 2.0	10.0	0.3	13.7	— »
Quartz	1.9	4.3		2.8	0.5	7.0	2.6 »
Olivine	0.3	—	—	—	—	—	— »
Pyroxenes	8.1	} 38.9	38.3	21.5	30.5	13.6	} 37.6 »
Amphiboles	10.9		—	4.8	7.7	14.1	
Epidote	1.3		—	—	—	—	
Chlorite	—		—	—	—	—	
Biotite	1.1	17.8	5.6	2.8	7.0	3.2	15.3 »
Ore	3.6	10.3	8.4	5.8	6.9	3.0	2.2 »
Apatite	1.3	2.5	0.1	3.0	5.4	1.2	0.7 »

The quartz diabase intrusion of Lautaniemi is a dark gray, coarse-grained, ophitic rock in its center. The plagioclase laths in it are often 2—3 cm long and 0.5 cm wide. The mineral composition of the diabase is given in Table V, No. 1. The composition of the plagioclase in the center of the crystal is (An_{61}, $\alpha = 1.560$, $\gamma = 1.568$). The plagioclase is zoned and its extinction angle decreases toward the margin in places more than 10° (An_{40}). The plagioclase is partially epidotized and the interspersed hornblende brings about a weed texture. Often olivine (Fa_{58}, $\alpha = 1.747$, $\beta = 1.778$, $\gamma = 1.792$, $2V\alpha = 69°$) occurs inside the augite and in its fissures there is black ore. In places the olivine is surrounded by a reaction rim. The pyroxene is largely clinopyroxene (augite). The augite ($2V\gamma = 46°$, $\alpha = 1.703$, $\gamma = 1.727$, $c \wedge \gamma = 29°$) appears as large crystals in the interstices. The reddish brown biotite ($\gamma \sim \beta = 1.664$) has begun to be chloritized in spots. In addition to hornblende the rock also contains pale amphibole. A chemical analysis of the middle part of the Lautaniemi diabase is given (p. 77, Table VIII, No. 3).

This diabase intrusion has nearly aphanitic chilling contacts. In the immediate proximity of the contact the mafic minerals have altered into amphibole, chlorite and biotite, while the plagioclase has epidotized and sericitized. The grain size of the groundmass of the rock somewhat farther from the contact is about 0.1 cm and it contains plagioclase phenocrysts measuring 0.5—1.5 cm in length. In addition, the rock contains amphibole, ore and biotite crystals as large as 0.2—0.4 cm. A couple of meters from the contact the mineral composition of the rock is shown in Table V, No. 2. The plagioclase is idiomorphic and clearly zoned. The pyroxene is largely of the orthopyroxene variety. The amphibole ($2V\alpha = 65°$, $c \wedge \gamma = 26°$) and biotite enclose plagioclase, pyroxene, ore and apatite; furthermore, they are enclosed within one another. There is always quartz in the interspaces and it often contains an abundance of apatite crystals.

The quartz diabase situated on the south side at the NNE end of Kelesjärvi is 1—2 mm, dark gray and ophitic. It contains plagioclase phenocrysts, 0.5 cm long. The mineral composition of the diabase a few meters from the contact is given in Table V, No. 3. The plagioclase is zoned (An_{55-45}) and fresh. The pyroxene occurs also in the form of phenocrysts, which are orthopyroxene ($2V\alpha = 51°$). Reddish brown biotite often occurs around the pyroxene and the ore. The ore occurs as xenomorphic crystals in the interspaces. There is very little amphibole. Apatite is present in the form of extremely small prisms. A chemical analysis of the marginal part of this diabase intrusion is given in Table VIII, No. 4, p. 77.

The intrusion E of Siikajärvi is a dark blue-gray diabase, which is greenish on its weathered surface. It contains plagioclase phenocrysts measuring 0.5 cm and here and there poikilitic amphibole crystals measuring 2—4 mm. The plagioclase of the groundmass occurs as laths measuring 0.7—0.3 mm in length and 0.1—0.3 mm in width. The mineral composition of the rock near the margin is given in Table V, No. 4. The plagioclase laths are zoned (An_{53-45}) and in their center are small, dark inclusions, whereas their margin is clear. Potash feldspar fills the interstices, replacing the plagioclase. The pyroxene consists of both orthopyroxene and clinopyroxene, being generally unaltered, though against the potash feldspar the rock has undergone alteration to a slight degree. The orthopyroxene ($2V\alpha = 52°$) extinguishes in thin sections in large areas at the same time and is zoned. The clinopyroxene occurs as independent crystals but also as lamellae in the orthopyroxene and then sometimes forms a coherent rim around it. The rim and the lamellae extinguish at the same time. Amphibole and biotite are often present as large, poikilitic crystals, enclosing plagioclase, pyroxene and ore. The biotite forms, in conjunction with the ore, a myrmekite-like intergrowth. Ore is present generally in indefinite patches (0.1—0.3 mm) in the plagioclase, pyroxene and amphibole. Apatite occurs partly in large and partly in small crystals. An interesting observation is that the apatite forms large crystals in the marginal zone against the potash feldspar of the plagioclase, which is there poorer in anorthite, and that it also occurs at the core of the same crystal as very tiny crystals.

The quartz diabase at the N end of Pankajärvi is dark gray, ophitic with sub-parallel plagioclase laths, 1 cm long and 2—3 mm wide. Its mineral composition near the S end of the intrusion is shown in Table V, No. 5. The plagioclase consists of zoned (An_{58-48}) laths. The pyroxene is both rhombic and monoclinic. The orthopyroxene ($2V\alpha = 52°$) occurs probably in greater amounts. The clinopyroxene is present often in the form of lamallae and patches enclosed in the orthopyroxene. In many cases the pyroxene has an amphibole rim, and the amphibole penetrates the plagioclase, producing a weed texture. In connection with the weed texture, the refractive index of the plagioclase appears to have diminished. The ore is xenomorphic and around it there is often a biotite rim, formed by crystals in numerous different positions. The apatite occurs as large idiomorphic crystals. At one point the apatite has crystallized around an xenomorphic ore grain. At another point the apatite is replaced by amphibole.

At Kuhaniemi the quartz diabase intrusion in the gabbro-anorthosite is ophitic, fine-grained around the margins and coarser-grained in the center. Its mineral composition is given in Table V, No. 6. The composition of the plagioclase is An_{53}. The pyroxene takes the form of both orthopyroxene and clinopyroxene, the former in greater quantity. Amphibole is often present around the pyroxene, but it also occurs as independent crystals. Brown biotite, again, is ordinarily met with around the amphibole. The ore has separated from the pyroxene, but it occurs also as independent anhedral grains. Apatite is to be observed as tiny prisms in the plagioclase, but in the potash feldspar, biotite and amphibole it forms large prisms.

North of the foregoing intrusion on Kuhaniemi, there is a dike in the migmatite consisting of greenish black, beautiful ophitic diabase, which is quite aphanitic and crushed at its margin and slightly coarser at the center. It contains yellowish gray plagioclase phenocrysts measuring 0.5 cm. The composition of the central part is shown in Table V, No. 7. The plagioclase is extremely zoned (An_{50-35}). To some extent the plagioclase is epidotized and to some extent stained with weed-like hornblende needles. Quartz occurs in the interstices, and also as small inclusions in the amphibole and biotite. The amphibole further contains ore inclusions and biotite. Brown biotite often occurs around the ore, and the margin of the biotite has altered into amphibole. Apatite is met with as thin, long laths.

The pyroxenes are of both the orthopyroxene ($2V\alpha = 51°$) and clinopyroxene ($2V\gamma = 49°$, $c \wedge \gamma = 32°$) varieties. Within the brown hornblende ($2V\alpha = 69°$, $c \wedge \gamma = 23°$) there is sometimes a small amount of pale amphibole.

CONTACTS OF QUARTZ DIABASES WITH GABBRO-ANORTHOSITE INTRUSIONS AND MICROCLINE GRANITE

The contact of the fine-grained quartz diabase and gabbro-anorthosite on the S side at the N end of Kelesjärvi is visible at the S margin of the diabase intrusion. It is a sharp chilling contact. The gabbro-anorthosite next to the contact is metamorphosed, while the plagioclase is epidotized and the pyroxene undergoing partial alteration into chlorite and amphiboles.

Both contacts, which are almost vertical, of the southern quartz diabase at the E end of Pankajärvi are visible. They are likewise sharp, and the diabase gradually becomes coarser toward the center of the intrusion. Here too the gabbro-anorthosite appears to have somewhat altered at the contact.

Both contacts, which are vertical, of the fine-grained quartz diabase dike situated on the eastern island, known as Haapasaari, off the E shore of Kuhaniemi, are exposed at two points. The contact is sharp and the gabbro-anorthosite has altered at the contact. Moreover, narrow, wedge-like, granitic veins, which seldom penetrate the gabbro-anorthosite, twist and turn in the diabase.

The quartz diabase in the gabbro-anorthosite of Kuhaniemi is fine-grained at its contact and grows appreciably coarser toward the center of the intrusion from both contacts.

On the westernmost of the Knuutinsaari islands a quartz diabase dike several meters wide with a strike of N 60° E and a vertical dip penetrates the gabbro-anorthosite intruded by microcline granite (see p. 31). The diabase dike contains winding, wedge-like, narrow, red, granitic veins, which also penetrate the gabbro-anorthosite. These veins hardly belong to the microcline granite, which cuts the gabbro-anorthosite as straight dikes, which generally run along the cleavage joints, whereas these veins twist and turn. Furthermore, the granite of the veins is also different in texture. The gabbro-anorthosite is somewhat metamorphosed at the contact. Its mafic minerals are green and its plagioclase pale yellow-green from epidote.

The fine-grained quartz diabase of the N end of the easternmost Knuutinsaari becomes notably coarser in grain as one proceeds northward. The center of the island, again, consists of migmatite, which contains a great abundance of microcline granite, so that the quartz diabase appears to be younger than the microcline granite.

N of the bay jutting in from Vuohijärvi on the S side of the Lautaniemi diabase intrusion, there is a contact between the quartz diabase and garnet-bearing microcline granite. At this contact the diabase is plainly younger than the microcline granite. Ramsay (1887, pp. 45—46) had found this contact and interpreted it in the same way. In this exposure the strike of the contact is N 60° W and its dip 40° N. After a short distance the contact bends, changing its strike to N 55° E and its dip to 75° W. At the point of the bend a diabase dike about 1.5 m long and 15 cm wide — but narrowing — penetrates the microcline granite. The diabase is very fine-grained at the contact and gradually grows coarser in grain. The microcline granite has become dark red and very fine-grained at the contact over a breadth of a few centimeters, and the garnet crystals have disappeared from it. From the microcline granite there branches off a thin, likewise fine-grained, red granite vein, which penetrates the diabase for a distance of less than a meter. The vein is evidently a product of partial remelting of the country rock induced by the diabase intrusion. In the fine-grained marginal zone of the microcline granite and in the granite vein just described there occur green, partly chloritized mica and more plagioclase than in ordinary microcline granite. Attention is also attracted by the abundance of apatite, which occurs in clusters of crystals, penetrating into other minerals. In part the apatite crystals have crystal faces but in part they occur as anhedral grains with irregular boundaries. In some cases the same individual crystal is xenomorphic at one end while the other has clear crystal faces.

The quartz diabase dike on Kuhaniemi NNW of the quartz diabase intrusion is 9 m wide and has a strike of N 55° W and a dip of 80° N and also clearly cuts the microcline granite. This diabase dike is in the migmatite. Its contact is visible for hundreds of meters and the country rock of the dike consists of veined gneiss (older migmatite), which the microcline granite penetrates in broad veins; but the veins always break off at the point where they meet a diabase dike. At the contact the microcline granite is always fine-grained and brownish red. Here and there in the diabase occur narrow, winding granitic veins, which appear identically both against the veined gneiss and the microcline granite. The diabase, again, has a clear, fine-grained chilled margin against the country rock, just as elsewhere.

Without a doubt the quartz diabases occur as cutting intrusions in the gabbro-anorthosite. A more difficult question, on the other hand, is to what extent they represent the veins of some neighboring and at the same time younger gabbro-anorthosite intrusions. This tends to be indicated by their varying composition; but all of them are by no means of such a description, for part, in accordance with the foregoing commentary, are clearly younger than the microcline granite. Furthermore, e. g. the quartz diabases on the N side of Kelesjärvi occur in gabbro-anorthosite that, according to the observations made, represents a younger intrusion than that on its E side.

BIOTITE RAPAKIVIS

Biotite rapakivi forms the main part of the Ahvenisto massif, surrounded by basic rocks. It has in places disintegrated into »moro», but to a great extent it is quite fresh granite. There is likely to be a greater abundance of the rock undergoing disintegration into »moro» in the marginal parts of the massif. Biotite rapakivi granite is brownish red or light brown in color, but in disintegrated places it is brownish gray. The rock varies in grain from medium to coarse. It contains potash feldspar grains 1—3.5 cm long and 0.5—1.5 cm wide, quartz grains measuring 0.2—0.4 cm in diameter, and biotite scales 0.1—0.4 cm in length. The potash feldspar crystals of the rock are angular, but in the central parts of the area they are in places ovoid in shape. In some cases the angular potash feldspar crystals are like bricks in a pile, giving the appearance of parallel orientation. Potash feldspar ovoids surrounded by plagioclase, as is typical of rapakivi rocks, are seldom met with. They have been run across NW of Pankajärvi, W of Enonvesi and E of Korpijärvi. In the highway cuts SE of Lake Valkjärvi (this new road is not marked on the map) there also occur some oligoclase rings around roundish groups of minerals. These mineral clusters consist of fine-grained granite and measure 2—5 cm in diameter. In places the biotite rapakivi is porphyritic. There potash feldspar phenocrysts 2.5—4 cm long and 1—2 cm wide occur in rapakivi that is distinctly finer in grain than elsewhere. The aforesaid types pass gradually one into the other. One such gradual transition is to be observed in the highway cut about 2 km SE from Valkjärvi. The rock of the thin dikes and sheets penetrating the gabbro-anorthosite in different positions is in part slightly smaller in grain than that of the rapakivi massif proper. The potash feldspar crystals of the last-mentioned, even-grained rapakivi are 1—1.5 cm long and 0.5—1 cm wide. Also the other minerals are somewhat smaller in grain than those of the main types. Otherwise, these rocks are the same in appearance and texture as other biotite rapakivis.

The mineral composition of biotite rapakivi varies, notably in respect to the relative amounts of potash feldspar and quartz. On the smooth surface of the rock it appears as if the quartz crystals formed a network in which there were different amounts of potash feldspar crystals in different places. The mineral composition of the biotite rapakivi is: potash feldspar 57—63 %, quartz 26—33 %, plagioclase 6—8 % and biotite 4—5 %. In addition to biotite they are likely to contain some hornblende. Accessory minerals are apatite, fluorite and zircon (0.5—1 %). Ore is always present, often hematite, and in addition alteration products.

The color of the potash feldspar varies between red-brown and light brown. The potash feldspar is partly orthoclase, since some chips //001 show parallel extinction, and partly microcline, as evidenced by a microcline quadrille structure, which, however, is often obscured by a thick hematite pigment. Plagioclase in the form of perthite accounts for 19—24 % of the volume of potash feldspar. The perthite occurs as very broad veins and in greater abundance in the center of the crystals than in the marginal areas. The plagioclase occurring as perthite often has broad twin lamellae, in accordance to the albite law. The potash feldspar grains sometimes consist of two parts. The center of the grain is an idiomorphic crystal, whose margin is visible. The marginal zone is anhedral and contains especially quartz inclusions, often arranged into zones. The entire grain extinguishes simultaneously.

The mineral constituent next in abundance is quartz. It varies in color in different types, being black-gray, light gray or reddish gray. The quartz occurs generally as idiomorphic crystals measuring 2—4 mm between the potash feldspar crystals. Crystal faces are to be seen in the quartz grains even megascopically. When situated side by side the quartz crystals sometimes are joined together in saw-tooth fashion. Another part of the quartz grains are quite xenomorphic. The xenomorphic quartz crystals are generally small (about 1 mm) in diameter, round in form or totally anhedral. They are often lighter in color than the idiomorphic crystals. These quartz grains occur generally in the marginal parts of potash feldspar crystals as inclusions, but they are met with also e. g. in the marginal areas of plagioclase crystals. In places the intergrowth of potash feldspar and quartz results in a beautiful graphic texture. The amount of idiomorphic and xenomorphic quartz varies from place to place. In e. g. the fine-grained types there is a greater abundance of xenomorphic than idiomorphic quartz.

The plagioclase ($An_{22\text{-}28}$; $\alpha = 1.542$, $\gamma = 1.550$, $2V\alpha = 80°$, its maximum extinction angle in sections $\perp$ 010 is at the margin 6° less than in the center of the crystal) is, owing to pigment or alteration, dark reddish brown, green-gray or yellowish gray in color. It occurs in small crystals, which are generally idiomorphic but, of course, not against idiomorphic quartz. The plagioclase crystals are often sericitized and epidotized in the center, but the margin of the crystals is clear. These altered crystals are greenish gray or yellowish gray. The reddish brown color, again, results from a fine hematite pigment. As in potash feldspar crystals there are quartz inclusions here and there in the marginal parts of the plagioclase crystals. In places these quartz grains are arranged into zones. The border of the idiomorphic central crystal of the plagioclase grains is often visible. Plagioclase grains occur in places also as inclusions in other large plagioclase grains, which are more albitic than the inclusions.

The mafic minerals chiefly consist of black biotite. There is some green hornblende here and there, but always in considerably smaller quantity than biotite. The biotite ($\gamma \sim \beta = 1.677$—$1.692$, $\gamma \sim \beta$ = black-brown, α = yellow-brown) occurs as flakes or clusters of crystals measuring about 1—4 mm in diameter. In places it is fresh but in other places it is in process of chloritization, in which case ore is separated into its cracks. The mafic minerals of the aforementioned types are megascopically greenish. The biotite encloses idiomorphic quartz and also potash feldspar.

Fluorite occurs as anhedral, in places rather large grains in interstices and often in conjunction with plagioclase or in cracks of chloritized and twisted biotite. Also apatite crystals are often found in conjunction with chloritized biotite. Zircon frequently is enclosed in biotite, ringed with a plechroic halo. Chemical analyses of the biotite rapakivi rocks are listed on p. 77. (Table VIII, Nos. 5, 6).

Here and there in the biotite rapakivi one runs across sharply bounded fine-grained, granitic, partly aplitic inclusions measuring between 5 and 30 cm in length. These inclusions are shaped like waterdrops or ellipsoids with one end sharper than the other. These ellipsoids are situated rather vertically (dip 60°—90°), their sharper end pointing downward. This phenomenon indicates an upward movement during crystallization. The inclusions often contain scattered, potash feldspar phenocrysts, 1—3 cm long, in many cases having a ragged marginal zone with inclusions of other minerals and a sharp border against the crystal core. Quartz also occurs as phenocrysts, which measure 1—4 mm in diameter, are partly idiomorphic and sometimes contain other minerals as inclusions. In thin sections plagioclase crystals slightly larger than the groundmass crystals can occasionally be seen. These grains of plagioclase likewise have a ragged marginal zone containing inclusions and abruptly bordering on the idiomorphic crystal core. Biotite is present in the inclusions, not only as small, independent crystals in the groundmass but also as large crystal clusters. The groundmass of the inclusions in places has a distinct micrographic texture. The pigment of the potash feldspar contained in the groundmass appears to grow more intense from the margin of an inclusion toward the center. Likewise the plagioclase is more sericitized and the biotite more chloritized in the center of an inclusion than at the margin.

In addition to the inclusions just described, the rapakivi contains, especially in the marginal parts of the intrusion, other kinds of inclusions, which are evidently fragments of country rock and which must be strictly distinguished from the former. Some of these fragments are angular and some of them rounded. In many instances they are surrounded by a fine-grained border 1—4 cm in width, poor in mafic minerals and granular in texture.

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PORPHYRY APLITES

Biotite rapakivi contains small veinlike porphyry aplite [1]) intrusions, situated in different positions, some of them vertical and some horizontal. The porphyry aplites are located chiefly in the marginal parts of the rapakivi area. Bordering very sharply on the rapakivi they contain rapakivi fragments. However, they have had no contact effect whatsoever on the rapakivi and are not even finer in grain along the margins of the intrusions than in their centers. Evidently the porphyry aplites represent a later differentiation (in situ) of the biotite rapakivi magma.

The porphyry aplites are reddish brown, fine-grained rocks (with grains measuring 1—2 mm). Sparsely scattered in them are potash feldspar phenocrysts 2—3 cm long and 1—2 cm wide, in many cases angular, though round grains also occur. Some of the potash feldspar phenocrysts have a ring of plagioclase. They appear to vary in amount from place to place quite arbitrarily. Notably idiomorphic, generally dark quartz phenocrysts measuring 2—4 mm in diameter are invariably present. Likewise idiomorphic, small plagioclase phenocrysts, often sericitized, are met with. Phenocrysts in the porphyry aplite have often subsequently continued to grow. In such cases the previous margin of a crystal has remained in evidence while the margin developing later often contains other minerals as inclusions.

The mineral composition of the porphyry aplites is: potash feldspar 42—50 % (without phenocrysts), quartz 21—29 %, plagioclase 18—20 %, biotite and a slight amount of amphibole 7—8 %, accessory minerals 0.4—1 % and some products of alteration. In conjunction with quartz the potash feldspar often forms a graphic texture, which in many instances is lacking in the crystal core. The center of certain potash feldspar grains is orthoclase, exhibiting a straight extinction in sections ⊥ 010, while the marginal part is microcline, for it exhibits a quadrille structure and the extinction is oblique in sections ⊥ 010 (Fig. 11). There appears to be less perthite in the center of the crystals than in their marginal parts. The average perthite content of potash feldspar is 8—10 % by volume, or considerably less than in the potash feldspar of rapakivi. The plagioclase (An_{28-20}, $\alpha = 1.541$) is idiomorphic and zoned. The hornblende is often absent. Whenever it happens to be contained in the rock, it penetrates the plagioclase, which also contains sericite. The biotite ($\gamma \sim \beta = 1.697$) occurs in poikilitic form or in grain clusters. It is locally chloritized. The

[1]) Kanerva (1928, p. 4) writes: »Ich werde hier nach dem Vorschlag von Professor Eskola die Benennung Porphyraplit für eine Reihe von Gesteinen anwenden, die zwischen den Apliten und den Granitporphyren stehen und die für das Vehmaagebiet sowie auch für das Laitilagebiet charakteristisch sind. Einige Vorkommen kommen den grobkörnigen Porphyrgraniten nahe, andere wieder ähneln schon den wirklichen Granitporphyren».

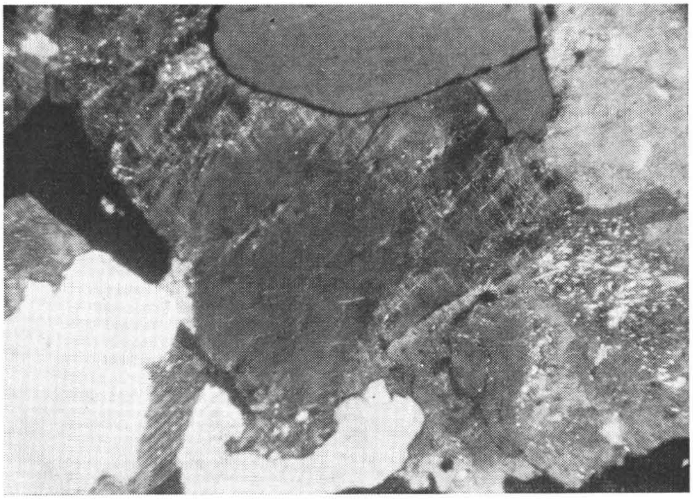

Fig. 11. Potash feldspar grain in porphyry aplite. Center of grain (dark) is orthoclase. Marginal parts are microcline (quadrille texture). Crossed nicols, x 35. Northward 2.5 km from the northern end of Iso-Vehkajärvi.

accessories are fluorite, zircon and apatite. Fluorite often occurs in the proximity of plagioclase and zircon within the biotite.

A chemical analysis of the porphyry aplite occurring about one kilometer east of Lake Korpijärvi is included in Table VIII, No. 7.

APLITES AND PEGMATITES

Both the biotite rapakivis and the porphyry aplites contain aplites and pegmatites of their own. There is not much of either, but the pegmatites exceed the aplites in quantity. Frosterus' publication (1902, p. 79) includes a microphoto of an aplite. The aplites mainly consist of feldspar and quartz with a few biotite flakes, and their texture is hypidiomorphic. The feldspar is albitic plagioclase for the most part. In some instances a little topaz was found. The pegmatites contain chiefly quartz, potash feldspar, albite and fluorite ($n = 1.434$). In some cases the fluorite in the miarolitic cavities of the pegmatites occurs as idiomorphic crystals of a violet hue and measuring over 1 cm in diameter. I have also found calcite crystals ($\omega = 1.661$, ε' on $10\bar{1}1 = 1.567$) though in only one pegmatite of the porphyry aplites, on the eastern side of Enonvesi. The same pegmatite also contained colorless albite crystals, 1 cm long. Evidently the fluorite occurring as fissure veins in the microcline granite and gabbro-anorthosite on the southern side of Ylä-Räävelinjärvi has been derived from the pegmatites of rapakivi. The biotite rapakivi and porphyry aplite also contain miarolitic cavities, which are generally met with in rapakivi rocks.

Quartz often occurs in pegmatites in the form of beautiful crystals. At the southern end of Pankajärvi a 20-cm wide pegmatite vein contained pale α-quartz crystals measuring 2—3 cm in length.

THE CONTACTS BETWEEN THE BIOTITE RAPAKIVI AND THE OLDER ROCKS

The contacts of the biotite rapakivi and its country rocks are cross-cutting and very sharp. Where there are enough exposures it is necessary to draw the contacts straight also on the basis map on the scale of 1: 10 000 and to make the bends along the way sharp. This feature occurs beautifully e. g. at the contact between the rapakivi and the migmatite at the western margin of the massif, where there are numerous outcrops. Moreover, it is to be observed at this point that the amount of the granite component of the migmatites and the degree of metamorphism of the gneiss component near the contacts vary quite arbitrarily and regardless of the rapakivi and in many cases increase on proceeding away from the rapakivi. The gabbro-anorthosite intrusions are cut by the rapakivi even more beautifully than the migmatites. Numerous straight dikes varying in thickness and position penetrate the gabbro-anorthosite, large fragments of which have remained inside the rapakivi. A mere glance at the map suffices to reveal the penetrating nature of the rapakivi.

The dip of the biotite rapakivi contacts is often rather vertical, but more gently sloping boundaries are also met with. Different values can often be measured in spots located near each other.

CONTACTS AGAINST THE GABBRO-ANORTHOSITE COMPLEX

Gabbro-anorthosite fragments are marked on the map on the cape jutting out in a westerly direction between Enonvesi and Ylä-Räävelinjärvi. The fragments and their contacts at the tip of the cape are wholly exposed. This area constitutes, in a sense, a huge eruptive breccia, and in addition the gabbro-anorthosite fragments contained in it are penetrated by biotite rapakivi dikes.

At the northern end of Lake Saukkolampi (this local name is not marked on the map), which is situated in the village of Enolahti on the N side of the small porphyry aplite area about 2 km NW of the northern shore of Pankajärvi, there occurs a contact between rapakivi and gabbro-anorthosite. The contact, which can be followed from the NE corner of the pond in the direction N 30°E, has a dip of 60°—75°W. At a point there occurs

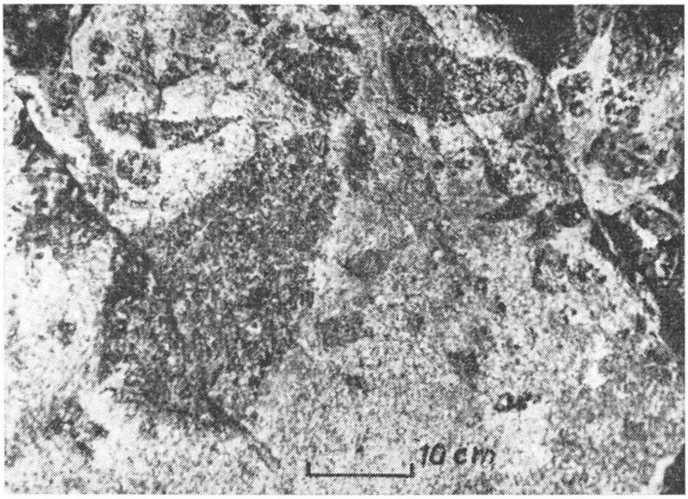

Fig. 12. Eruptive breccia. Gabbro-anorthosite fragments in biotite rapakivi. 2.5 km NW from northern end of Pankajärvi.

a breccia, with angular, coarse-grained gabbro-anorthosite fragments contained in the biotite rapakivi (Fig. 12); these fragments have altered, at least in their marginal parts. The plagioclase has epidotized and sericitized. There appears to be a greater amount of potash feldspar and quartz than generally in gabbro-anorthosite. The mafic minerals have altered into biotite and amphibole, which together form crystal clusters. Biotite is usually present in the margin of such a cluster, while in the center amphibole and quartz are found in addition to biotite.

About 0.5 km WNW of Saukkolampi there is another contact, with a strike of N 20°W and a dip of 80°E. From the biotite rapakivi there runs a dike about 20 cm broad into the coarse-grained gabbro-anorthosite.

The gabbro-anorthosites are cut by numerous rapakivi dikes, whose connection to the rapakivi is not to be seen directly; but in texture and appearance they resemble biotite rapakivi dikes. In many cases a porphyry aplite dike occurs in conjunction with such a biotite rapakivi dike, and it either runs parallel to the rapakivi dike or intersects it. Porphyry aplite dikes of this description are to be found, for example, north of Siikajärvi.

CONTACTS AGAINST THE MICROCLINE GRANITE AND THE SCHISTS

Some 600 m north of Viilajärvi there is a vertical contact (Fig. 13) between the microcline granite, which cuts the amphibolites, and the biotite rapakivi. The contact is to be seen in an almost vertical wall of rock about

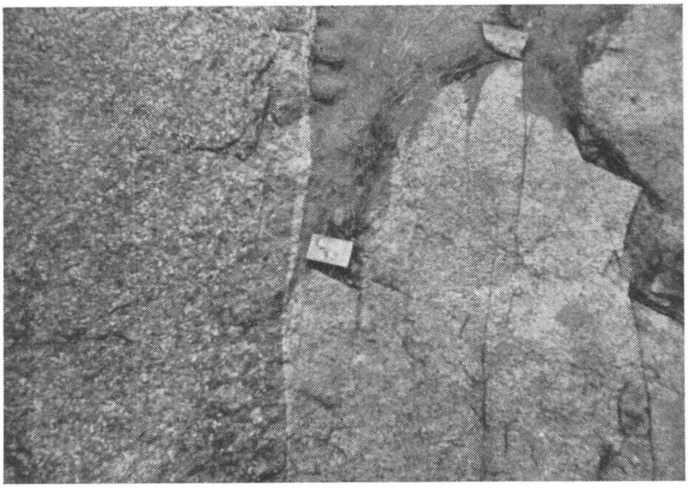

Fig. 13. Contact between biotite rapakivi and amphibolite as well as microcline granite. 600 m north of Viilajärvi.

5 m high, and from on top of the rock it can be observed for a distance of more than 100 m in a southerly direction. The rapakivi is coarse-grained as far as the contact. Upon schists running into contact with the rapakivi, they are in many cases metamorphosed to a width of 1—5 cm at the contact, and their mafic minerals have partly altered into orthopyroxene.

About 100 m north of Viilajärvi there occurs a contact between rapakivi and microcline granite in the amphibolites, the dip of which is 60°E. From the rapakivi runs a dike about 20 cm wide into the microcline granite, and the former contains fragments of the latter, at the margin of which there is often a dark selvage 2—3 cm wide, containing an abundance of green hornblende, biotite and ore. Quite a number of similar contacts occur between Imjärvi and Kesiönjärvi. The microcline granite often has a dark, narrow border at the contacts with rapakivi.

A rapakivi dike exceeding 10 m in width cuts into the amphibolite in a N 60°E direction at the southern end of Viilajärvi.

Approximately 750 m N from Viilajärvi there is a breccia, where the rapakivi contains angular amphibolite fragments. The schistosity and strike of the different fragments vary (*cf.* Eskola, 1955, p. 125).

Some 400 m northward from the northern shore of Kesiönjärvi, a contact occurs with a dip generally of 50°W (sometimes gentler). To a width of about 20 cm the coarse-grained biotite rapakivi, otherwise red-brown, is dark gray. This dark variety contains very dark, partly chloritized biotite and some green hornblende, which produces a weed texture. The plagioclase

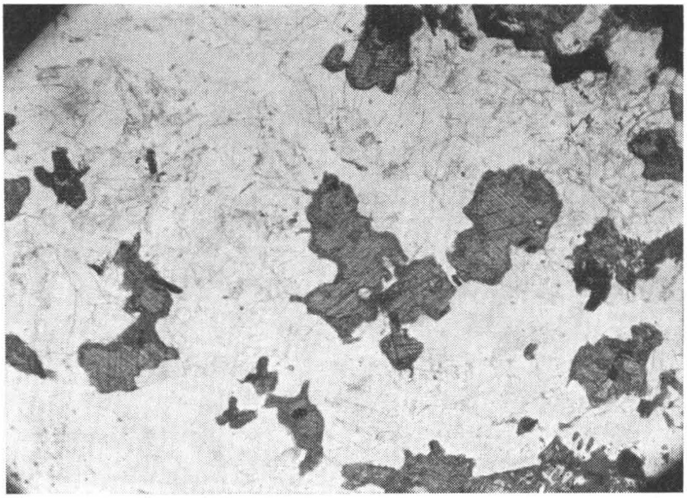

Fig. 14. Metamorphosed gneiss at contact of biotite rapakivi. Plain light, x 40. (Photo by E. Viluksela.)

is sericitized and epidotized, and there is a greater prevalence of a micrographic texture than usual in the biotite rapakivi. The country rock is fine-grained (grain size 0.2 mm) biotite-plagioclase gneiss, which is distinctly schistose (N 30°E, 80°W). The mineral composition of this rock 5 cm from the contact, immediately next to the metamorphosed marginal zone, is: plagioclase (An_{32}) 46.9 %, quartz and potash feldspar 2.8 %, biotite 31.6 %, amphibole and chlorite 12.5 %, pyroxene 4.4 % and ore 1.8 %, as well as small amounts of apatite, sericite and epidote. There is less potash feldspar than quartz.

To a width of 1—5 cm from the contact the biotite-plagioclase gneiss has metamorphosed strongly. Its orientation has totally been lost, and it has become greenish and coarse-grained (grain size 0.6 mm). The mineral composition of this variety (Fig. 14) is as follows: plagioclase (An_{32}) 37.1 %, potash feldspar 26.7 %, quartz 6.3 %, pyroxene 10.1 %, hornblende 10.8 %, biotite 8.3 %, ore 0.5 % and apatite 0.2 %. Some of the plagioclase grains have grown and others have become enclosed. These crystals have beautiful twin lamellae, whereas they are indistinct in the enveloping plagioclase grains. Potash feldspar occurs either within the plagioclase or, usually, at its margins as indistinct veinlets. Myrmekite has been formed at the contacts of the plagioclase and microcline. This rock contains both orthopyroxene ($2V\ \alpha = 75°$) and clinopyroxene ($2V\ \gamma = 0$). The clinopyroxene often occurs as thin lamellae in the orthopyroxene, but it is also met with as independent crystals. The formation of these pyroxenes in contact metamorphism is

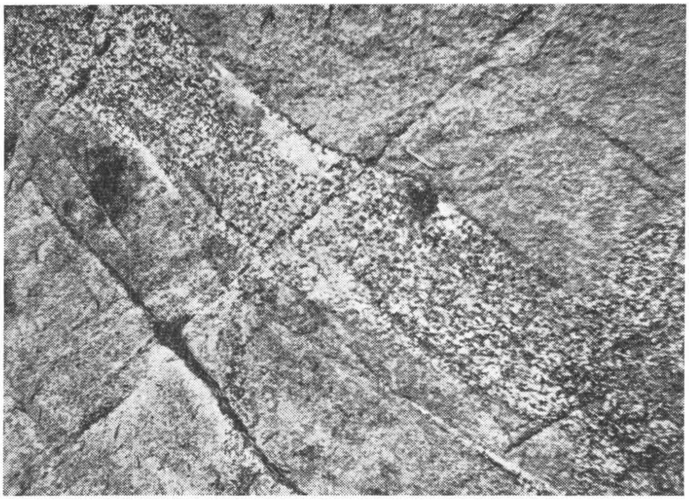

Fig. 15. Biotite rapakivi dike in microcline granite. 0.5 km south of Ylä-Rääveliniärvi.

interesting in that the clinopyroxene resembles pigeonite in its characteristics and that the lamellae occurring in the orthopyroxene produce an intergrowth like an unmixing texture. Amphibole ($2V\ \alpha = 76°$, $c \wedge \gamma = 24°$) often surrounds the pyroxene grains. Biotite often occurs in conjunction with quartz.

Rapakivi also contains fragments of the country rocks as far as 2—3 m from the contact, and they range in diameter from a few centimeters to nearly a meter. I succeeded in detaching one 20-cm-long fragment intact. Its center consisted of the biotite-plagioclase gneiss just described and it had a coarse-grained, metamorphosed margin 1—2 cm wide.

Diopside-rich zones along the contacts between rapakivi and limestone at Pitkäranta in the Salmi area have been described by Trüstedt (1907, p. 105) and Saksela (1951, p. 221).

In the village of Kousaniemi on the southern side of Ylä-Rääveliniärvi there is a separate area of microcline granite between the gabbro-anorthosite and biotite rapakivi. This microcline granite cuts the gabbro-anorthosite and is in turn intersected by rapakivi. On the western side of Karjolahti (this local name is not marked on the map), the long bay extending SE from Ylä-Rääveliniärvi, a contact can be seen about 700 m inland at the southern edge of the microcline granite. From the rapakivi at that point dikes run into the microcline granite, and the former contains a fragment of the latter about 1 m long. Near the eastern shore of Karjolahti, between the rapakivi and microcline granite there is a sharp contact, and the rapakivi penetrates the microcline granite as a dike. In the same exposure of the microcline granite a gabbro-anorthosite fragment is to be seen. Likewise, about 100 m NW from the northern shore of Lake Kousajärvi (this local name is not marked on the map), situated on the western side of Karjolahti, there occurs an exposed contact, where apophyses run from the biotite rapakivi into the microcline granite (Fig. 15).

CONTACTS AGAINST THE QUARTZ DIABASES

The quartz diabase in the gabbro-anorthosite of Kuhaniemi, on the northern side of Ylä-Rääveliinjärvi, is cut by dikes of rapakivi several meters thick.

A broad rapakivi dike has been drawn on the map in the quartz diabase intrusion situated north of Pankajärvi. Both contacts of this dike are exposed, and the entire dike as well as its surrounding rock are in plain view.

Likewise, the quartz diabase dike situated farthest to the south on the eastern side of Pankajärvi is cut by a biotite rapakivi dike about 10 m broad, which runs across the quartz diabase approximately west by east.

The quartz diabase intrusion of the peninsula of Lautaniemi is cut by the rapakivi of the Viipuri region. At the SE end of the island of Kuisaari there occurs a contact between coarse-grained diabase and rapakivi, with a nearly vertical dip. Close to the point where the contact bends, the diabase is penetrated by dikes of rapakivi.

SHEAR ZONES

Frosterus (1902) states that, *inter alia*, the Rääveli lakes lie in fault zones, pointing as evidence to the strongly mylonitized rocks near the Paaso Estate, situated between Ylä- and Ala-Räävelinjärvi. These rocks contain heavily crushed migmatites. It is difficult to obtain a sizable specimen, because the rock tends to break up into small pieces, owing to the fact that slickensides cut each other at small angles.

Strong shear zones are typical of all the rocks of the Ahvenisto area with the exception of the olivine diabases, hornblende rapakivis and granite porphyries.

A beautiful shear zone occurs in the microcline granite about 2.5 km east of Nurmaanjärvi. The strike of the zone is N 30° E, the dip 60° S and the dip of the lineation 30° NE. The direction of the lineation clearly exposed on slickensides deviates conspicuously from the general direction of lineation in this area. This shear zone is about 20 m broad, all told, with crushed and sheared areas measuring a few meters in width occurring at short intervals. In sheared spots the microcline granite has become fine-grained, and the large garnet and cordierite grains in it have been broken up into small, separate grains. In thin section it may be observed how also the potash feldspar crystals have been crushed up, the quartz has developed a more strongly undulating extinction, and muscovite appeared in the rock.

About 2 km north of Lake Sarkavesi the coarse-grained porphyritic granodiorite contains a shear zone about 3 m wide, whose strike is N 80° E and dip 70° S. Throughout the shear zone the rock has been crushed up and become fine-grained. At the same time the biotite has largely chloritized and the potash feldspar content increased.

About 3 km W from the church village of Mäntyharju occurs a shear zone, the strike of which is N 25° E and dip 80° E. The quartz diorite is gray and of medium coarseness. The zone contains reddish areas varying between 1 and 20 cm in width at short intervals. The reddish color derives from eye-shaped potash feldspar grains about 0.3 cm long that have appeared in the rock. In thin section it can be observed how at the same time the biotite of the quartz diorite has chloritized and the plagioclase epidotized (*cf.* Chayes, 1955).

The gabbro-anorthosite on the western shore of Juolasvesi has a shear zone several meters broad, with a strike of N 20° W and a dip of 60° E and slickensides situated one right next to another. In this shear zone the rock has turned yellowish gray and mottled green. The An-content of the plagioclase in the rock had diminished to An_{26} ($\gamma = 1.549$). At the same time calcite and epidote have appeared in the rock. The mafic minerals have turned into chlorite and amphibole.

At Kuhaniemi the gabbro-anorthosite contains another beautiful crushed zone, the strike of which is N 33° W and the dip 60° E. The structure of this zone is identical to that of foregoing.

On the northern side of Pankajärvi the quartz diabase contains a shear zone whose strike is N 60° W and dip vertical. In it there are numerous dark green, fine-grained streaks 1—10 mm wide and situated side by side. In thin section it may be noticed how all the minerals in the rock have altered in the streaks into chlorite, amphibole and epidote and how the ore has separated into them.

The gabbro-anorthosite about 3 km east of Enonvesi contains a shear zone with a strike of N 60° W and a dip of 60° N and which runs through the 50—100 m broad biotite rapakivi vein. The rapakivi in the shear zone has wholly lost its rapakivi structure and altered into eye-gneiss, which contains 0.5—1 cm long, eye-shaped potash feldspar grains surrounded by mafic minerals. Carstens (1924, 1925) has described similar phenomena from the Trondhjem region.

In the biotite rapakivi on the NW side of Lake Kuijärvi there is a shear zone, which has a strike of N 55° W and a dip of 70° E. In this zone the shearing has proceeded much farther than in the preceding one. The rapakivi contains dark gray, extremely fine-grained streaks 5—15 cm wide, consisting almost totally of muscovite and crushed up quartz.

Shearing may also be rather slight, as on the western side of Enonvesi, where the biotite rapakivi contains slickensides in a broad zone, intersecting each other at small angles. In such places the rapakivi often appears to disintegrate more easily than elsewhere.

These shear zones met with in the Ahvenisto area, the orientation of which is independent of the general tectonic character of the vicinity, appear to have originated in the consolidated rock in conjunction with movements of a later stage (*cf.* Sederholm, 1913, and Asklund, 1923). It appears evident that the shear zones in this area have originated, at least in part, in connection with the intrusion of the rocks of the Ahvenisto massif. In such cases, the younger intrusion has always caused shearing in the older ones.

METAMORPHIC AND METASOMATIC PHENOMENA IN THE GABBRO-ANORTHOSITE COMPLEX

Successive intrusions have each left their own mark on the gabbro-anorthosites. E. g. the granite dikes intersecting the gabbro-anorthosite have affected them in different ways. The contact influence of microcline granite on the gabbro-anorthosite has been stronger than that of the rapakivi rocks.

About 1 km NNW of the northern end of Nurmaanjärvi granitic dikes occur that evidently consist of microcline granite. The width of the dikes varies from a few meters to a few centimeters. In spots they cut the gabbro-anorthosite. In the proximity of the dikes to a width of about 1—15 cm, the gabbro-anorthosite contains brownish red albite porphyroblasts measuring 0.5—1 cm in length and 0.2—0.5 cm in width. At the same time the color of the rock has changed to a motley green and yellowish gray. The original plagioclase crystals in the gabbro-anorthosite have become albitic. Within them and in their margins there is an abundance of epidote (pistacite). The original plagioclase crystals are dull in thin sections, but the albite porphyroblasts are bright. The former have kept their original idiomorphic character, but the latter are xenomorphic and serrated at their borders. The mafic minerals are mainly green chlorite and bluish green hornblende, and they contain a large quantity of ore as inclusions. The rock further contains a slight amount of quartz, potash feldspar and apatite.

The contact effects of the quartz diabases have been described in the paragraph dealing with the contact relations between the gabbro-anorthosites and quartz diabases.

Also the contact effects of biotite rapakivi have been discussed in several connections in the foregoing. In addition, it may be pointed out that e. g. on the western side of Pankajärvi there appear near the biotite rapakivi contact in both the gabbro-anorthosite and the quartz diabase brownish red potash feldspar porphyroblasts measuring in some cases over 0.5 cm in length. The mafic minerals of the rock alter in part into amphibole and also the biotite content increases.

The effect of the hornblende rapakivi on the gabbro-anorthosite in e. g. the village of Nurmaa (p. 66) is slight. The most striking feature is that the biotite content of the gabbro-anorthosite increases in the immediate proximity of the contact, and evidently also the amount of potash feldspar and quartz is slightly greater than in normal gabbro-anorthosite. To a width of a few millimeters the anorthite content of the plagioclase has also decreased.

On p. 27 there is a description of a large gabbro-anorthosite fragment occurring on the western side of Juolasvesi. It is hard to say to what extent the olivine diabase and the hornblende rapakivi and to what extent the microcline granite and the autometamorphism of the gabbro-anorthosite intrusion have affected the metamorphism of this rock and that of the gabbro-anorthosites in general.

A description of the effect of the last »juices» of the autometamorphism of the gabbro-anorthosite is given on p. 22. Such phenomena are by no means limited to the marginal parts of intrusions, for autometamorphism has taken place in a notable degree in the centers of the intrusives.

OLIVINE DIABASES

There are two olivine diabase intrusions in the Ahvenisto area. A large intrusion is found in the village of Hietaniemi (this local name is not marked on the map), on the western side of Juolasvesi. The other, smaller intrusion is located immediately NE of the rural church of Heinola. The olivine diabases of both intrusions are dark bluish gray in color, with a tinge of violet, and in texture they are beautifully ophitic, in spots with a sub-parallel arrangement of plagioclase laths. The composition of the plagioclase is An_{60-68}. Quartz is generally lacking, but a slight amount of potash feldspar is likely to be present. The principal mafic mineral in the olivine diabases is olivine. In addition, pyroxene (augite) and biotite as well as their alteration products are to be found. According to the chemical analysis (Table VIII, No. 8) and the optical properties of the minerals, the Niggli number mg for the olivine diabases is appreciably larger than for the quartz diabases.

I have been unable to obtain a clear picture of the position of the contacts of the olivine diabase intrusion in the village of Hietaniemi or of the form of the entire original intruded mass, for the contacts are poorly exposed. The intrusion has fine-grained, ophitic chilled contacts — partly with a sub-parallel arrangement of plagioclase laths. At the center of the intrusion the olivine diabase is coarse-grained ophitic and contains plagioclase laths (An_{66}), measuring 1—2 cm in length and 0.2—0.5 cm in width. In their interstices are idiomorphic olivine crystals ($2V\alpha = 77°$) surrounded here and there by a kelyphitic rim, although in some spots the olivine is surrounded by augite. Augite ($2V\gamma = 52°$, $\gamma \wedge c = 41°$) occurs in the interstices as xenomorphic crystals. The augite spots occurring separately in thin section extinguish at the same time over considerable areas. The olivine and augite do not appear to be evenly distributed but form groups of crystals situated apart from each other. There is very little orthopyroxene; in some spots none whatsoever. Here and there are to be found large grains of ore with a biotite border. Reddish brown biotite occurs also as independent crystals.

At the southern end of the intrusion, approximately 50 m from the contact, the olivine diabase contains ophitically arranged plagioclase laths (An_{63}, $\alpha = 1.561$, $\gamma = 1.569$) measuring 0.2—0.7 cm in length and 0.1—0.3 cm in width. The mineral composition of the rock is given in Table VI, No. 1. The olivine ($2V\alpha = 77°$, $\alpha = 1.723$, $\beta = 1.750$, $\gamma = 1.765$) is idiomorphic, occurring on the average as crystals 0.2 cm long, and it is generally well preserved. In places the olivine is surrounded by a reaction rim, consisting of serpentine, amphibole and biotite. In such places the pyroxene has also altered to some degree. The pyroxene is predominantly xenomorphic augite ($2V\gamma = 50°$, $\alpha = 1.693$, $\gamma = 1.719$, $c \wedge \gamma = 40°$). Red-brown biotite ($\gamma \sim \beta = 1.623$) occurs as independent grains and surrounding the ore. In chemical composition the rock (Analysis 8, Table VIII) resembles the olivine diabase of Satakunta.

Nearer the contact the diabase becomes still finer-grained. At the southern end of the intrusion, near the contact, the diabase exhibits a beautiful ophitic texture with a sub-parallel arrangement of the plagioclase laths. Very fine-grained olivine diabases occur at the head of Leppälahti. North of this point Juolasvesi forms a cove in a westerly direction, and on its shore a very fine-grained olivine diabase dike about 1.5 m wide and containing plagioclase phenocrysts penetrates the gabbro-anorthosite. Its mineral composition is shown in Table VI, No. 2. The olivine occurs as

Table VI. Modes of olivine diabases

	1	2	3
Plagioclase	69.3	68.8	51.0 %
Potash feldspar	—	0.4	3.5 »
Olivine	13.2	14.5	28.7 »
Pyroxenes	8.0	3.8	11.1 »
Biotite	5.7	2.0	1.2 »
Amphibole	1.9	7.8	— »
Serpentine	1.2	—	— »
Ore	0.5	2.4	4.0 »
Apatite	0.2	0.3	0.5 »

idiomorphic crystals and apparently separate grains often extinguish simultaneously. The augite ($2V\gamma = 50°$) occurs as xenomorphic crystals. The orthopyroxene ($2V\alpha = 61°$) is represented by grains scattered here and there. The apatite crystals are generally large and occur most often in conjunction with augite.

The olivine diabase intrusion located near the rural church of Heinola exhibits throughout a sub-parallel arrangement of plagioclase laths, and it is finer in grain than the diabase of Hietaniemi. This diabase is likewise finer-grained near the contact of the intrusion than at the center. The mineral composition of the rock is given in Table VI, No. 3. The composition of the plagioclase is An_{61} ($\alpha = 1.560$, $\gamma = 1.568$). The olivine ($2V\alpha = 77°$) is idiomorphic and quite fresh. The augite occurs as large poikilitic crystals, which enclose clusters of olivine crystals. In some cases, the individual olivine crystals also have a pyroxene border. Hypersthene occurs here and there in rather large crystal clusters. This diabase contains hardly any alteration products.

CONTACTS OF THE OLIVINE DIABASE AGAINST OLDER ROCKS

The olivine diabase intrusion near the rural church of Heinola is surrounded by microcline granite. To be sure, I have not succeeded in exposing the contact between it and the microcline granite, but it appears certain that the olivine diabase is younger than the microcline granite. This conception is supported by the following observations: the olivine diabase has chilled marginal zones against its country rock; nowhere in the olivine diabase are microcline granite veins or dikes to be observed, notwithstanding the fact that the entire olivine diabase intrusion is well exposed; and, finally, the olivine diabase is altogether unmetamorphosed.

The contact between the olivine diabase and the microcline granite on the western side of Juolasvesi at Hietaniemi is nowhere exposed, but the contacts between the gabbro-anorthosite and the olivine diabase are adequately in view. On the southern shore of the Juolasvesi inlet north of Leppälahti, there are outcrops of coarse-grained gabbro-anorthosite 2—3 m high (see p. 58). They are bounded on the west and the south by a swampy area several dozen meters broad. The opposite side of the swamp is bordered by somewhat lower exposures, consisting of extremely fine-grained olivine diabase, which gradually becomes coarser in grain as one proceeds in a W by SW direction. The contact between the olivine diabase and gabbro-anorthosite cannot, to be sure, be seen; but it is evident that this gabbro-anorthosite has been detached from a large gabbro-anorthosite complex upon the intrusion of the olivine diabase. On the western shore of the same inlet occurs another gabbro-anorthosite area, the southern end of which is penetrated by an olivine diabase dike about 1.5 m wide (see p. 27). The ones mentioned are not the only gabbro-anorthosite fragments in the olivine diabase.

The great biotite rapakivi area of the Ahvenisto region does not come into direct contact with the olivine diabase. The only possibility of encountering a contact between them is to find one between a biotite rapakivi dike cutting the gabbro-anorthosite and the olivine diabase. Unfortunately, it has been possible to run across only one observation of this kind, though the value of the evidence it provides is by no means indisputable. At the northwestern end of the contact between the hornblende rapakivi and the olivine diabase on the western shore of Juolasvesi, near the olivine diabase contact is situated a crushed disintegrating »moro» outcrop of granite. Judging from the structure of this rock it cannot be either hornblende rapakivi or microcline granite. It resembles more closely the biotite rapakivi fragments contained in hornblende rapakivi (see p. 71). The outcrop gives the impression that this granite belongs among the biotite rapakivi variety and had been crushed during the intrusion of the olivine diabase.

The lack of biotite rapakivi dikes in the olivine diabase of Hietaniemi also indicates that the olivine diabase is younger than the biotite rapakivi, especially in view of the fact that the gabbro-anorthosite alongside contains an abundance of biotite rapakivi dikes.

I regard the presence of powerful shear zones in the migmatites, quartz diorites, microcline granites, gabbro-anorthosite, quartz diabases and biotite rapakivis and their absence from the other rocks of this area as strong evidence that the olivine diabases are younger than the biotite rapakivi rocks.

HORNBLENDE RAPAKIVIS

Hornblende rapakivi rocks are to be found in the eastern and southern parts of the Ahvenisto massif. In the village of Hietaniemi, on the western side of Juolasvesi, four intrusions occur: one on the western shore of Juolasvesi and three in the vicinity between Leppälahti and Siikajärvi. Three intrusions are met with in the village of Nurmaa: on the northwestern shore of Hietastenlampi, between Hietastenlampi and Nurmaanjärvi, and northwest of Nurmaanjärvi. In the village of Enolahti, on the western shore of Siikajärvi, there is one intrusion, the dip of the western contact of which is 20° E. The largest intrusion is situated in the village of Paljakka, and it extends from the northwestern shores of Nurmaanjärvi to the northern end of Kelesjärvi.

Hornblende rapakivi rocks are gray, greenish gray, brownish gray or green in color. They are of medium coarseness (grain size 0.2—0.5 cm) and contain a sparse scattering of potash feldspar phenocrysts measuring 1—1.5 cm in diameter, some of which are rather rounded. The composition of the plagioclase is in the range of An_{23-34}. The potash feldspar in the rocks is, at least to a large extent, microcline. There is invariably a greater amount of green hornblende in them than biotite. The marginal varieties, which are often green in hue, regularly contain fayalite and, in some instances, also pyroxene. In the chemical analyses of the hornblende rapakivis (Table VIII, No. 9, 10, 11) the SiO_2 content is appreciably smaller than in the biotite rapakivis, and e. g. the MgO, CaO and FeO contents are greater than in the biotite rapakivi rocks. In chemical composition, texture and appearance the hornblende rapakivis resemble the Lappee granites (Hackman, 1934, p. 17) and the Tarkki granites (Laitakari, 1928, p. 9).

The hornblende rapakivi situated on the western shore of Juolasvesi at Hietaniemi (Fig. 16) is greenish gray, in places brownish gray, in hue and its grain measure 0.2—0.3 cm. Approximately 100 m south of the northern corner of the intrusion and about 20 m west of the biotite rapakivi fragments (see p. 71) about 10 per cent of the rock consists of potash feldspar phenocrysts measuring 1—1.5 cm in diameter and often round in shape. To a large extent they are microcline and in some cases surrounded by a ring of oligoclase. The mineral composition of the groundmass of the rock is shown in Table VII, No. 1. The plagioclase (An_{24}, $\alpha = 1.540$, $\gamma = 1.548$) occurs as idiomorphic crystals, the margin of which against the potash feldspar is more albitic (An_{16}) than the center. In the fissures of the crystals there is ore pigment, and in the center they are in many instances sericitized. Myrmekite is sometimes met with at the ends of the plagioclase crystals against the potash feldspar. Albitic plagioclase also occurs as streaks in the fissures of the potash feldspar. This phenomenon

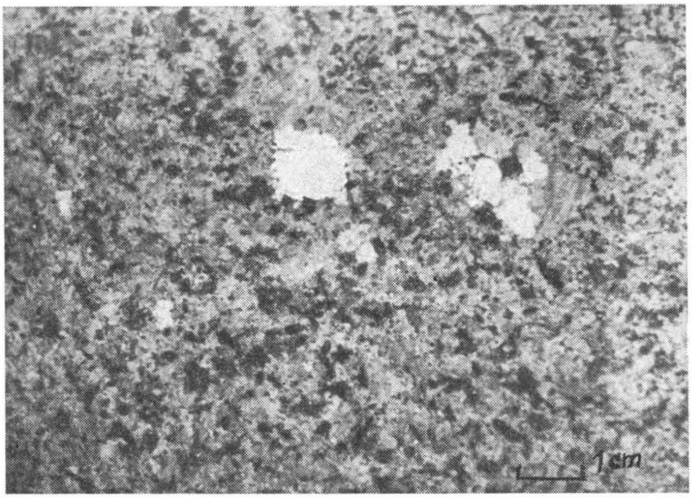

Fig. 16. Hornblende rapakivi. From near the western shore of Juolasvesi. (Photo by E. Viluksela.)

is the same as that described by Popoff (1903) in regard to numerous rapakivi types found in Russia and the rapakivi area of Viipuri and of which he presents good photographs. The potash feldspar often exhibits a quadrille texture, and in sections // 001 its angle of extinction $\alpha' \wedge 010 = 14°$. Perthite occurs as thin threads in the potash feldspar, which in places contains shreds of plagioclase and sometimes also biotite and hornblende grains. The quartz is of two generations: idiomorphic and xenomorphic. The latter is often contained within the potash feldspar. The hornblende at times exhibits crystal forms, but often it occurs as xenomorphic grains around the potash feldspar and euhedral quartz crystals. It also produces a weed texture. In places the crystal sheets parallel to 001 of the biotite alternate with the hornblende layers. The biotite ($\gamma \sim \beta = 1.697$) is

Table VII. Modes of hornblende rapakivi

	1	2	3	4
Potash feldspar	44.0	43.7	44.9	46.6 %
Quartz	27.6	20.4	28.2	22.6 »
Plagioclase	18.5	22.1	15.3	14.7 »
Olivine	—	5.1	—	2.3 » (Olivine + Pyroxene)
Pyroxene	—	4.6	—	
Hornblende	4.7	3.3 (Hornblende + Biotite)	6.2	9.1 »
Biotite	4.6		4.3	3.5 »
Apatite	0.1	0.1	1.1 (Apatite to Ore)	1.2 » (Apatite to Ore)
Fluorite	0.1	—		
Zircon	0.1	0.6 (Zircon + Ore)		
Ore	0.3			

poikilitic, enclosing quartz and potash feldspar. In some cases, it thrusts a weed texture into the potash feldspar. Apatite occurs as large prisms in the potash feldspar. A chemical analysis of this rock is given in Table VIII, No. 9.

The same type of hornblende rapakivi is represented by the middle intrusion between Siikajärvi and Leppälahti. The mineral composition of the somewhat yellowish green marginal variety at the western edge of this intrusion is shown in Table VII, No. 2. The composition of the plagioclase in the rock is An_{25-15}. It occurs partly as inclusions in the potash feldspar, which in places exhibits a quadrille structure and often occurs in conjunction with quartz to produce a micrographic texture. Quartz also occurs as idiomorphic crystals. The hornblende ($\alpha = 1.708$, $\gamma = 1.734$, $\gamma \wedge c = 23°$) penetrates the plagioclase, potash feldspar and fissures in the quartz, producing a weed texture. The olivine is fayalite ($2V\alpha = 49°$), and it often occurs within the pyroxene, which is diopsidic augite ($2V\gamma = 55°$, $\gamma \wedge c = 44°$, $\beta = b$). In many cases the augite, in turn, has a hornblende border. The augite contains quartz inclusions, but where the augite comes into contact with the quartz, the latter is likely to contain augite inclusions near the augite. The apatite occurs as long, thin prisms, which intersect e. g. the augite and the hornblende. A chemical analysis of this rock is given in Table VIII, No. 10.

The hornblende rapakivi about 0.5 km northwest of Nurmaanjärvi is a greenish, brown-gray, fine-grained rock, containing rather roundish potash feldspar phenocrysts measuring 1 cm. The mineral composition of the rock is given in Table VII, No. 3. The plagioclase (An_{30}, $\alpha = 1.543$, $\gamma = 1.551$) is idiomorphic and occurs to some extent in the form of fairly large crystals. Generally, it is sericitized in its central parts, but different lamellae have sericitized in varying degrees. The margin of the plagioclase against the potash feldspar is more albitic (An_{19}) than the core of the crystal. At least to a large extent, the potash feldspar is microcline, for a quadrille structure is to be observed in it often, and the sections // 001 extinguish obliquely. The potash feldspar phenocrysts seldom consist of a single crystal but rather of crystal clusters. In the perthite of the potash feldspar, comprising 22.5 % by volume of the entire crystal, twinning according to the albite law is to be observed. The quartz occurs as idiomorphic crystals, which show a somewhat undulatory extinction; but it also forms anhedral grains, whereupon it is often contained as inclusions in the marginal parts of the potash feldspar crystals. The green hornblende ($\gamma \wedge c = 21°$, γ = blackish brown-green, β = brownish green, α = yellowish brown) occurs as poikilitic crystals, growing to some extent into the plagioclase. Also the blackish brown biotite encloses other minerals and occurs in streaks in the plagioclase. Apatite is present in large crystals.

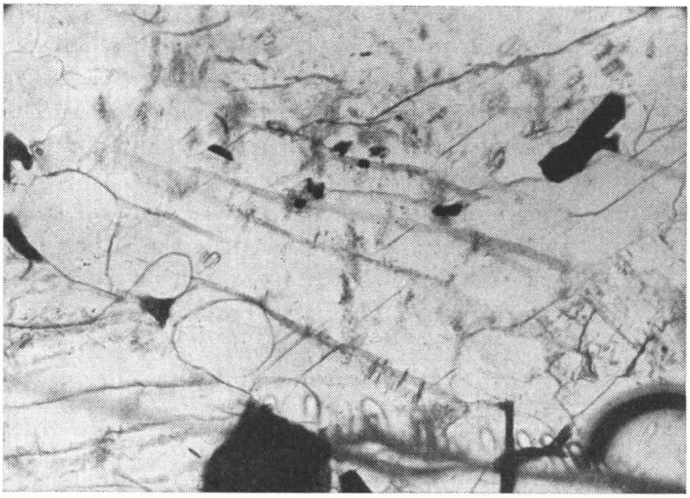

Fig. 17. Hornblende weed texture around the quartz (roundish), and within the potash feldspar (large-grained) and margin of the plagioclase (the lower part of the picture). Green marginal variety of hornblende rapakivi. Plain light, x 85. Southwest of Nurmaanjärvi. (Photo by E. Viluksela.)

In the sections of the rock at the SW end of this intrusion, the hornblende rapakivi can be observed grading over beautifully toward the contact into a green variety. These varieties are green except for the potash feldspar phenocrysts contained in them, which are reddish brown at least in the central part of the crystal. The transition occurs about 5 m before the contact at an interval of 10—20 cm. The change in color is caused by the weed texture produced by the green hornblende. The hornblende very intensively gathers around all the crystals, fills the cleavage cracks and penetrates the minerals (Fig. 17). It has failed to penetrate only the centers of the potash feldspar phenocrysts. The contact against the country rock (gabbro-anorthosite) is sharp, and the hornblende rapakivi is the intersecting rock.

The mineral composition of the green contact variety of the hornblende rapakivi here is shown in Table VII, No. 4. The plagioclase (An_{34}, $\alpha = 1.546$, $\gamma = 1.555$) is partly idiomorphic and at the border against the potash feldspar more albitic than at the core of the crystal. The perthite in the potash feldspar occurs as thinner streaks than in the center of the intrusion. Myrmekite is met with at the ends of the plagioclase crystals against the potash feldspar. The quadrille structure of microcline is not so plainly visible in the potash feldspar as in the center of the intrusion. On the other hand, the micrographic texture produced by the potash feldspar and quartz is much more distinct than in the center of the intrusion. Quartz inclusions are lacking only in the cores of the large potash feldspar crystals.

The hornblende ($2V\alpha = 60°$, $\gamma \wedge c = 23°$, $\beta = b$, $\alpha = 1.687$, $\gamma = 1.713$, $\gamma - \alpha = 0.028$ (with a Berek compensator), γ = brownish green, α = light greenish brown) occurs more often poikilitically than in the center of the intrusion — this for apparently the same reason as the occurrence of the weed texture. The blackish brown biotite ($\gamma \sim \beta = 1.695$, $2V\alpha = 20°$) is xenomorphic and penetrates as tongues into the other minerals. The fayalite ($2V\alpha = 49°$, $\alpha = 1.821$, $\gamma - \alpha = 0.052$ (with a Berek compensator), specific gravity > 4.3, distinct cleavage crack //010) is poikilitic and encloses, inter alia, quartz and potash feldspar grains. In places tongues extend from the fayalite crystals into the interstices of neighboring crystals, but occasionally the fayalite crystals exhibit distinct prismatic and pyramidal faces. The fayalite is generally well preserved, though in some cases yellowish brown alteration products are present in its fissures and at its margins. In the marginal varieties apatite and zircon occur as larger crystals than those at the center of the intrusive. A chemical analysis of this rock is presented in Table VIII, No. 11.

The hornblende rapakivi situated between Hietastenlampi and Nurmaanjärvi is somewhat more reddish around the middle than the foregoing types. Its contact against the migmatite inclusions contained in the microcline granite is exposed near the northern end of Nurmaanjärvi, and 50 m southward from this contact the transition of hornblende rapakivi into the green marginal variety is to be observed in a highway cut. This variety is identical to the green ones described in the foregoing. It contains both fayalite and pyroxene.

The hornblende rapakivi intrusion west of Nurmaanjärvi is coarser-grained than the intrusions just described, but otherwise it is similar in mineral composition to the other hornblende rapakivi rocks. It has the same kind of marginal transitions as the intrusions already mentioned against both gabbro-anorthosite and microcline granite.

Hornblende rapakivi also contains granitic inclusions, which in both form and structure are the same as in biotite rapakivi. (See p. 49.) In addition, they have the interesting feature of also being green inside the green varieties and in the cases studied also contain fayalite.

Likewise, hornblende rapakivi rocks contain fine-grained veins, which were intruded later and which are comparable to some extent with the porphyry aplites in biotite rapakivis. One such vein occurs at the southern end of the westernmost intrusion in the village of Hietaniemi between Siikajärvi and Leppälahti, where it also intersects the olivine diabase. This rock is light gray in hue, and it contains potash feldspar, quartz, plagioclase, biotite, chlorite, ore, zircon, fluorite and apatite.

CONTACT AND AGE RELATIONS OF THE HORNBLENDE RAPAKIVI

In connection with the description of the hornblende rapakivi rocks, I have touched upon their green marginal varieties. A sharp contact between a green hornblende rapakivi and gabbro-anorthosite occurs northwest of Nurmaa. The green variety grades over at an interval of about 5 m into normal hornblende rapakivi. With migmatite as country rock the same phenomenon is to be seen at the western border of the hornblende rapakivi intrusion between Nurmaanjärvi and Hietastenlampi, near the northern end of Nurmaanjärvi. In both cases it is clear that the hornblende rapakivi is younger than its country rocks, migmatite and gabbro-anorthosite. At the southern end of the westernmost intrusion between Siikajärvi and Leppälahti at Hietaniemi, the hornblende rapakivi cuts the olivine diabase. The latter contains hornblende rapakivi dikes of varying thickness, while the hornblende rapakivi contains olivine diabase fragments. Fayalite regularly occurs also in the margins of the dikes. Accordingly, the olivine diabase must be older than the hornblende rapakivi.

The green marginal varieties are typical of hornblende rapakivi rocks. They apparently correspond to the fine-grained chilled contacts of the granite porphyry dikes against diabase. The transition of the marginal varieties into normal hornblende rapakivi takes place gradually in the same way as in the case of the fine-grained chilled contacts just mentioned. The transition also fits in with the theoretical chilling curves for igneous layers presented by Bowen (1921). On the basis of the foregoing, I regard the origin of the green marginal contact variety of hornblende rapakivi as a phenomenon of chilled contacts. The only difference is that the cooling down and the crystallization processes took place under slightly different conditions. After the intrusive process there first began the crystallization of the marginal zone. It continued during the subsequent slow crystallization of the central part and under the influence of the heat given off by it. This, then, accounts for the poikilitic occurrence of the minerals, the weed texture of the hornblende — which gives the rock its green hue —, the micrographic structure, the origin of myrmekite, and the crystallization of the augite and the fayalite in the marginal variety. Also the grain size of the rock became distinctly smaller in the marginal zones of the intrusions than in the middle parts, although this cannot be easily noticed in the field on account of the intensive green color.

Green rapakivi varieties situated in the Viipuri rapakivi area around the town of Lappeenranta are described by Wahl (1925), who terms part of them as tirilite. He also found (pp. 28—32) sharp contacts between the green rapakivi varieties and normal rapakivi rocks, normal rapakivi fragments in green rapakivi and green rapakivi dikes in normal rapakivi.

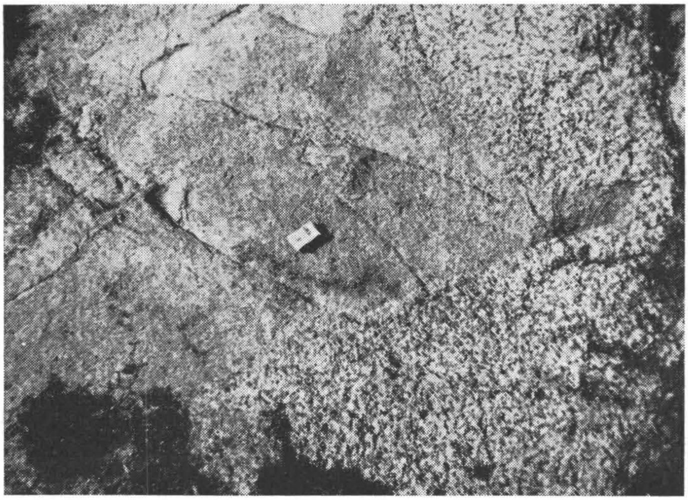

Fig. 18. Contact between biotite rapakivi fragment (below right) and hornblende rapakivi. Near the shore of Juolasvesi.

Furthermore, he saw green rapakivi grading over into rapakivi syenite, by which term he designated the Lappee granite. Hackman (1934, p. 22) describes a contact between Lappee granite and typical rapakivi granite from the Lappeenranta area, near Rutola. The contact is sharp, the Lappee granite at the contact is green in color and contains red-brown potash feldspar phenocrysts. The green variety then grades over into Lappee granite. According to Hackman (1934, p. 28), Lappee granite has the same kind of contact against the pyterlite and viborgite types of rapakivi. Inasmuch as the Lappee granite is a more basic rock than viborgite or pyterlite, both Wahl and Hackman consider, in the aforesaid publications, the Lappee granite an earlier member of the rapakivi magma differentiation. Sample No. 3 372 in the collections of the Geological Institute of the University of Helsinki is from the Suurkuukka quarry, located north of the Tani railroad depot (collected by V. Hackman, 1931). The sample shows a contact between pyterlite and a green variety (tirilite). The contact is sharp. The green color in this and other tirilite specimens in the collections of the Geological Institute is due to the weed texture of the hornblende. It is my contention that the Lappee granite is a younger intrusion than the pyterlite and viborgite, while the green marginal varieties of Lappee granite are to be interpreted in the same way as those of the hornblende rapakivi rocks of the Ahvenisto area.

The hornblende rapakivi is also younger than the biotite rapakivi. The northern end of the hornblende rapakivi intrusion along the western shore

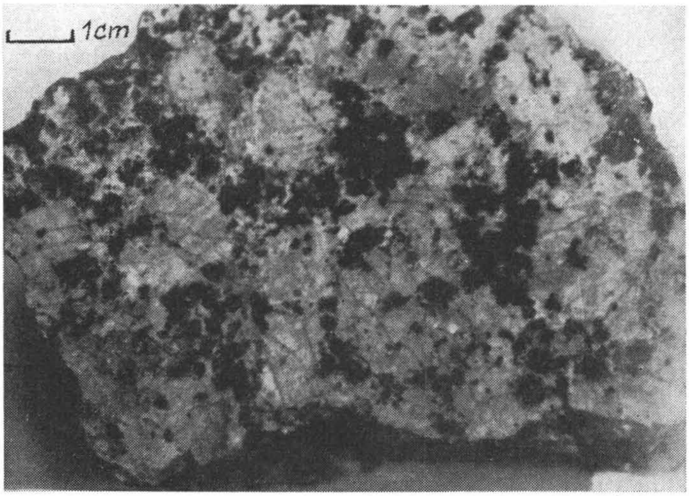

Fig. 19. Biotite rapakivi fragment in hornblende rapakivi. Near western shore of Juolasvesi. (Photo by E. Viluksela.)

of Juolasvesi near the water is almost wholly exposed. The contact between the intrusion and the migmatite is in view on the shore of the lake at many points. The hornblende rapakivi itself contains numerous different kinds of fragments, including e. g. porphyritic granodiorite, microcline granite and biotite rapakivi. The biotite rapakivi fragments are, like the others, of varying size and angular, and they border sharply on the hornblende rapakivi. Some 100 meters south of the northern corner of the intrusion, there is a sharp-edged biotite rapakivi fragment about 20 m long. The contacts of the fragment are exposed on every side, and it borders quite sharply on the hornblende rapakivi (Fig. 18). The fragment is angular and its boundary also has inwardly turned angles.

In the preceding chapter (p. 64) there is a description of a hornblende rapakivi specimen collected about 20 meters west of this big fragment. A picture taken of a specimen of the fragment is reproduced in Fig. 19 (*cf.* Fig. 16). The rock is red-brown in color, and it contains potash feldspar crystals measuring 1—1.5 cm in length, quartz crystals 0.2—0.5 cm in diameter, small, light brown plagioclase crystals and black biotite. The mineral composition of the rock is potash feldspar 56.4 %, quartz 34.9 %, plagioclase 6.2 % and biotite 2.5 %, as well as small amounts of ore, zircon, apatite and fluorite. The potash feldspar contains perthite to an amount of 23.5 % by volume, and in places it exhibits a quadrille texture; but there is more of it in the marginal parts of the crystals than at their cores. The potash feldspar crystals occasionally have sharply bounded inner zones showing more idiomorphic crystal forms than the crystal as a whole. The potash feldspar in some cases contains anhedral plagioclase crystals.

The plagioclase (An_{25}) also contains other plagioclase grains as inclusions, which appear to have a slightly greater refractive index than the surrounding plagioclase. The refractive index of the plagioclase against the potash feldspar has decreased, and in some instances the plagioclase crystals appear to surround the potash feldspar crystals. Some of the plagioclase crystals have sericitized, while some, again, are quite fresh. The quartz has a somewhat undulatory extinction. Part of it is idiomorphic and part xenomorphic; the latter type often occurs as inclusions in potash feldspar. The margins of the quartz crystals against each other are in many cases serrated. The biotite ($\gamma \sim \beta = 1.692$) is very dark brown, nearly black, and it seldom is distinctly idiomorphic. In addition to zircon, it contains, inter alia, quartz inclusions. A chemical analysis of this fragment is given in Table VIII, No. 6.

The large fragment just described consists of biotite rapakivi in structure, mineral composition and chemical composition like the rocks of the biotite rapakivi intrusion situated in the center of the Ahvenisto massif.

The hornblende rapakivi rocks are thus younger than the biotite rapakivis and olivine diabases. There remains to be considered the question as to whether the hornblende rapakivis are younger or older than the porphyry aplites. Inasmuch as no contacts between these rocks have been met with anywhere, we must rest content with other observations.

1. Just as in the case of the olivine diabases, the hornblende rapakivis lack powerful shear zones, which I have regarded, at least in part, as brought about by later intrusions.

2. The biotite rapakivi rocks are older than the hornblende rapakivis, and the porphyry aplites are closely associated with the biotite rapakivis. Most probably the porphyry aplites are a differentiation product of the same magma intrusion, from which the biotite rapakivi crystallized first and the porphyry aplites at a later stage.

3. The hornblende rapakivi rocks have their own residual crystallizations corresponding to those of the porphyry aplites.

4. The porphyry aplites have, as later crystallizations ought to have, e. g. a higher F-content than the biotite rapakivis, whereas the F-content of the hornblende rapakivis, on the other hand, is approximately the same as that of the biotite rapakivis.

5. The biotite rapakivi dikes in gabbro-anorthosite areas are often cut by porphyry aplite dikes, running parallel to or intersecting the biotite rapakivi dikes. The porphyry aplites also form independent dikes in the gabbro-anorthosite, but both the porphyry aplite and biotite rapakivi dikes are lacking in the olivine diabase.

6. The porphyry aplites — even when their country rock is gabbro-anorthosite — lack green, fayalite-bearing marginal varieties, notwithstanding their frequent occurrence in hornblende rapakivi rocks.

7. As further evidence might be cited the fact that plagioclase perthite is contained in the potash feldspar of the hornblende rapakivi to the extent of 20 % by volume, in the potash feldspar of biotite rapakivis 19—24 % and in that of porphyry aplites 8—10 %.

The foregoing observations, in my opinion, show that the hornblende rapakivis are not to be placed in the same category as porphyry aplites and that they are younger than the porphyry aplites, even though this cannot be established for sure on account of the lack of contacts.

GRANITE PORPHYRY DIKES

The granite porphyry dikes of the Ahvenisto area all consist of typical hypabyssal rocks. They contain orthoclase phenocrysts 1—4 cm long and 0.5—2 cm wide, quartz phenocrysts measuring 0.2—0.7 cm in diameter and some 0.5 cm long plagioclase phenocrysts. All the phenocrysts, by and large, are idiomorphic (see Eskola, 1946, Fig. 331). All the dikes likewise have chilled contacts of finer grain, though even at the margins of the dikes the groundmass is still wholly crystalline.

Two granite porphyry dikes 20—25 m wide run in a N 55°—60° W direction near the SW border of the biotite rapakivi massif. These dikes have already been described by Frosterus (1902). I have been able to follow the more northern dike for a longer distance at the SE end and noted that its strike is finally east by west. Accordingly, it apparently does not extend to the Viipuri rapakivi area at all. The more southern dike is straighter and terminates at its SE end in the bay of Karijärvi. The dip of both dikes is vertical or a few degrees either way. From the more northern granite porphyry dike there takes off at the SW corner of Salajärvi an apophysis 2—3 m thick running northward. The groundmass of the rock of this apophysis is very dense, though still quite crystalline, and its phenocrysts have very beautiful crystal forms.

Both dikes contain an abundance (26 % by volume) of idiomorphic potash feldspar phenocrysts 1—4 cm long and 0.5—2 cm wide. They have a small amount of unmixed plagioclase perthite, but they are covered by a thick reddish brown hematite pigment, which is stronger in the middle than at the margins of the dikes and often also at the core than at the margins of crystals. Quartz phenocrysts (13 % by volume) occur as light gray, euhedral crystals measuring 0.5 cm in diameter. Frequently one may see in the weathered surfaces of the outcrops beautiful crystals of hexagonal bipyramidal shape. There is a small quantity of yellowish green, tiny plagioclase phenocrysts (1 % by volume), which are invariably sericitized and epidotized (pistacite). In the center of the dikes the plagioclase phenocrysts are almost non-identifiable, whereas at the margins lamellae according to the albite law can still be seen. Under the microscope flakes of biotite are also likely to be observed as phenocrysts.

The groundmass of these dikes, which takes up 60 % by volume, is dense-grained at the border but coarser in the middle. The groundmass of the center reveals a skeleton structure of minerals. The skeleton crystals generally enclose quartz grains, which are in spots somewhat corroded. Skeletal groups without any visible crystallization center always occur in the groundmass. Sometimes skeleton crystals are met with around potash feldspar and plagioclase phenocrysts. In addition to potash feldspar, quartz and plagioclase, the groundmass contains dark biotite, which is chloritized in the center of the dikes, and fluorite, which is invariably more abundant and occurs as larger crystals in the center than at the margins of the dikes.

Besides the ones just mentioned, four other granite porphyry dikes have been found in the Ahvenisto area. Between Imjärvi and Korpijärvi there runs a granite porphyry dike about 5—7 m wide in a N 45° W direction, while another dike of equal width runs between Korpijärvi and Valkjärvi in the direction of N 30° W. Between Imjärvi and the biotite rapakivi massif there is situated a narrow (about 2 m wide) granite pophyry dike, running N 40° E. Another, similar (1.5 m wide) dike runs N 50° E from Pankajärvi about 1 km northward.

These four granite porphyry dikes are very much alike. Perhaps the latter two are slightly finer-grained than the former. They contain phenocrysts of potash feldspar (orthoclase), quartz, plagioclase and biotite. The orthoclase ($2V\alpha = 87°$) occurs as reddish brown crystals 0.5—2 cm long and 0.3—1 cm wide. The quartz appears as idiomorphic crystals, 0.5 cm in diameter, which often take the form of hexagonal bipyramids. Plagioclase is met with here and there as small, slightly greenish grains. In thin section biotite may also be observed as phenocrysts. In the margins of these dikes the phenocrysts are all well preserved. In the center of the dikes the plagioclase is sericitized and epidotized, while the biotite is chloritized. The groundmass of the margin is bluish gray and aphanitic but holocrystalline. (Fig. 20.) In the center of the dikes the rock is reddish brown, twice as coarse-grained as at the margins and individual mineral grains can be recognized by the naked eye. Fluorite is present in the center of the dikes in far greater abundance and as large violet-hued crystals. A chemical analysis of the center of the dike running between Korpijärvi and Imjärvi is given (No. 12, p. 77, Table VIII).

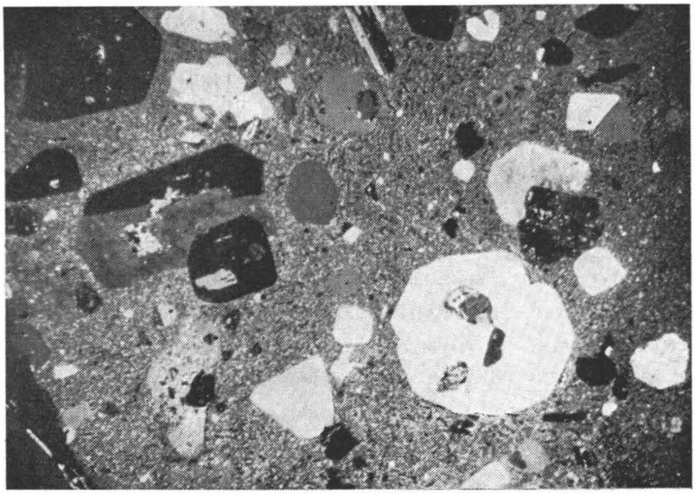

Fig. 20. Marginal variety of granite porphyry dike. Crossed nicols x 15. 100 m southwest of Valkjärvi. (Photo by E. Viluksela.)

The granite porphyry dikes are in some cases cut by narrow (1—10 mm wide) pegmatite veins mainly containing quartz. These pegmatite veins also cut the country rocks of the granite porphyries and penetrate them as much as 2—3 meters. These pegmatites presumably represent, at least in part, the last stage of crystallization of the granite porphyry dikes.

THE MODE OF OCCURRENCE OF THE GRANITE PORPHYRY DIKES AND THEIR CONTACT RELATIONS

The hypabyssal granite porphyry dikes of the Ahvenisto area, which have fine-grained, aphanitic chilled contacts against all its country rocks, form a fan whose tip is on the northeastern side of Karijärvi. This indicates that the eruption of the granite porphyry magma took place from the southeast. The dip of the granite porphyry dikes is nearly vertical and in their dip no regular inclination to either side of the vertical position can be observed.

The contact influences of the granite porphyry dikes on their country rocks are generally slight. The microcline granite has a green seam at the contact measuring about 1 mm in width, which receives its color from chlorite and epidote. At the contact the schistosity is disturbed in the mica gneisses and amphibolites, and chloritization takes place over a width of about 2 mm. The biotite rapakivis have altered over a wider space.

E. g. on the SW side of Valkjärvi the biotite rapakivi has lost its rapakivi structure over a width of about 5 cm, and it has altered into a fine-grained rock. Perhaps this is due to the fact that rapakivi is more porous than other rocks.

As the granite porphyry dikes are petrographically and structurally very similar and appear to form a uniform fan-like system, it seems reasonable to place them in a common category. Accordingly, it appears self-evident, looked at even on the map, that they are younger than the biotite rapakivis of the Ahvenisto area and all the still older rocks. As early as 1902 Frosterus (p. 82) described how an apophysis branching out from the granite porphyry dike at the western end of Kivijärvi (this local name is not marked on the map), situated at the edge of the biotite rapakivi intrusion WNW of Salajärvi, penetrates the biotite rapakivi. Around the middle of the southern side of Kivijärvi I have run across another spot where rapakivi dikes branching out from biotite rapakivi rocks are cut by a granite porphyry dike.

On the NE side of Korpijärvi runs a granite porphyry dike in a N 30° W direction. Near the shore of Korpijärvi there is also a porphyry aplite dike, starting from the NE side of the granite porphyry dike and extending even to the other side of the granite porphyry dike. The granite porphyry dike runs as a rocky ridge rising up from the terrain and cuts across the porphyry aplite dike. In addition, the sharp contact between them, where the granite porphyry has a plain chilled contact, is exposed for a short distance. The conclusion to be drawn is that also the porphyry aplites are older than the granite porphyry dikes and that the porphyry aplites, like the biotite rapakivi rocks, had time to cool down before the granite porphyry dikes were intruded.

The southernmost of the granite porphyry dikes terminates at the NW end of the bay extending NW from Karijärvi and vanishes into the lake. Rapakivi rocks typical of the Viipuri rapakivi area occur on both shores of the bay. The contact is not exposed for understandable reasons, but the dike must obviously either originate in the rapakivi (Frosterus, 1902, p. 80, and Wahl, 1925, p. 23) or intersect it. For the reasons to be given in the following, I consider this and the other granite porphyry dikes of the Ahvenisto area younger than the rapakivi rocks of the Viipuri area occurring here.

1) About 100 m southward from the aforementioned granite porphyry dike there occurs a rapakivi dike resembling the rapakivi met with on both shores of the bay. Another dike like it is situated a little farther away. Both dikes run N 60° W. Why should some of the dikes starting from the same spot in the Viipuri rapakivi area consist of rapakivi and some of granite porphyry if both types are dikes originating in rapakivi? 2) The

Table VIII. Chemical analyses of rocks of the Ahvenisto massif

	1	2	3	4	5	6	7	8	9	10	11	12
					Weight percentage							
SiO_2 ..	53.33	52.84	49.26	51.46	73.84	76.68	73.40	47.87	68.32	69.50	65.87	77.50
Al_2O_3 .	27.79	22.16	19.33	15.35	13.09	11.96	12.26	19.89	13.81	12.34	13.81	11.33
Fe_2O_3 .	0.09	1.76	2.71	1.53	0.87	0.53	1.07	0.93	1.18	2.02	0.98	1.41
FeO ..	0.49	4.93	8.99	12.37	1.79	1.54	2.24	9.82	4.70	3.97	4.98	0.87
MgO ..	0.17	1.91	3.91	4.42	0.23	0.20	0.24	7.30	0.58	0.35	0.77	0.32
MnO .	0.01	0.05	0.08	0.10	0.03	0.02	0.02	0.12	0.07	0.06	0.11	0.02
CaO ..	12.11	9.74	8.70	7.32	1.12	0.90	1.22	8.82	2.31	2.33	3.10	0.94
BaO ..	—	—	—	—	0.02	0.02	0.06	—	0.02	0.03	0.02	0.03
Na_2O .	4.46	3.70	2.62	2.94	2.32	2.36	2.60	3.02	2.72	2.50	3.66	2.58
K_2O ..	0.58	1.24	1.10	1.64	6.24	5.28	5.76	0.85	5.62	5.80	5.57	4.43
TiO_2 ..	0.25	0.90	2.23	1.95	0.22	0.20	0.35	0.76	0.49	0.45	0.78	0.13
P_2O_5 .	0.07	0.27	0.53	0.79	0.05	0.06	0.03	0.28	0.13	0.08	0.21	0.08
F	—	—	—	—	0.17	0.11	0.25	—	0.12	0.11	0.13	0.19
H_2O +	0.66	0.44	0.91	0.56	0.45	0.50	0.64	0.46	0.38	0.43	0.48	0.70
H_2O- .	0.02	0.08	0.06	0.04	0.07	0.04	0.02	0.02	0.07	0.10	0.11	0.01
	100.03	100.02	100.43	100.47	100.51	100.40	100.16	100.14	100.52	100.07	100.58	100.54
—O=F					0.08	0.05	0.11		0.05	0.05	0.05	0.08
					100.44	100.35	100.05		100.47	100.02	100.53	100.46
					Norms							
Q	0.30	2.04	2.28	1.32	33.61	40.08	32.81	0.54	22.23	26.68	15.11	43.68
or	3.34	7.23	6.68	9.46	36.74	31.18	33.96	5.01	33.40	34.52	32.84	26.16
ab	37.76	31.47	22.03	24.65	19.41	19.93	22.03	25.70	23.08	20.98	30.94	22.03
an	54.25	40.06	37.84	24.20	3.98	3.34	4.31	38.11	8.62	5.29	4.74	2.84
C	—	—	—	—	1.05	1.12	0.15	—	—	—	—	1.20
hy	0.40	6.33	10.69	18.34	2.24	2.11	2.64	—	6.99	4.88	7.26	0.10
en	0.40	4.72	9.74	11.05	0.60	0.50	0.60	—	1.41	0.90	1.91	0.80
wo ...	2.09	2.79	0.93	3.13	—	—	—	1.63	0.46	1.97	3.31	—
fa	—	—	—	—	—	—	—	12.53	—	—	—	—
fo	—	—	—	—	—	—	—	12.73	—	—	—	—
ap	0.17	0.68	1.26	1.91	0.14	0.14	0.07	0.68	0.34	0.34	0.68	0.20
ilm ...	0.46	1.52	4.25	3.64	0.46	0.46	0.60	1.52	0.91	0.91	1.52	0.30
mt ...	0.23	2.55	3.94	2.32	1.16	0.69	1.62	1.39	1.62	3.01	1.39	2.08
fl	—	—	—	—	0.42	0.28	0.61	—	0.26	0.28	0.30	0.47
	99.40	99.39	99.64	100.02	99.81	99.83	99.40	99.84	99.32	99.76	100.00	99.86
					Niggli values							
si	153	146	125	132	421	490	412.5	107	304	325	267	504
al	47	36	29	23	44	45	40.5	26	36	34	33	43.5
fm ...	2.2	23	39	47	14	13	17	45	25	25.5	25	15
c	37.2	29	24	20	7	6	7.5	21	11	12	13.5	6.5
alk ...	13.5	12	8	10	35	36	35	8	28	28.5	28.5	35
k	0.08	0.18	0.22	0.27	0.64	0.60	0.59	0.16	0.58	0.61	0.50	0.53
mg ...	0.31	0.34	0.38	0.36	0.15	0.15	0.12	0.55	0.15	0.10	0.19	0.21
c/fm ..	16.62	1.25	0.60	0.43	0.49	0.48	0.43	0.47	0.44	0.46	0.54	0.45
qz	—1	—2	—7	—8	181	246	172.5	—24	92	111	52	264

1. Fine-grained anorthosite. The island east of Kuhaniemi in Lake Ylä-Räävelinjärvi.
2. Coarse-grained gabbro-anorthosite. About 1.5 km north of the northern end of Siikajärvi.
3. Coarse-grained quartz diabase. Lautaniemi, on the western side of Vuohijärvi.
4. Fine-grained quartz diabase. Northeast of Kelesjärvi.
5. Biotite rapakivi. About 1 km east of Korpijärvi.
6. Biotite rapakivi fragment in the hornblende rapakivi. Near the western shore of Juolasvesi.
7. Porphyry aplite. About 1 km east of Korpijärvi.
8. Medium-grained olivine diabase. From between Siikajärvi and Leppälahti, near the southern end of the intrusion.
9. Hornblende rapakivi. From near the western shore of Juolasvesi.
10. Hornblende rapakivi (olivine-bearing). From between Siikajärvi and Leppälahti.
11. Green marginal variety of hornblende rapakivi. About 0.5 km northwest of Nurmaanjärvi.
12. Granite porphyry (center of dike). From between Imjärvi and Korpijärvi.

dike running on the northern side of the foregoing granite porphyry dike arches on its eastern end so much in a northerly direction that it evidently does not reach the Viipuri rapakivi area. It is also very improbable that all the other granite porphyry dikes of this area start from the Viipuri rapakivi. 3) The granite porphyry dikes are younger than the porphyry aplites, which in turn are younger than the biotite rapakivi.

I have not encountered olivine diabase and hornblende rapakivi in association with granite porphyry dikes in the Ahvenisto area. In the present study I have set the granite porphyry dikes down as of later origin principally for the reason that they are the most superficial rocks occurring in the Ahvenisto area.

ON THE PROBLEMS OF THE AHVENISTO MASSIF AND THE AGE OF THE BASIC ROCKS SURROUNDING THE RAPAKIVI

The observations made indicate that the Ahvenisto massif is the result of six separate magma intrusions of different age and different composition. Also magma of the same composition intruded and extruded at different times, forming clearly distinguishable intrusions and dikes. The crystallization of all the intruded masses took place under relatively peaceful conditions, without disturbing movements. They all differentiated upon crystallizing in varying degrees and in different ways. The direction and degree of their differentiation depended on the composition of the intruded and extruded magma, the form and size of the intruded mass, the location of the intrusion, the speed of the cooling down process, etc. From these different intrusions have originated the rocks of the Ahvenisto massif, which, listed in order from the oldest to the youngest, are:

- the rocks of the gabbro-anorthosite complex
    - fine-grained marginal varieties
    - anorthosites
    - gabbro-anorthosites and anorthosite-gabbros
    - pegmatitic gabbros and anorthosites
    - amphibole gabbros (in part)
    - albite diabases
- quartz diabases
- biotite rapakivis, porphyry aplites, aplites and pegmatites
- olivine diabases
- hornblende rapakivis, their porphyry aplites, aplites and pegmatites
- granite porphyries

The basic rocks associated with the Ahvenisto massif to a large extent arch around the biotite rapakivi body and on account of their position seem to be closely connected to it. Observations nevertheless indicate that the intrusions of different ages belonging to the Ahvenisto massif are not genetically directly interrelated. At least, they have not become differentiated in situ from the same magma after the intrusion. Also the time interval between different intrusions has been at least long enough —

and even longer — to permit the preceding intrusions to cool down completely before the next intrusion. Sederholm (1928, p. 84) writes about the relation to one another of the basic rocks existing in association with rapakivis, though of older origin, the following: »Basic rocks occur closely associated to them, but it is doubtful, whether they are really, as has been assumed, differentiation products from the same magma. In many cases, at least, they are syntectic rocks formed by the assimilation of basic rocks which are somewhat older than the rapakivi.» What, then, took place before the intrusion and extrusion process? Without speculating, it may only be affirmed that the intrusions and extrusions took place from one or more magma reservoirs. If only a single magma reservoir existed, then the composition of the magma would have had to change fundamentally between the intrusions and extrusions for some reason.

The gabbro-anorthosite complex surrounding the rapakivi massif is divided, according to field observations, into several different intrusions (p. 31). All these intrusions have chilled contacts against the country rocks and each other, Each intrusion includes a series of rocks ranging from anorthosites to albite diabases. These rocks form a beautiful series in accordance to the crystallization differentiation theory. Their differentiation has largely taken place subsequent to the intrusion stage.

The opinion generally advocated by the earlier investigators, that the basic rocks would stand in a close genetic connection with the rapakivi rocks, may appear natural for the following reasons: 1) Most other rapakivi massifs are accompanied by similar basic rocks, as those on Åland (Sederholm, 1934, p. 55), Laitila (Hietanen, 1947, p. 1054), Nordingrå (Sobral, 1913, v. Eckermann, 1938), Ragunda (Högbom, 1899), Loos-Hamra (v. Eckermann, 1936). 2) In the Viipuri area some basic rocks are connected with the rapakivi (according to Wahl, 1925, Hackman, 1934). 3) In certain areas (e. g. Nordingrå and Loos-Hamra), as also in the Ahvenisto area, the basic rocks have more fine-grained marginal zones, regarded as chilled borders.

The following facts, in the opinion of the present author, contrary to the prevailing conception, indicate that the gabbro-anorthosite complex is older than part of the microcline granites occurring in the Ahvenisto area, as a consequence of which the connection of the gabbro-anorthosite complex with the rapakivi cannot be very close. 1) The microcline granite, which is situated between the biotite rapakivi and gabbro-anorthosite on the southern side of Ylä-Räävelinjärvi and which is cut by the biotite rapakivi, contains gabbro-anorthosite fragments (right against the biotite rapakivi) (see p. 40). 2) The microcline granite penetrates the gabbro-anorthosite intrusions as such broad dikes (up to about 50 m) that the dikes cannot be regarded as having been generated by the partial remelting of the country rock caused by the intrusion itself. Speaking against the palingenetic origin of the granite dikes is the fact, first of all, that at contacts of gabbro-anorthosite with clearly older rocks (e. g. the older gneissose granites and granodiorites at the western border of the arch) the contact effects are negligible. 3) The gabbro-anorthosite intrusions are not very large, either. For instance, the quartz diabase intrusion at Lautaniemi is at least as large as any single gabbro-anorthosite intrusion occurring in the Ahvenisto area and yet its contact effects on the country rocks are slight. If the gabbro-anorthosite complex were a uniformly large intrusion, then perhaps the large dikes of microcline granite described (p. 34) might be considered palingenetic. On the other hand, the rocks of the dikes are similar to microcline granite in texture and composition. This fact also proves that they cannot be considered rapakivis, either, inasmuch as they contain, i n t e r a l i a, large grains of garnet, which never has been found in rapakivi rocks and the refractive indices of their biotite are notably smaller than those of rapakivis. The frequent occurrence of basic rocks near the rapakivi intrusions need not necessarily prove a close genetic or temporary connection between them, for the occurrence of both kinds of rocks in the same tracts may simply be due to the tectonic conditions.

The reader may ask why the gabbro-anorthosite complex has not been metamorphosed more strongly and why the mineral composition of its rocks does not represent the same metamorphic facies as the surrounding rocks. This may be explained in two ways: 1) The small, separate gabbro-anorthosite intrusion on the shore of Nöilöppijärvi has only amphiboles and no pyroxenes whatsoever as mafic minerals. Furthermore, elsewhere in the gabbro-anorthosite complex amphibole gabbro-anorthosites occur in abundance. The present author simply has not wished to take a stand concerning to what extent the rocks are autometamorphic and to what extent altered under the effect of the penetrating intrusions. 2) Evidently, also, such a basic, rigid mass is resistant enough against metamorphosing agencies. Phenomena of this kind are by no means rare in the Archaean formations (see e. g. Sederholm, 1923, p. 91, Plate V, Fig. 2).

This is the conclusion that has to be drawn, since the older migmatites occurring in contact with the gabbro-anorthosites, as appear from chilled border zones, are older than the latter and since the microcline granite forms eruptive breccias containing fragments of veined gneiss belonging to the older migmatites. Accordingly, the microcline granite has not originated (anatexis) in its present location at the same time and in the same conditions as the migmatites surrounding the gabbro-anorthosites, but rather has the microcline granite intruded after the formation of the older migmatites and must be even considerably younger than the metatect of these older migmatites. Certain tectonic observations likewise point the same way.

The gabbro-anorthosite complex of the Ahvenisto area does not apparently belong to the sub-Jotnian formations. Possibly it may perhaps better be compared to the Keuruu-type gabbros of Central Finland (*cf.* Väyrynen, 1954, pp. 91 and 97). Another, perhaps greater possibility is that they are Karelian in age. This brings up the question as to what extent the basic rocks older than the rapakivis occurring around other rapakivi areas are comparable in age to the gabbro-anorthosite complex of the Ahvenisto massif.

According to the prevailing conception, the post-Archaean and pre-Cambrian formations in Finland include the sub-Jotnian diabases and rapakivis, the Jotnian sandstones stratified on top of them and the post-Jotnian diabases intersecting the sandstones. Writing of the Loos-Hamra area in Sweden, v. Eckermann (1936, p. 331) states: »Summarising my conception of the Jotnian, this epoch is marked by four magmatic periods and three periods of sedimentation . . .» In the Loos-Hamra area the magmatic periods alternate with the sedimentation periods and are divided further by eruptions intersecting each other. Eskola (1955, p. 126) brings forth the conjecture that the rapakivi of the Laitila area may perhaps be younger than the Jotnian sandstone of Satakunta. Inasmuch as the Jotnian sandstones are lacking in the Ahvenisto area, a precise age comparison is not possible. The formations younger than the gabbro-anorthosite complex in the Ahvenisto massif are, however, evidently post-Archaean and pre-Cambrian.

CRYSTALLIZATION OF RAPAKIVI

Rapakivis are medium- and coarse-grained, partly porphyritic granites disintegrating to »moro». They occur in many places in Finland over wide areas. It may, in fact, be said that the rapakivis are, above all, typical Finnish rocks. The term »rapakivi» (r a p a u t u v a k i v i = disintegrating rock) is a Finnish word, established in geological literature by Sederholm (1891), but introduced already by Urban Hjärne in 1694 (Eskola, 1930 a).

Rapakivis have been the object of general interest for over two centuries, and many works on the rocks have been written. It is pertinent herein to attempt a review of what different writers have regarded as common and characteristic features of rapakivi rocks. The potash feldspar grains are most often more or less roundish (ovoids) and in many cases enclosed in a shell of plagioclase. In not nearly all the rapakivi types do potash feldspar grains enclosed in plagioclase shells occur. The potash feldspar of rapakivis is primarily orthoclase (Mäkinen, 1917, Eskola, 1929) and stained with a dark red-brown pigment (hematite), which gives the entire rock a red-brown color. Disintegration is a very common but capricious feature of the rapakivi rocks. Different types of rocks disintegrate to different degrees, and often the same type has undergone no disintegration in one spot and is wholly disintegrated in another, resulting in a »moro» (Eskola, 1930, 1930a, 1949). The totally unoriented and directionless structure of rapakivis has been known for a long time. At quite an early period the hypabyssal, partly effusive character of rapakivis was described. Likewise, the occurrence of miarolitic cavities was recognized to be typical of rapakivi, and the scarcity of aplites and pegmatites was known. It has been a generally shared conception that the quartz is euhedral, but numerous investigators have observed that it occurs in two generations, of which the later is xenomorphic. The assertion has also been made that the potash feldspar crystals are partly euhedral and partly anhedral. The occurrence of fluorite has likewise been regarded characteristic of rapakivis, as has that of zircon. The former has been mentioned as also often occurring in miarolitic cavities. In regard to chemical composition, all the rapakivis have been considered as just about the same species of rock with a rich content of K_2O and SiO_2, although various types, differing in composition, are known (Niggli, 1923).

Starting with the magmatic nature of rapakivi and its aforementioned features, the following explanations have been brought forth as to the structure of the rock:

Sederholm's (1891) hypothesis of the impurity of the ovoids.

Popoff's (1897) hypothesis of gravitative movements of the rapakivi ovoids.

Holmquist's (1901) liquation hypothesis.

Vogt's (1906) and Harker's (1909) hypothesis of alternating resorption stages in a eutectic mixture.

Wahl's (1925) hypothesis of refusion.

Sederholm's (1928) hypothesis of the analogous origin of the rapakivi structure and the orbicular granite structure.

v. Wolff's (1932) hypothesis of the hybrid magma.

Turner and Verhoogen (1951, p. 294) write about the rapakivi question: »The origin of extensive bodies of consistently porphyritic granite — the best known instance being the pre-Cambrian rapakivi of Finland and Sweden — presents a problem, which has not been satisfactorily solved.»

As to the magmatic origin of rapakivi granites, all the Finnish and also Swedish geologists have been unanimous, with the exception of Backlund. To support the thesis of its magmatic origin, the following observations have been presented, among others: that the rapakivis are partly effusive, such as the granite porphyries and quartz porphyries; that the effusive types grade over in places into normal rapakivi; that rapakivis have quite sharp contacts with their country rocks; that they lack all relict features of an earlier structure; that rapakivis form eruptive breccias, in which schist fragments are likely to be found in haphazard positions; and that they contain elements, such as F and Zr, absent or scarce in granites, granites regarded as palingenic.

As for the Ahvenisto area, it may be mentioned e. g. that the rapakivis cut the far older gabbro-anorthosites as straight dikes running along the fracture lines and as nearly horizontal sheets and that they occur in the same way in the quartz diabases, which are typical hypabyssal rocks. A glance at the map, on which it has been possible to mark down only a few of the broader dikes, suffices to show the wholly cross-cutting nature of rapakivis. The penetrating character is so clear that believing in the magmatic origin of these rapakivis is unavoidable. Also the contacts against the microcline granites and older migmatites are just as sharp (see contact marked on map at western margin of the biotite rapakivi area). The rapakivi further brecciates all its aforementioned country rocks, forming beautiful eruptive breccias. In these breccias the schist fragments are often in haphazard positions, as Eskola (1950, 1955) has described from the Laitila rapakivi area. Finally, it may be mentioned that in proceeding along the contact between the older migmatite and rapakivi the amount of the granite component of the migmatites and the degree of metamorphism of the gneiss component vary quite irrespective of the rapakivi. In many places it increases in proceeding away from the contact.

In regard to the form and manner of intrusion of the rapakivi massifs, numerous differing conceptions have been presented. Ramsay (1890) stated that in connection with the sinking of the earth's crust a quartz porphyry bed extended to Suursaari and that simultaneously the rapakivi was emplaced in southern Finland. Sederholm (1891) presented additional grounds for the vertical movements of the earth's crust taking place in connection with the setting into place of the rapakivis, and he termed the rapakivi masses taphroliths. Subsequently, he somewhat modified his ideas and regarded the rapakivis as laccoliths or perhaps batholiths. Högbom (1899) explained the Ragunda massif as a laccolith. Wahl (1925) described the Viipuri rapakivi massif as an enormous intrusion-sheet, whereas Hackman, again, designated it as a batholith. Eskola (1955) writes that »the rapakivi is typically disharmonious granite.»

The relations and the degree of idiomorphism of the minerals occurring in rapakivis are quite exceptional.

All rapakivi investigators have been unanimously of the opinion that the quartz of rapakivis occurs in two generations. The first generation is euhedral and the other xenomorphic. Certain investigators, e. g. Sederholm (1891, p. 4), Holmquist (1904, p. 86), v. Eckermann (1937, p. 514, 1944, p. 726), have noted that the first quartz generation has crystallized as hexagonal bipyramids. The quartz grains of the second generation, again, are xenomorphic in the interspaces or intergrown with the feldspars (graphic texture).

The quartz of the rapakivi types of the Ahvenisto massif occur in quite the same way. The quartz phenocrysts of the granite porphyries are beautiful hexagonal bipyramids. The quartz phenocrysts of the porphyry aplites may be recognized as such, too, although they are in some cases partly roundish. In biotite rapakivis corrosion has proceeded farther, but in them as well it is sometimes possible to recognize hexagonal bipyramidal forms. Unfortunately, it has not yet been possible to determine the fluctuations in the temperature of the high-low inversion of the quartz of the rapakivi types of Ahvenisto (see Keith and Tuttle, 1952, 1954).

Wahl (1925) distinguishes two potash feldspar generations. Eskola (1928, p. 18) mentions micropegmatitic zones as occurring around the potash feldspar grains. Wahl's conception is supported by v. Eckermann (1937, p. 514). In the rapakivi types of the Ahvenisto area the potash feldspar also occurs in two generations. In them may e. g. be seen potash feldspar grains with an idiomorphic core crystal surrounded by a sharply bounded graphic zone.

Wahl (1925) describes also the occurrence of plagioclase in two generations. Characteristic of rapakivis, furthermore, is the occurrence of plagioclase as a shell around the potash feldspar ovoids. Such a plagioclase shell may occur around fine-grained clusters of rock minerals as well, according to Wahl (1925, p. 59). In the rapakivi types of Ahvenisto may be found plagioclase grains the center of which is idiomorphic and the marginal zone a sharply limited intergrowth of quartz and plagioclase. Sometimes, moreover, it is possible to find potash feldspar grains with plagioclase shells as well as clusters of granite minerals with plagioclase zones.

The mafic minerals likewise occur in two generations. According to Wahl (1925, p. 108) the later generation includes mica and hornblende between idiomorphic quartz and feldspar grains. Sederholm (1916, p. 115) writes of rapakivi (viborgite): »This biotite is of the greatest interest because it is associated with vermicular quartz and typical myrmekite.» To this he adds that in spots the biotite is idiomorphic. In the area of the Åland Islands Sederholm (1916, p. 116) finds that the biotite has crystallized in cavities. It may often be observed in regard to the rapakivi types of Ahvenisto that the mafic minerals as biotite and hornblende are xenomorphic and that they tend to fill cavities, though idiomorphism is also to be met with.

From the rapakivi descriptions of different investigators it may be noted, as from the rapakivi types of Ahvenisto, that the minerals of the earlier generation are idiomorphic against those of the later generation, regardless of what minerals are situated side by side.

In regard to the sequence of crystallization of the minerals occurring in rapakivis, Sederholm (1916, p. 116) writes: »In general the biotite is a late constituent in the rapakivi rocks, where most of it is entirely allotriomorphic.» In 1928 (p. 85) Sederholm reiterates: »In the typical rapakivi, again, the greater part of the plagioclase, as well as the quartz, and almost all biotite, have crystallized later than the main part of the orthoclase.» V. Eckermann (1937, p. 514) writes: »The younger quartz-feldspar generation occurs as an eutectic graphic intergrowth around the crystallization-kernels of the older generation, which intergrowth, as clearly brought out by the microscopic picture, is the last one to have solidified.» Eskola (1928, p. 15) having observed the peculiar crystallization and idiomorphic habit of feldspar crystals in the graphic granites and rapakivis, writes: »These facts are seemingly contradictory to the generally accepted theories of magmatic crystallization. On the other hand, they are apparently of great general importance for the understanding of the mode of crystallization of graphic granites and rapakivi which is still very ill understood. Therefore it may be well to suggest some points of view towards their understanding, even if a definitive explanation is premature.» In the same paper (p. 16) he writes: »The three stages traceable in the crystallization of our graphic granites i. e. 1. the stages of the phenocrysts, 2. that of the micropegmatite, and 3. that of the coarse interstitial mass and the unakitization, are doubtless representatives of widely different temperature ranges.» Sederholm (1928 a, p. 49) mentions in respect to the final crystallization stage of rapakivis that in them are to be noted the formation of myrmekite and weak autometamorphic phenomena from the effect of the rocks' own residual juices. On the other hand, Sederholm and other researchers have stated that rapakivis contain little aplite and pegmatite. From this follows the conception that residual solutions have not been present in any large amounts in the rapakivi magma.

The next task is to try to ascertain to what extent the mode of occurrence and idiomorphic order of the rapakivi minerals correspond to the crystallization sequence of these minerals and in what way the rapakivi magma has possibly differentiated.

In the Ahvenisto massif the biotite rapakivis, porphyry aplites and their aplites and pegmatites belong in the same series. The said rocks have crystallized in the listed order from the same magma after this magma had intruded into its present position. The rocks thus form a differentiation series from rapakivi magma. The granite porphyries of the Ahvenisto area, on the other hand, correspond in chemical composition to rapakivi, whereupon the phenocrysts of the granite porphyries represent the part of the rapakivi magma which crystallized first. The mineral composition of the biotite rapakivis, again, corresponds nearly to the composition of the rapakivi magma of this massif as such, i. e. the mineral composition of the rock that forms when the main part of this rapakivi magma crystallizes under peaceful conditions. The porphyry aplites, furthermore, represent the composition of the part of the magma separated from it after it had largely undergone crystallization. They are a distinctly later differentiation from the rapakivi magma. The slight amounts of aplite and pegmatite are the final product of crystallization, having crystallized at a low (perhaps very low) temperature. Their quartz e. g. is low quartz. In both the foregoing main types the quartz (at least the phenocrysts) are, again, high quartz. There is, in fact, a difference in principle between the crystallizations of these two types of rock. The main part of the magma has certainly crystallized at a temperature of more than 572° C. The temperature evidently must have been considerably higher, for according to Yoder (1950, p. 832), under a pressure of 2 000 bars the high-low quartz inversion takes place at 626° C and correspondingly under a pressure of 4 000 bars at 679° C.

Table IX. Mineral composition of certain rapakivi types of the Ahvenisto area, per cent by volume

	1	2	3	4
Potash feldspar	26	60	56.4	47
Quartz	13	29	34.9	26
Plagioclase	1	7	6.2	19
Mafic minerals	—	4.5	2.5	7.5
Groundmass	60	—	—	—
Plagioclase perthite in potash feldspar	—	21.5	23.5	9

1. Granite porphyry (phenocrysts + groundmass; average),
2. biotite rapakivi (average),
3. biotite rapakivi and
4. porphyry aplite (average).

Let us compare, then, the mineral compositions of the aforesaid rapakivi types. First it must be observed that the respective amount of potash feldpar and quartz varies in the same type (Table IX, 2 and 3), but the content of other minerals remains nearly stable. Eskola has written about this (1928, p. 15). In examining the mineral compositions given in Table IX, it will be noted that the porphyry aplites contain more than twice as much plagioclase as the biotite rapakivi. Likewise, there is approximately twice the amount of mafic minerals. The plagioclase and the mafic minerals have clearly become enriched into the subsequent separation. On the other hand, the phenocrysts of the granite porphyry appear to contain less plagioclase than the other types, and megascopic phenocrysts of mafic minerals are totally absent.

In Table X the ratios potash feldspar: plagioclase and quartz: plagioclase have been calculated from Table IX. In them the course of the crystallization is beautifully revealed in that the ratios decrease from the start of crystallization toward the end. This signifies that the relative amount of plagioclase must increase during fractional crystallization. The plagioclase must thus either have begun to crystallize later or, at least, its crystallization must have become intensified toward the end.

Table X

	1	2	3	4
Ratio potash feldspar: plagioclase	26	8.6	9.1	2.5
Ratio quartz: plagioclase	13	4.1	5.6	1.4

1 Granite porphyry (from phenocrysts), 2 biotite rapakivi, 3 biotite rapakivi and 4 porphyry aplite (average).

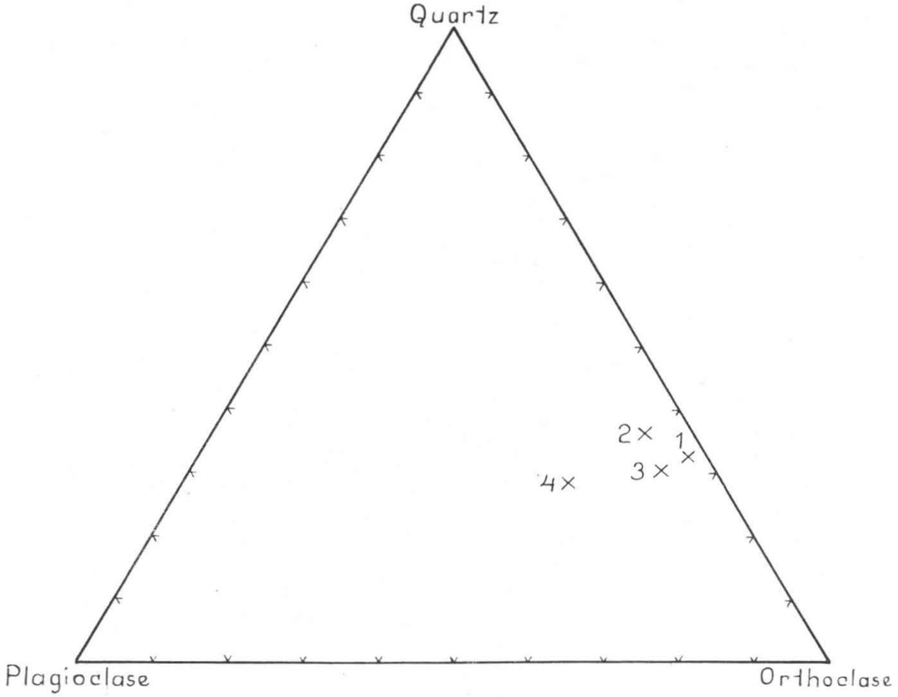

Fig. 21. Diagram of the modal composition of the Ahvenisto rapakivi rock types (Pts. 1, 2, 3, 4 — see Table IX).

If, then, we calculate from the mineral contents of Table IX the amount of quartz, potash feldspar and plagioclase on the basis of a hundred and mark down the values thereby obtained on a triangular diagram, we arrive at Fig. 21.

Thereby, the granite porphyry (point 1) is placed closest to the quartz-potash feldspar side of the triangle. The biotite rapakivis (points 2 and 3) are closer to the plagioclase tip of the triangle, and the porphyry aplite (point 4) is still notably closer. The same differentiation tendency is to be seen in this way, too.

Chayes (1952a) has presented modal analyses of 145 thin sections of New England calcalkaline granite in ternary projection, using total feldspar (F), quartz (Q) and dark minerals (M) as co-ordinates, whereupon the points fall into a small area. It is interesting to observe — even though this area need not be the average eutectic field of granites — that the points representing the rapakivi types fall outside this area on the opposite side of M, and that F is also somewhat behind this area.

In the chemical analyses (Table VIII, Nos 5, 6, 7, 12) the trend of differentiation is also revealed (see Fig. 22). To be sure, the ratio K_2O: Na_2O

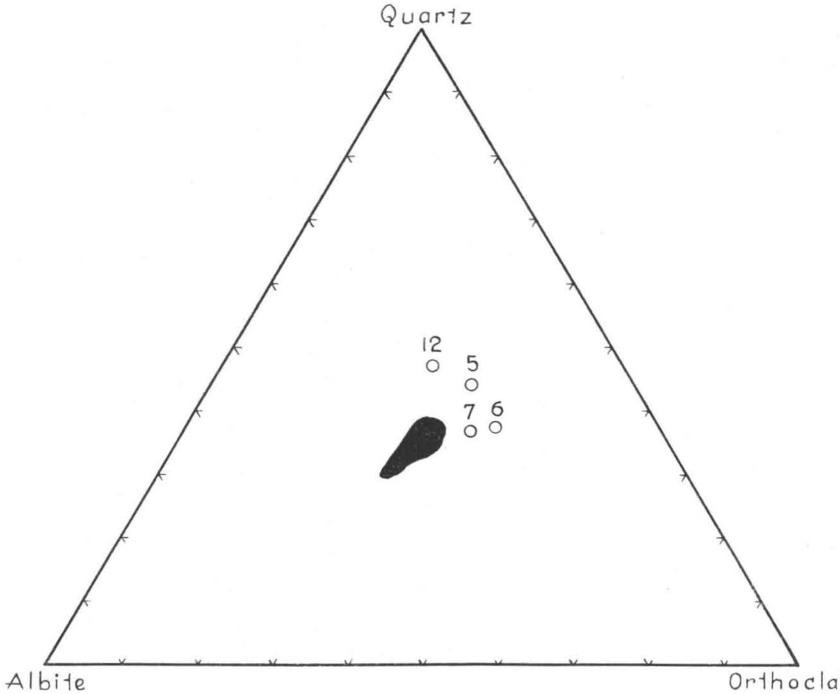

Fig. 22. Diagram of the normative composition (albite + orthoclase + quartz) of the Ahvenisto rapakivi rock types. (Pts. 5, 6, 7, 12 — see Table VIII). The black area is drawn according to ADAMS (1952.)

does not change clearly, but this evidently is due to the fact that plagioclase perthite accounts for approximately 22 % of the potash feldspar of biotite rapakivis, but only 9 % of that of porphyry aplites, as well as that the biotite contains an abundance of potash. However, on the other hand, the amount e. g. of volatile substances increases and the mg-value decreases, as is to be expected, from biotite rapakivi to the porphyry aplite.

Is the course of crystallization and differentiation thus depicted in conflict with the classical crystallization differentiation theory?

Bowen (1928, p. 227), in dealing with the fractional crystallization of rocks rich in potash and silica from the standpoint of the classical theory, writes: »If the feldspars have that relation to each other which is commonly accepted a liquid very rich in potash feldspar would never appear as a mother liquor of crystallization... If the relation between the three feldspars $NaAlSi_3O_8$, $CaAl_2Si_2O_8$ and $KAlSi_3O_8$ were that deduced by several investigators of rocks there would be no possibility of the derivation of potash-rich granitic liquid as a mother liquor in the fractional crystallization of basaltic liquid.»

In the albite — orthoclase — quartz triangular diagram (Fig. 22) the normative composition of the rapakivis of the Ahvenisto area analyzed have been marked down (Table VIII). In addition, in it has been marked the black area to indicate the contoured frequency-distribution diagram of the normative composition of 571 analyzed rocks (granites and syenites) (Bowen and Tuttle, see Adams, 1952, p. 41). All the rapakivis marked down lie outside the black area, which is between them and the albite. The end of the black area toward the quartz corresponds to the experimentally determined minimum temperature of this system (Bowen, 1954, p. 10). Upon an increase in the pressure of water vapor, the minimum shifts toward the albite. It seems as if under all conditions in these systems the crystallization of the rapakivi must lead to a residual solution rich in albite. This tendency is revealed by the points marked down.

In the system $NaAlSi_3O_8$—$KAlSi_3O_8$—H_2O (Bowen and Tuttle, 1950) the normative composition of rapakivis is between the minimum and the potash feldspar (see Table XI). To be sure, the anorthite component has some effect, but apparently it does not cause the prior crystallization of the plagioclase.

The only difficulty is that not even in the system albite-orthoclase-quartz-H_2O (Adams, 1952) does the crystallization temperature decrease in the area of the two feldspars. The granite porphyries offer us a clear example, however, of the fact that, before the beginning of crystallization in the groundmass, the crystallization of the potash feldspar and plagioclase phenocrysts had begun simultaneously, i. e. before 40 % by volume of the rock had crystallized. Evidently also all the other components of the rock besides the quartz lower the minimum temperature of crystallization somewhat. Perhaps e. g. fluorine has a greater effect than water. Also the anorthite component facilitates the simultaneous crystallization of the two feldspars (Tuttle, 1952).

Table XI. The normative potash feldspar and albite of the rapakivi types of Ahvenisto calculated on the basis of 100

	or	ab
5	65.4	34.6
6	61.0	39.0
7	60.7	39.4
12	54.3	45.7
E	35	65

5. Biotite rapakivi,
6. biotite rapakivi,
7. porphyry aplite,
12. granite porphyry (*cf.* Table VIII, p. 77) and
E. the eutectic ratio in the minimum field of potash feldspar and albite (Bowen and Tuttle 1950).

According to the rules established for the dry systems investigated, the crystallization of the rapakivi magma must also be like that just described. To be sure, not much can be based on them, for they do not correspond to the real conditions prevailing in a magma. It is nevertheless noteworthy that the normative composition point of rapakivi magma in the equilibrium diagram of the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2 falls close to the orthoclase tridymite eutectic line and that the normative composition point of the system Ab — An — Or in the equilibrium diagram falls into the orthoclase field. (See also e. g. Geijer (1922) and v. Eckermann (1936) and *cf.* Higazy (1949)).

The crystallization differentiation of rapakivi magma is not, even though crystallization does begin with quartz and potash feldspar, in conflict with the physico-chemical principles of the classical crystallization differentiation theory. Each magma simply crystallizes so that the residual liquid shifts toward the minimum point (field) of the magma in a manner depending on its chemical composition and the prevailing crystallization conditions. Thus, for instance, alkaline rocks have an agpaitic crystallization course (Fersmann, 1929). The birth and formation of magmas is, again, another matter.

What, then, is the genetic history of rapakivis like? The rapakivi magmas have intruded into the crust of the earth, partly up to the surface, and crystallized under extremely peaceful conditions. The crystallization of the magmas has begun (perhaps in many cases before the stage of intrusion) with quartz and potash feldspar above the quartz's high-low inversion temperature. After some time the plagioclase and dark minerals have also begun to crystallize. Finally, crystallization has continued in the minimum temperature field. The marginal parts of the intrusions have naturally crystallized more rapidly than the central parts. As the temperature dropped and the massifs contracted, residual magma intruded from the centers of the massifs into opened fissures in the marginal zones as dikes situated in different positions. From these residual magmas there crystallized rocks richer in plagioclase and mafic minerals than the main part of the intrusion. This resulted from the prior crystallization of the potash feldspar and quartz. Finally, the slight amounts of aplites and pegmatites crystallized and the autometamorphic alterations took place at a low temperature.

In the descriptive section reasons have been given for the conclusion that the Lappee granite in the Viipuri rapakivi area is probably younger than the viborgite and pyterlite. Upon studying the analyses of Wahl (1925) and Hackman (1934), it will be noted that the differentiation here has proceeded much farther than in the Ahvenisto massif. This is only natural, since the chilling, crystallization and differentiation of a far larger mass of magma is involved. On the other hand, differentiations corresponding to the porphyry aplites are not known at all in the Suomenniemi massif situated east of the Ahvenisto massif. This massif is, in fact, held to be a thin sheet, in which case there would not have been time during the period of chilling and crystallization for any noteworthy differentiation to take place.

It is characteristic of rapakivis that their crystallization has started with the potash feldspar and quartz while the composition of the residual magma moves toward the granitic minimum and that the younger rock types of the same intrusion are richer in plagioclase and mafic minerals. Thus crystallizes the rapakivitic magma type (to borrow the term coined by Niggli, 1923, *cf.* Sahama, 1945). As a consequence of the inverse crystallization of the rapakivi magma, the rapakivi structure and texture and the formation of the potash feldspar ovoids enveloped in a plagioclase shell are self-evident.

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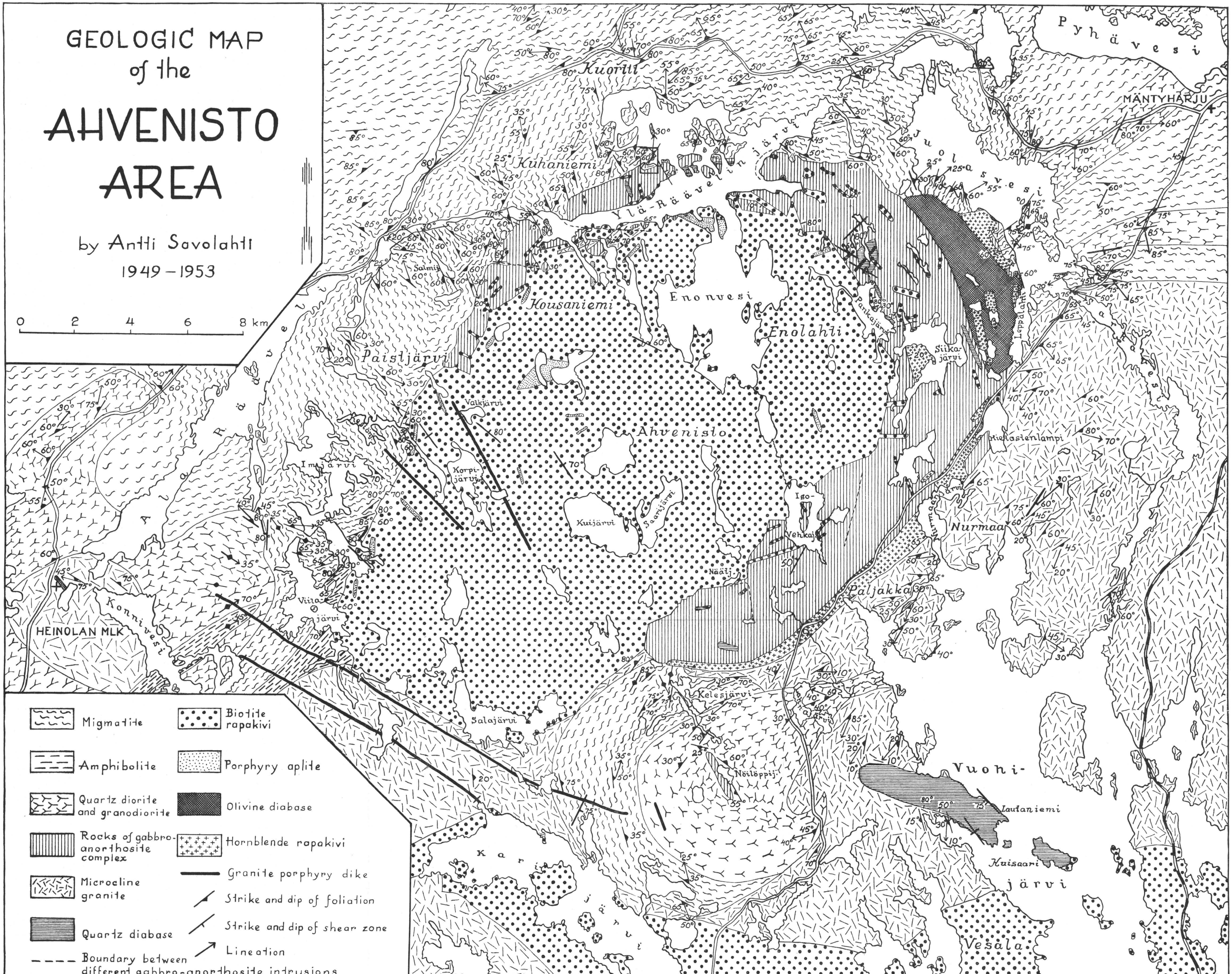
GEOLOGIC MAP
of the
AHVENISTO
AREA
by Antti Savolahti
1949 – 1953
0 2 4 6 8 km
Migmatite
Amphibolite
Quartz diorite and granodiorite
Rocks of gabbro-anorthosite complex
Microcline granite
Quartz diabase
Boundary between different gabbro-anorthosite intrusions
Biotite rapakivi
Porphyry aplite
Olivine diabase
Hornblende rapakivi
Granite porphyry dike
Strike and dip of foliation
Strike and dip of shear zone
Lineation
Pyhävesi
MÄNTYHARJU
Kuortti
Kuhaniemi
Ylä-Räävelinjärvi
Juolasvesi
Enonvesi
Enolahti
Kousaniemi
Paistjärvi
Ahvenisto
Kuijärvi
Nurmaa
Paljakka
Ala-Räävelinjärvi
Konnivesi
HEINOLAN MLK
Kelesjärvi
Vuohijärvi
Lautaniemi
Kuisaari
Vesala
Salajärvi
Karijärvi