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by Atso Vorma

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ON TWO ROOF PENDANTS IN THE WIBORG RAPAKIVI MASSIF, SOUTHEASTERN FINLAND

BY

ATSO VORMA

WITH 65 FIGURES, 4 TABLES AND ONE APPENDIX

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The age relations, contact metamorphism, hybridization and genesis of the rocks contained in the Ruoholampi and Hyvärilä roof pendants in the northeastern part of the Subjotnian Wiborg rapakivi granite massif (age c. 1700 m.y.) are described. The roof pendants consist of rocks belonging to the Svecokarelidic orogenic complex (metamorphosed about 1900 m.y. ago) and rocks belonging to the Subjotnian complex.

Of the rocks of the Subjotnian complex, the diabase and porphyries comagmatic with the rapakivi, are described in detail. Chemical analyses are given of both of these rock groups. The lead-uranium age of the zircon contained in the diabase is 1690 m.y. and in the so-called Hiidenniemi porphyry 1685 m.y. The field relationships indicate the diabase to be older than the porphyry. The hybridization of the diabase by porphyry is discussed and emphasis is laid on the ocellar and relict porphyritic textures produced.

The rocks belonging to the orogenic complex were metamorphosed thermally by rapakivi granite and porphyries under low-pressure conditions. Andalusite and cordierite hornfelses were produced from metapelites. The granodioritic rocks altered under the conditions of pyroxene-hornfels facies into cordierite-rich rocks. These the author is inclined to regard as analogous with the basic »behinds» as presented by Read.

Volcanic and subvolcanic Subjotnian rocks evidently formed most of the roof of the Wiborg rapakivi granite massif.

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CONTENTS

INTRODUCTION

This paper deals with problems of age relations, contact metamorphism, hybridization and the genesis of rocks enclosed in the Wiborg rapakivi granite massif in southeastern Finland. The author regards these rock remnants as roof pendants. The rocks studied are situated mainly in the southern part of the Ruoholampi roof pendant in the northeastern part of the Wiborg massif (roof pendant No. 2 in the index map of Appendix 1). Some data from the Hyvärilä roof pendant (No. 1) will also be given. The northeastern part of the Wiborg massif contains more country rock fragments than those shown in the index map of Appendix 1 (Nos. 1—4), but they are so small they cannot be shown on that map.

The roof pendants Nos. 2, 3 and 4 have been previously described in some detail by Hackman in 1934, and Nos. 1 and 2 by the present author (Vorma 1964 and 1965). The author remapped the southern part of the Ruoholampi roof pendant in 1969 and collected new material from the Hyvärilä roof pendant.

The crucial parts of the area shown in Appendix 1 are only slightly exposed because the central part of the map area is covered by the broad First Salpausselkä end moraine, the trend of which is nearly east-west. The general shape of the Ruoholampi roof pendant can, however, be deduced from the aeromagnetic maps of the Geological Survey.

The Subjotnian Wiborg rapakivi granite massif is a composite epizonal postorgenic, possibly anorogenic batholith (see, e.g., Vorma 1972). In age— 1700 m.y. —, it is postorogenic in respect to the Svecokarelidic orogeny, during which the metamorphism culminated about 1900 m.y. ago. Different varieties of rapakivi granite and their mutual relations were recently described in 1971, and a general description of the metamorphism around the batholith was published in 1972, both by Vorma. In the present paper, only certain rapakivi varieties will be designated by name. They are as follows.

Tirilite: a fayalite-bearing even-grained, dark, in places almost black ferrohastingsite granite of medium coarseness. When Streckeisen's terminology (1967) is used, most of the composition points fall into the granite field 3a, near the junction between the fields of syeno-granite, syenite and monzonite. A few of the specimens investigated fall into the syenite field (quartz-bearing syenites).

Lappee granite: an even-grained brown or reddish brown ferro-hastingsite granite of medium coarseness with a gradual change to tirilite.

Wiborgite: the typical rapakivi, i.e., porphyritic ferrohastingsite granite in which the potash feldspar phenocrysts are ovoidal in shape and surrounded by plagioclase mantles. This variety forms almost 80 per cent of the Finnish part of the Wiborg massif and it is younger than the two foregoing varieties.

Pyterlite: a porphyritic biotite granite in which the potash feldspar phenocrysts are ovoidal in shape but not mantled by plagioclase. Usually it exhibits a gradual change to wiborgite.

Porphyritic rapakivi: as pyterlite; the phenocrysts are angular in shape.

Porphyry: in the area shown in the appended map, porphyry is met with only in the roof pendant area. There it occurs both as an almost horizontal subvolcanic or volcanic sheet (Hiidenniemi porphyry) and as thermally metamorphosed subvolcanic and volcanic equivalents of the rapakivi (felsite porphyries).

The rapakivi of the present erosion level is thought to represent an intrusion depth of about 3 km (see, e.g., Vorma 1971, p. 60). The estimated thickness of the massif, computed from gravity data (Laurén 1970), is from 8 to 19 km. The occurrence of volcanic and subvolcanic rapakivitic rocks in the Ruoholampi roof remnant which is surrounded by the typical »deeper seated» rapakivi and the non-rapakivitic rocks in this remnant that was thermally metamorphosed by rapakivi under low-pressure conditons, have led the author to regard the Ruoholampi country rock remnant as a roof pendant (see also Hackman 1934, p. 49). It is highly possible that the southern part of the Ruoholampi roof pendant represents some kind of volcano-tectonical subsidence structure.

When describing the Ruoholampi country rock remnant (No. 2 in the index map of Appendix 1), the Toivarila-Lipiälä remnant (No. 3) and the Taalikkala remnant (No. 4), Hackman (1934) regarded most of their rocks as Svecofennidic, i.e., rocks of the orogenic complex. Hackman described as plutonic rocks: 1. coarse-porphyritic biotite granite, 2. gray, medium-grained granite (granodiorite in the present paper), 3. red felsite porphyry (felsite porphyry of the rapakivi suite in the present paper), 4. rapakivi granite porphyry (porphyry in the present paper); as supracrustal Svecofennidic rocks: 1. metabasalt (Subjotnian diabase in the present paper), 2. migmatite, 3. quartz-cordierite rock (hornfels in the present paper), 4. quartzite, 5. leptitic volcanogeneous schists (some of these are thermally metamorphosed volcanic equivalents of rapakivi granite and certain other ones thermally metamorphosed cataclastic rocks, while some can be possibly regarded as metasiltstones), 6. conglomerate (tectonic breccia in the present paper). Furthermore, many of the more basic leptites are interpreted in this paper as hybrid rocks derived from diabase and rapakivitic melt. These are major differences between Hackman's interpretations and those of the present author.

SUBJOTNIAN ROCKS

In the study area, the Subjotnian complex comprises different kinds of rapakivi granites, their subvolcanic and volcanic equivalents, rapakivitic dike rocks, and diabases, part of which appear originally to have extruded as plagioclase-porthyritic lava flows. Next, first diabase, then rapakivi porphyries will be described, followed by a description of the hybridization of diabase by rapakivi porphyry.

Diabase

Hackman (1934) gave a highly detailed description of the diabase, designating it as plagioclase porphyrite. He described the rock from the Ruoholampi and Taalikkala roof pendants (Nos. 2 and 4). The nature of the emplacement of the diabase, whether extruded as lava flows, as assumed by Hackman, or intruded as subvolcanic sills and dikes, is somewhat problematic. Dealing with the Taalikkala roof pendant, Hackman described amygdaloidal porphyrite in connection with the typical plagioclase porphyrite. A lava character is dominant there. In the Ruoholampi roof pendant, amygdules are rarer. The Hyvärilä roof pendant (No. 1) contains basic rocks too, and the present author is inclined to interpret them as subvolcanic for the most part. Thus, in the following description, the term diabase will cover both the volcanic and subvolcanic basic Subjotnian rocks, even though this may cause some confusion when correlations with other areas are made. For instance, the Dala Subjotnian complex in western Sweden contains in its Dala volcanics formation rocks similar to the diabases in the roof pendants inside the Wiborg massif, although they are referred to as porphyrite.

Geological setting

At the southwestern margin of the Hyvärilä roof pendant (Fig. 1), diabase occurs as sheet-like bodies between wiborgite rapakivi and Svecokarelidic porphyroblastic granodiorite. The bodies trend almost east-west and dip 60°—70° to the south. Their original form may have been displaced in connection with intrusive faulting during the emplacement of the rapakivi and they may be only remnants of considerably larger bodies.

Fragments of thermally metamorphosed diabase in different states of hybridization are encountered within the wiborgite south of the diabase bodies. Fig. 2 illustrates a diabase/wiborgite rapakivi eruptive breccia located on the northern shore of Kotajärvi (see Fig. 1), just 100 m to the south from the western diabase body.

The age relation between the diabase and the granodiorite in the Hyvärilä and Ruoholampi roof pendants is revealed in only one outcrop, which deserves special attention. The locality is in the northern margin of the western diabase body. This body is composed mainly of coarse-

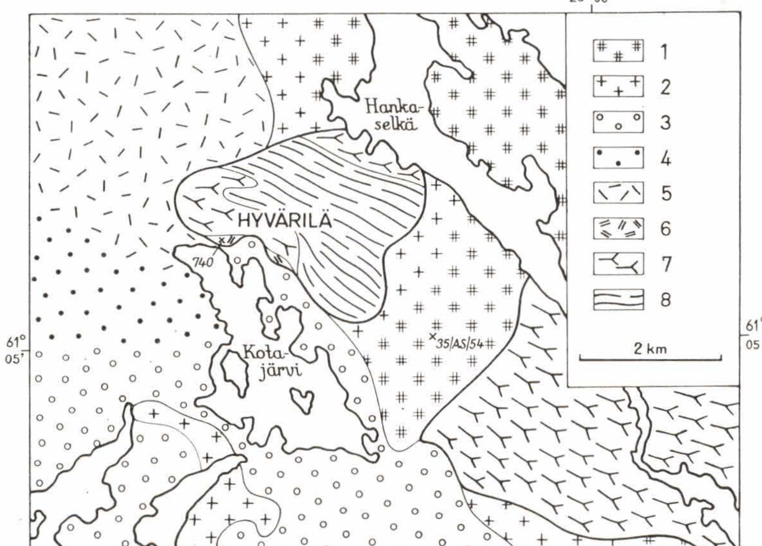

FIG. 1. A geological sketch map of the Hyvärilä roof pendant, Lemi, southeasternFinland, northeastern part of the Wiborg rapakivi granite massif, simplified from the petrological map quadrangle No. 3134, Lappeenranta, compiled by Atso Vorma (1964).

1. tirilite, 2. Lappee granite, 3. wiborgite, 4. pyterlite, 5. porphyritic rapakivi, 6. diabase, 7. granodiorite, 8. biotite gneiss.

grained diabase with a marked alignment of the plagioclase laths (Fig. 3) parallel to the plane of the diabase »sheet». This variety is irregularly banded. The bands are small-grained, consisting in places of almost aphanitic diabase and measuring a few meters in breadth. The bands are also parallel to the longitudinal direction of the body.

Fig. 4 shows a boudinaged, fine-grained diabase dikelet, which runs almost perpendicular to the alignment of the plagioclase laths of the coarse-porphyritic host diabase. The dikelet seems to have originated from the core of the diabase body, the marginal parts of which fractured when the rock was almost consolidated but still capable of flowing. Melt from the interior of the consolidating diabase body filled the fractures and the boudinage was caused by the stress produced by the flow. Fig. 5 illustrates the continuation of the dikelet into the adjacent porphyroblastic granodiorite. The contact between the granodiorite and the diabase body is not exposed. There is a gap a few meters broad between the two rocks, which is hidden under the overburden. Also the granodiorite was deformed cataclastically during the emplacement of the diabase or during the emplacement of the adjacent rapakivi. Subparallel to the flow direction in the diabase body proper,

FIG. 2. Eruptive breccia. Fragments of thermally metamorphosed and hybridized diabase in wiborgite. Northern shore of Kotajärvi, southwest of the Hyvärilä roof pendant, Lemi.

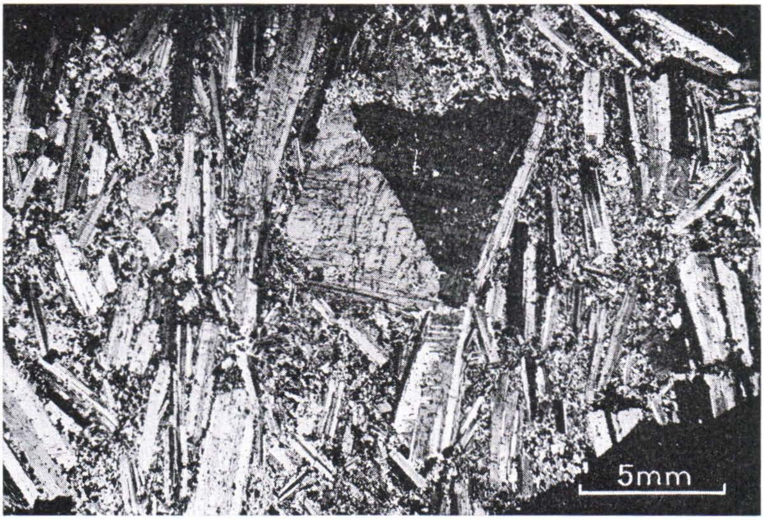

FIG. 3. Diabase with well-aligned plagioclase laths. Hyvärilä roof pendant, north of Kotajärvi, Lemi. Crossed nicols.

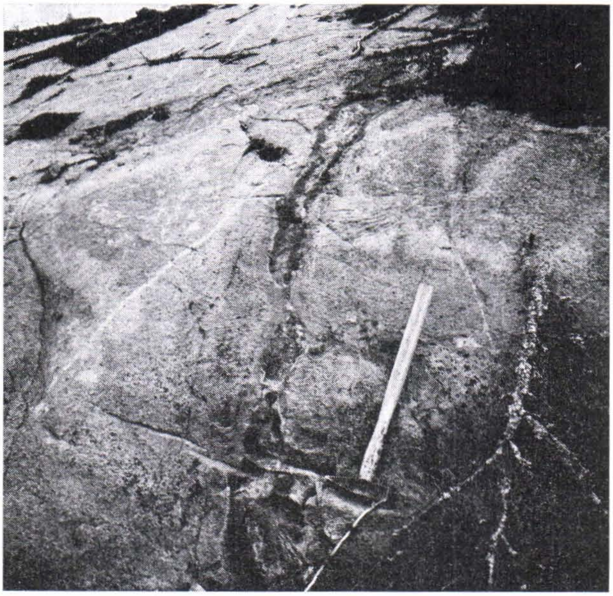

FIG. 4. A boudinaged, small-grained diabase dikelet cutting the coarse-porphyritic Hyvärilä diabase. Hyvärilä roof pendant, Hyvärilä, Lemi.

FIG. 5. A part of the continuation of the diabase dike of Fig. 4, cutting the porphyroblastic granodiorite. For further information, see text. Hyvärilä roof pendant, Hyvärilä, Lemi.

the granodiorite has shears along which small displacements have taken place (Fig. 5).

The Ruoholampi diabase, like that of Hyvärilä, contains in places steeply dipping bands, which measure from some tens of centimeters to tens of meters in thickness and vary in grain size. An example is exposure No. 45, to the north of Yllikkälä (Appendix 1), which is characterized by an alternation of coarse-porphyritic diabase, amygdaloidal diabase, a pyroxene-bearing diabase and a small-grained diabase. On this exposure, the banding runs parallel to the trend of the tension joints, which are filled with granitic material (tension dikes, presumably of rapakivitic origin), and also parallel to the direction of some rapakivi aplite and porphyry aplite dikes up to 2—3 m in breadth. This rock might well have been produced by extrusive lava.

Tension dikes occur in the southern part of the Ruoholampi roof pendant in diabase near its contact with the Lappee granite. They are represented by granitic or pegmatitic lenses of varying length and thickness. Especially in exposure No. 22 in Tapavainola (Appendix 1) [1]),

1) On the map of Appendix 1, deviating from the general principle that the tectonic sign shows at the same time the point where the observation is made, the symbol denoting the direction of the tension dikes is drawn next to the symbol indicating the observation point.

they are well developed. They form there en échelon lenses about 10 cm long, in exceptionally instances up to 1 m long, the width varying from 0.1 to 2 cm. In certain other exposures, the tension dikes are somewhat thicker and longer. The dikes run subparallel to the southern contact of the diabase against the rapakivi. The author attributes the formation of these tension dikes to the emplacement of rapakivi, causing an almost vertical stress against the floor of the roof pendant.

Only one thin section was made from the rock of the tension dikes. In this sample (No. 45, Yllikkälä), the mineral composition is potash feldspar, plagioclase (An_{40}) and quartz, with minor amounts of biotite, chlorite, sphene, opaque minerals and analcime. The texture is granoblastic.

The occurrence of tension dikes is correlated with the emplacement of rapakivi. Also to this same episode should be correlated the few rapakivi granite, rapakivi pegmatite and rapakivi aplite dikes, which vary from some tens of centimeters to a few meters in width, cutting the diabase.

Hackman (1934, p. 64) described two contact exposures between the rapakivi and diabase (his plagioclase porphyrite), one from Yllikkälä, another from Tapavainola. In the former contact, the rapakivi penetrates the diabase as dikes and apophyses; in the latter, a granite porphyry contact facies has been generated in the rapakivi and the diabase has been thermally metamorphosed at the same time.

The author found, in addition, the diabase/Lappee granite contact at three localities along the southern margin of the Ruoholampi roof pendant. The contact is sharp. The rapakivi dips under the diabase. In two of the exposed contacts, there is a pegmatite seam, a few centimeters broad, between the rocks, while in exposure No. 44 at Yllikkälä, there is a pyterlite-like contact rock about one meter broad with slightly smaller potash feldspar insets than in the pyterlite proper. Viewed with the naked eye, the diabase looks quite fresh up to the contact. Under the microscope, however, it can be seen that the rock has suffered intensive thermal metamorphism near the rapakivi contact.

West of Yllikkälä, in exposure No. 53, a marginal granite porphyry against the diabase in the Lappee granite has formed. The contact line itself is not, however, exposed there.

Intrusive breccias proper have not been discovered along the contact zone under discussion. Northeast of Yllikkälä, it is true, some rounded fragments of thermally metamorphosed diabase occur in the Lappee granite close to the contact line, the longest axis of the fragments being aligned parallel to the contact.

The southern contact gives an impression of its having been produced by intrusive faulting; this supports the view that a subsided roof pendant is in question.

The contact relations of the diabases with the rapakivi porphyries will be discussed later in this paper (pp. 22 and 35—50). No exposures have been found that would elucidate the contact relations of the diabase with the Svecokarelidic supracrustal rocks. Mention should be made, however, of occasional quarzite inclusions, measuring up to a few centimeters in diameter, found in the diabase (see also Laitakari 1969, pp. 45—48).

Radiometric age

There are two major reasons for selecting the coarse-grained Hyvärilä diabase, illustrated in Fig. 3, for a radiometric age determination. First, there seems to be an absence of hybridization phenomena caused by rapakivi porphyries, and second, the thermal metamorphism caused by the adjacent rapakivi granite seems to be quite faint in comparison with the diabases in the Ruoholampi roof pendant. The sample locality — 740 — is indicated in Fig. 1.

Using the lead-uranium method, Dr. Olavi Kouvo determined the radiometric age of zircon separated from the diabase. The age was read as 1690 m.y. from the concordia diagram by means of the diffusion model of Wasserburg (1963). The individual apparent ages are: 1628 m.y. for $^{206}Pb/^{238}U$, 1652 m.y. for $^{207}Pb/^{235}U$ and 1682 m.y. for $^{207}Pb/^{206}Pb$. These data show the diabase to represent Subjotnian igneous activity.

Laitakari (1969) reports an isochron age (lead-uranium method) for sphene from a rheomorphic dikelet cutting a diabase dike of the Häme diabase dike set as 1670—1710 m.y. The $^{207}Pb/^{206}Pb$ age was reported as 1670 m.y. The radiometric data indicate that both the diabases occurring in the roof pendants inside the rapakivi massif and those belonging to the Häme diabase dike set, northwest of the main Wiborg massif and extending at least 150—200 km nortwest from the nortwestern contact of rapakivi, belong to the same Subjotnian basic igneous activity preceding the emplacement of the rapakivi granites.

Petrography

The diabase is a massive dark-gray rock on the weathered surface of which white plagioclase laths stand out in relief. The plagioclase laths are mostly 0.5—8 mm in length; occasionally, however, the diabase is even coarser in grain. Thus, e.g., on the small island (exposure

No. 792) in Ruoholampi the diabase is characterized by phenocrysts 1—2 cm, in patches up to 3—5 cm, in diameter. In addition, megacrysts, from 6 to 8 cm in diameter also occur. In the same exposure, the rock grades over into a diabase variety poor in phenocrysts and into an amygdaloidal variety.

In some of the exposures, the plagioclase laths are aligned parallel to the banding. The alignment of the laths is quite marked for example in the Hyvärilä diabase (see Fig. 3).

Amygdaloidal varieties are rare. They are present in, for example, exposures Nos. 22, 45, 48, 774, 792 (Appendix 1). In addition, scattered amygdules have been encountered in certain other exposures of the diabase.

The phenocryst plagioclase is often observed to be zoned and clouded by sericite, often by epidote as well, and, in the thermally metamorphosed parts, also by opaque minerals and late muscovite and biotite. In composition it is mostly in the range An_{40-60}. Usually the phenocryst plagioclase has a higher An content than the groundmass plagioclase, as, e.g., in the Hyvärilä diabase (Fig. 3), where An_{57} was measured for a homogeneous plagioclase phenocryst, but An_{45} for the groundmass plagioclase.

In the groundmass, the grain size varies from 0.05 mm to 0.1 mm, occasionally reaching 0.3 mm. It is composed of plagioclase, biotite, which has in many instances altered into chlorite, opaque minerals (magnetite and ilmenite), leucoxene, quartz, epidote and apatite. Muscovite and carbonate minerals occur in some of the samples studied; some contain diopside, too, as poikiloblasts, and in certain cases the monoclinic pyroxene is evidently a relict. The actinolitic hornblende is quite idiomorphic in shape in certain of the samples, and in some the poikiloblastic form is well developed. Sphene occurs mostly as allotriomorphic grains in the allotriomorphic-granular groundmass, in many places also as leucoxene rims around opaque-mineral grains. Poikiloblasts of sphene have likewise been encountered.

Depending on the recrystallization stage, the texture of the groundmass varies from intergranular to hypidiomorphic granular, in places to allotriomorphic granular, and to that characteristic of hornfelses.

The amygdules have not been investigated systematically. The few samples studied show them to consist mainly of epidote, quartz, chlorite and amphibole.

Ocellum-like structures will be described in connection with the discussion on the hybridization of the diabase by rapakivi (pp. 35—51). Some of the ocelli, being merely mineral aggregations formed during the thermal metamorphism, might well have developed in diabase without any hybridization. Fig. 6 illustrates a quartz ocellum in diabase surrounded by poikiloblastic diopside of secondary origin. Some of the ocelli might also have originally been vesicles, filled later with siliceous material.

The thermal metamorphism produced by the rapakivi granite has left marked imprints in the diabase. Some examples will be given.

Fig. 7 illustrates the most common effect of thermal metamorphism. The groundmass of the diabase is thoroughly recrystallized; poikiloblasts of late hornblende and biotite are common.

In exposure No. 22, in Tapavainola, the portions of diabase are altered into a garnet-plagioclase-hornblende-diopside hornfels (Fig. 8). The hornfels contains poikiloblasts of andradite, the composition of which, according to a micro-probe analysis by J. Siivola, is: SiO_2 37.56, TiO_2 0.83, Al_2O_3 4.44, Fe_2O_3 (tot. iron) 25.97, MnO 0.56, MgO 0.1, CaO 30.00, sum 99.46 %. It also contains granoblastic, small-grained (0.05 mm) and polysynthetically twinned basic plagioclase, and light-coloured hornblende, which is slightly coarser in grain than the plagioclase. The hornblende is partly idiomorphic, partly allotriomorphic and also occurs as poikiloblasts. Furthermore, diopside is met with partly as poikiloblasts, partly as aggregates. Hematite occurs as thin laths (Fig. 9) surrounded by narrow leucoxene rims. Recrystallized apatite, too, occurs as long slender crystals. The altered diabase grades over into a slightly better-preserved diabase, the groundmass of which contains poikiloblasts of biotite and hornblende, the latter containing remnants of diopside. The plagioclase phenocrysts are preserved. Titanomagnetite grains, many of them surrounded by leucoxene, occur as opaque minerals.

In exposure No. 45 in Yllikkälä, the diabase contains thermally metamorphosed amygdules. One of the amygdules investigated contains andradite, epidote, diopside, sphene and fluorite; another contains plagioclase, epidote and carbonate. Fig. 10, taken of a sample from this exposure, shows how small flakes of late biotite penetrate the plagioclase phenocrysts of a small-grained diabase. The groundmass is completely recrystallized.

Thermally metamorphosed amygdules occur likewise in certain other exposures along the southern margin of the Ruoholampi roof pendant. Then, further from this contact area, features indicating thermal metamorphism have been found, as, e.g., at Selkäharju, in exposure No. 775, where there occour scattered quartz ocelli (Fig. 6) rimmed by poikiloblastic late diopside.

FIG. 6. Typical diabase from the Ruoholampi roof pendant. Note the quartz ocellum in the centre of the photograph. The ocellum is surrounded by large poikiloblasts of monoclinic pyroxene (p). Exposure No. 775 in Appendix 1. Northwest of Selkäharju, Lappeenranta. Crossed nicols

FIG. 7. Thermally metamorphosed diabase. Laths, plagioclase; h = hornblende poikiloblasts, bi = biotite poikiloblasts. Two meters from the contact against the Lappee granite. Exposure No. 26 in Appendix 1. Tapavainola, Lappeenranta. Crossed nicols.

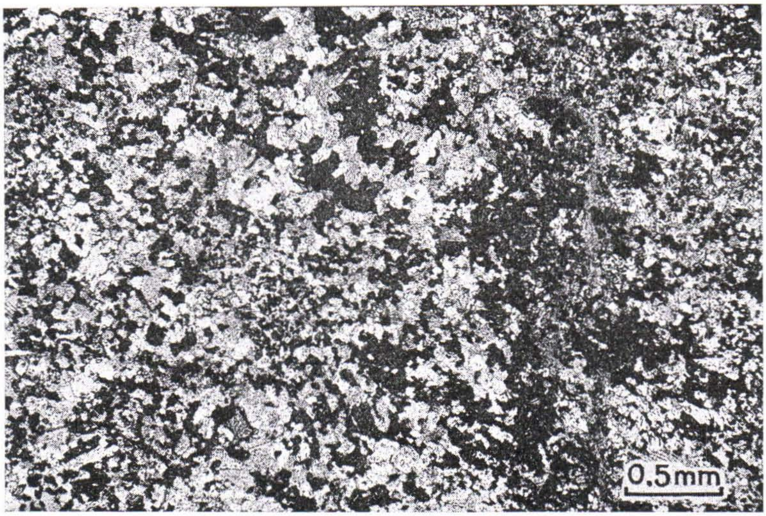

FIG. 8. Andradite-plagioclase hornfels. Dark, andradite; light, mostly An-rich plagioclase; black, opaque minerals. Thermally metamorphosed diabase from southeastern part of the Ruoholampi roof pendant. Exposure No. 22 in Appendix 1. Tapavainola, Lappeenranta. Crossed nicols $-10°$.

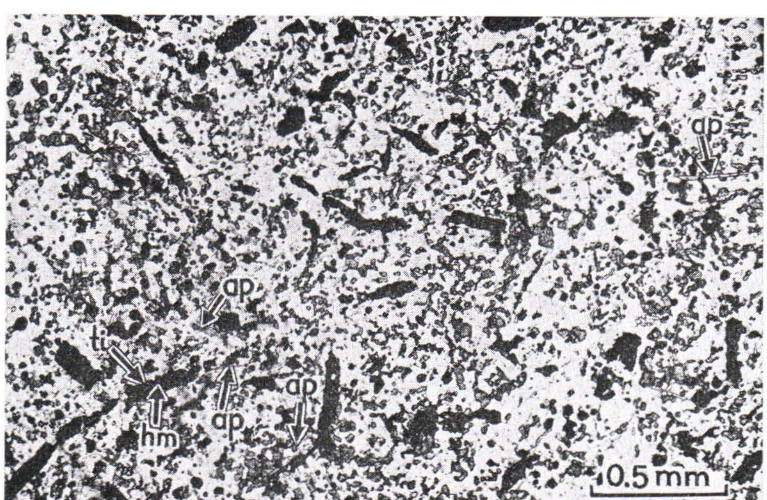

FIG. 9. Hematite laths (hm), rimmed by sphene (ti) in thermally metamorphosed diabase. White, calcic plagioclase; gray, hornblende and diopside. Note the slender crystals of apatite (ap). Same thin section as in Fig. 8. Parallel nicols.

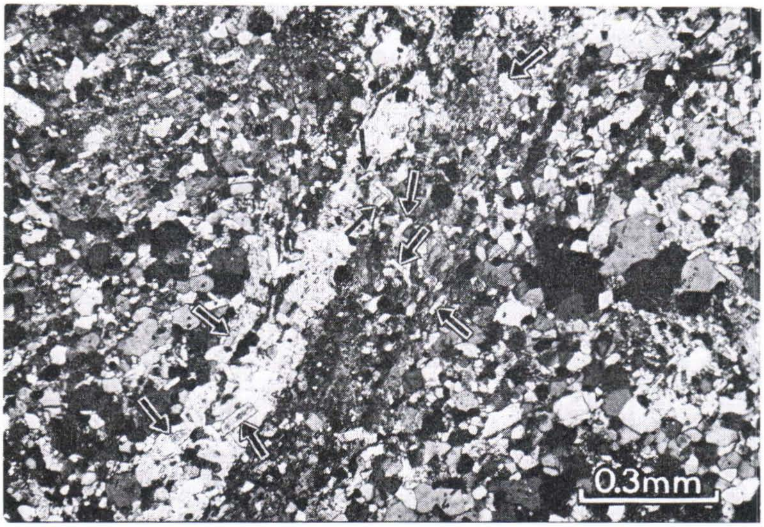

FIG. 10. Thermally metamorphosed diabase. Note the small biotite flakes, some of which are indicated by arrows, penetrating the plagioclase laths. Exposure No. 45 in Appendix 1. North of Yllikkälä, Lappeenranta. Crossed nicols.

Chemical composition

A chemical analysis of the diabase from the Ruoholampi roof pendant is given in Table 1, analysis No. 1. Microscopical study reveals that the rock has undergone quite strong thermal metamorphism, whereby the groundmass was thorouhgly recrystallized. It is now characterized by poikiloblasts of hornblende and diopside, and by a richness of biotite in the groundmass.

In its chemical composition, the Ruoholampi diabase corresponds closely to the Subjotnian volcanic basic porphyritic lavas, which extruded before the main quartz porphyry of the Island of Hogland (Suursaari), south of the Wiborg massif in the Gulf of Finland (see Wahl 1947, p. 294, Table III). The chemical analysis also closely corresponds to the ones made of the Subjotnian quartz diabases around the Mäntyharju (Ahvenisto) rapakivi massif, northwest of the main Wiborg massif, described by Savolahti (1956, p. 77, anal. Nos. 3 and 4). Small differences do, however, exist. Analysis No. 1 in Table 1 shows the rock to represent a higher state of oxidation. The K/Na ratio is higher than in the Mäntyharju quartz diabases. The high K/Na is possibly due to an insrease in the K content during the thermal metamorphism that produced the groundmass biotite (see also p. 83).

Analysis No. 2 in Table 1, cited from Hackman (1934), is of a plagioclase porphyrite from the Taalikkala roof pendant (No. 4). In this analysis, the high Ca, Fe^{3+} and Al figures point to a somewhat epidotized plagioclase porphyrite. Petrographically, the plagioclase porphyrites of the Taalikkala roof pendant correspond closely to the diabases of the Hyvärilä and Ruoholampi roof pendants. The latter are frequently found to be quite conspicuously epidotized.

TABLE 1

Chemical composition of Subjotnian basic volcanic/subvolcanic rocks from the Ruoholampi and Taalikkala roof pendants.

	1.	2.
SiO_2	50.20	48.72
TiO_2	2.07	2.52
Al_2O_3	16.78	19.12
Fe_2O_3	4.47	5.58
FeO	8.16	5.69
MnO	.18	.09
MgO	4.64	2.59
CaO	6.77	12.24
Na_2O	1.90	1.92
K_2O	2.82	1.25
P_2O_5	.53	.11
CO_2	.00	—
H_2O+	1.11	.48
H_2O-	.08	.08
Cl	.22	—
F	.11	—
S	.00	—
Li_2O	.014	—
Cs_2O	.001	—
Rb_2O	.010	—
SrO	.054	—
ZrO_2	.039	—
BaO	.14	—
	100.30	100.39
—O=Cl,F	.10	—
	100.20	100.39

1. Diabase. Exposure No. 774 in Appendix 1. South of Ruoholampi, Lappeenranta. Silicate analysis by Risto Saikkonen, with XRF-analysis of Rb, Sr, Zr and Ba by Maija Hagel.
2. Plagioclase porphyrite. Taalikkala, Nuijamaa. Roof pendant No. 4 in the index map of Appendix 1. Anal. L. Lokka (Hackman 1934, p. 79, anal. No. 16).

Comparison

Mineralogically and texturally the diabases from the Hyvärilä and Ruoholampi roof pendants correspond to those of the plagioclase porphyrites of the Subjotnian Dala volcanics formation in western

Sweden (see Lundqvist 1968). There the groundmass of the porphyrites characteristically contain chlorite and epidote as the mafic minerals, occasionally accompanied by biotite, hornblende and augite. Leucoxene is a common constituent. The rocks have been interpreted as basic lava flows. According to Lundqvist (*op.cit.*, p. 78), the basal layers of the Dala volcanics formation are in general overlain by Dala porphyrites and the main mass of Dala porphyries is younger than the porphyrites. The Dala porphyries have been regarded as the volcanic counterparts of the Dala granite, which in turn is related to the rapakivi granites. In the Ruoholampi and Hyvärilä roof pendants, the diabase is older than the rapakivi and the rapakivi porphyries, i.e., the age relation is the same as in the Dala volcanics formation.

Laitakari (1969) described a set of olivine diabase dikes — the Häme diabase dike set — located northwest of the Wiborg massif. He regards the dikes as Subjotnian in age and the intrusion as genetically related to the emplacement of rapakivi. Mineralogically, the groundmass of these diabases is different from that of both the Dala porphyrites and the diabases of Ruoholampi and the Hyvärilä roof pendants. The Häme diabases, being rich in olivine and pyroxene, are more closely related to the basic inclusions in the rapakivi in the Wiborg massif, 10—15 km south of Lappeenranta, described by Hackman (1934), and to the large diabase bodies around the Mäntyharju satellite massif (see Savolahti 1956) as well as to the Lovaskoski diabase (see Simonen and Tyrväinen 1965) between the Suomenniemi satellite massif and the main Wiborg massif than to the diabases occurring in the roof pendants of Hyvärilä and Ruoholampi.

The porphyrites of the Taalikkala roof pendant (No. 4) are identical with the diabases from the Ruoholampi area, also mentioned by Hackman in 1934. Re-examination of the thin sections used by Hackman shows his sheared and foliated porphyrites to be hybrid hornfelses of the Ruoholampi type. Thus the grade of »deformation» cannot be used as a criterion for an Archean age as done by Hackman.

On the island of Hogland, the Subjotnian volcanic rocks (Kranck 1928, Wahl 1947), the extrusion of which took place concurrently with the rapakivi emplacement, overlie the orogenic complex. Both in age and in composition, the early lava flows correspond to the diabases of the roof pendants. The Hogland volcanite formation has been interpreted as having subsided in relation to the Wiborg rapakivi granite massif in the north (Ramsay 1890).

The diabases of the Ruoholampi and Hyvärilä roof pendants (also those of Taalikkala) represent a higher niveau of emplacement than those of the Häme diabase dike set, the diabase bodies around the

Mäntyharju satellite massif, the Lovaskoski diabase, and the basic inclusions in rapakivi to the south of Lappeenranta. The diabases in the roof pendants were subjected to thermal metamorphism possibly in two stages. First, a quite low-temperature thermal metamorphism led to the recrystallization of the groundmass, resulting in the formation of epidote, chlorite, actinolitic hornblende and leucoxene. This took place either in connection with the early stages of rapakivi emplacement or through postmagmatic activity, possibly also hydrothermal activity in late faults and fissures in the way proposed by Lundqvist (1968, p. 77) as regards the low-temperature alterations in the Dala volcanics formation.

This low-temperature episode was followed by a high-temperature phase as evidenced in the roof pendants by the presence of hornfelses and hydridization phenomena, probably produced in connection with large-scale volcano-tectonical subsidences. The major causes of the differences between the roof pendant diabases and the other diabases contemporaneous with or slightly older than the rapakivi seem to be their different emplacement niveaus and their different thermal histories during the emplacement of the huge rapakivi granite bodies.

Porphyries

Two main varieties of rapakivi porphyry, as defined on p. 6, occur in the area of the Ruoholampi roof pendant, viz., the massive Hiidenniemi porphyry, with its contaminated marginal facies and the red or reddish, in places gray, felsite porphyry. The felsite porphyry is met with near Selkäharju and between Selkäharju and Tapavainola. At Tapavainola, the rock probably forms larger bodies near the rapakivi border. In addition, rapakivi porphyry dikes of different width are met with occasionally cutting the roof pendant rocks. These porphyry dikes are not dealt with in the present paper.

Hiidenniemi porphyry

Hackman (1934) described briefly this rock using the name rapakivi granite porphyry. He noted that the rock completely deviates in colour from all other rapakivi porphyries. Vorma in 1965 doubted the rapakivitic origin of this porphyry. The data at hand, however, show without doubt the rock to belong genetically to the rapakivi suite.

Geological setting

The Hiidenniemi porphyry is a subhorizontal subvolcanic or volcanic sheet, tilting slightly to the northwest. To the west, the porphyry is bordered by diabase; to the north and east, by thermally metamorphosed mica gneiss, now altered into hornfelses; to the southeast, by brecciated and fragmented contact gneisses, also thermally metamorphosed; and to the south, by hornfelses, the origin of which is to some extent undetermined. As shown in Appendix 1, the non-Subjotnian country rocks dip gently towards the porphyry.

Most of the porphyry is quite homogeneous. In places, however, a banding is visible; the bands have a strike parallel to the contacts and they dip gently to the west. The banding is probably due partly to flow, partly also to the screens from the enveloping rocks. Especially northeast of Ruoholampi, the Hiidenniemi porphyry occurs as patches in andalusite hornfels. On the map in Appendix 1, this is marked by mixed andalusite and porphyry symbols. The brecciated and thermally metamorphosed country rock in the east has the same dip near the contacts as the banding of the porphyry. In this zone, near the contacts, migmatization produced by the porphyry has taken place, in many places in the form of silicification of the country rock.

To the south, the contact is complicated owing to the intense penetration of the contaminated marginal modification of the Hiidenniemi porphyry into the country rock. Here the porphyry evidently overlay the country rocks. The present erosion surface is presumably subparallel with the original contact surface.

On the northeastern shore of Ruoholampi, in exposure No. 765 of Appendix 1, the contact against the diabase is exposed. Near the contact, there is a coarse-grained, almost pegmatitic contact rock, tens of centimeters broad, which penetrates the diabase as dikes and apophyses.

A thin section of the diabase, 20 cm from the contact, reveals the rock to have been thermally metamorphosed, as evidenced by the development of late muscovite and biotite and by the hornfels texture of the rock. An ocellar texture, to be discussed in connection with hybridization, is also to be observed. At a distance of 1.3 m from the contact, the hornfels texture is still marked. The plagioclase phenocrysts, however, are not as intensely penetrated by the late minerals as in the specimen just described. A specimen taken at a distance of 4.5 m from the contact does not show the presence of these late minerals at all. Another specimen, taken 1 m from the contact at a point adjacent to the penetrating dikelet containing a marginal modification of the porphyry, is conspicuously hybridized in a way similar to that illustrated in Fig. 21.

Radiometric age

Dr. O. Kouvo determined the radiometric age of the zircon contained in the Hiidenniemi porphyry (exposure No. 795 in Appendix 1) using the lead-uranium method. From the plot on the concordia diagram, the age was measured by means of the diffusion model of Wassenburg (1963) as 1685 m.y. The discordant ages are: 1580 m.y. for $^{206}Pb/^{238}U$, 1620 m.y. for $^{207}Pb/^{235}U$ and 1670 m.y. for $^{207}Pb/^{206}Pb$. It is noteworthy that the common lead content is quite high, which leads to large corrections.

The radiometric age fits well with the age of the postorogenic Subjotnian igneous activity represented by the rapakivi granites in the Baltic Shield. The zircon ages of the Wiborg rapakivi granite massif indicate an age slightly less than 1700 m.y. (Kouvo and Simonen 1967). The zircon from the tirilitic rapakivi located southeast of the Hyvärilä roof pendant (location — 35/AS/54 — marked in Fig. 1) and plotted on the concordia diagram (of Wetherill 1956) is reported by Kouvo (1958, p. 43) to register an age of 1670 m.y. In this case, the $^{207}Pb/^{206}Pb$ age is 1650 m.y. Significantly, the Rb/Sr whole rock age of the Subjotnian Dala porphyries in western Sweden is practically the same, viz. 1669 m.y. (an isochron age by Welin and Lundqvist 1970) and that of the Småland porphyries in southeastern Sweden, 1695 m.y. (Åberg 1972).

Petrography

The Hiidenniemi porphyry is a massive light-gray rock. White feldspar phenocrysts, mostly of potash feldspar, and darkish quartz phenocrysts are densely scattered in a gray phaneritic groundmass (Fig. 11). In places, a slight alignment of the phenocrysts is to be seen. Closer to the contacts, the rock exhibits in places a banded structure resembling flow layering. Some of this is due the contamination of the porphyry by its country rocks; e.g., andalusite, late muscovite and fibrolite bundles have been found in the porphyry. Some of the banding, as mentioned earlier, is due to real andalusite-hornfels screens (e.g., northeast of Ruoholampi). Some of the banding in the rock was produced also by protoclasis.

The groundmass of the porphyry has an allotriomorphic-granular texture, the grain size being about 0.1 mm. It is composed of potash feldspar, quartz, and plagioclase of varying composition (oligoclase-

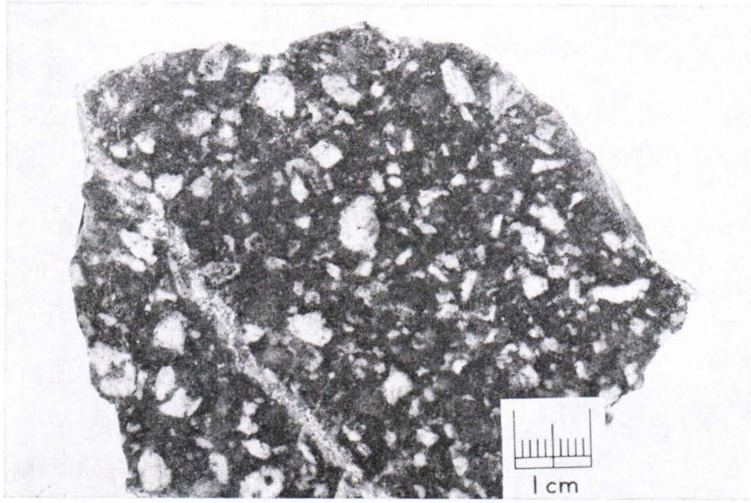

FIG. 11. Hiidenniemi porphyry. Exposure No. 795 in Appendix 1. Hiidenniemi, Lappeenranta.

andesine), and minor amounts of biotite, chlorite after biotite, late muscovite, epidote, opaque minerals, fluorite, zircon, apatite and monazite.

The phenocryst potash feldspar is orthoclase [1]). Under the microscope, some of the grains, however, show patches with faint microcline twinning. Many of the phenocrysts are irregular in shape (see Fig. 12 [2])), being fragments of larger crystals. They vary in diameter from 2 to 8 mm. The perthite texture is very weakly and irregularly developed. Homogenized for three hours at 1000° C, the bulk composition turned out to be $Or_{90}Ab_{10}$ (by the X-ray powder method; the separation between the $2\Theta(10\bar{1}0)$ of quartz and $2\Theta(\bar{2}01)$ of alkali feldspar was measured). This is far richer in Or than any other orthoclase analysed by this method from rapakivi granite (see Vorma 1971, Table 2). But also the K/Na ratio of this rock (Table 2, anal. 1) is higher than that of any other sample known to the author to have been analysed chemically from the Wiborg massif.

The potash feldspar of the phenocrysts often contains inclusions of granoblastic quartz and/or quartz+plagioclase as irregular pools or

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1) The potash feldspar was separated by heavy liquids from only one sample, viz. No. 795, and investigated by the X-ray powder method.

2) Fig. 12 resemles closely the microphotograph of the Subjotnian phenocryst-rich Dala porphyry published by Lundqvist in 1968, Fig. 97. The Dala porphyry, however, is poorer in quartz phenocrysts. In connection with the Dala porphyries, textures proving their ignimbritic origin have been extensively described (see Lundqvist, *op. cit.*).

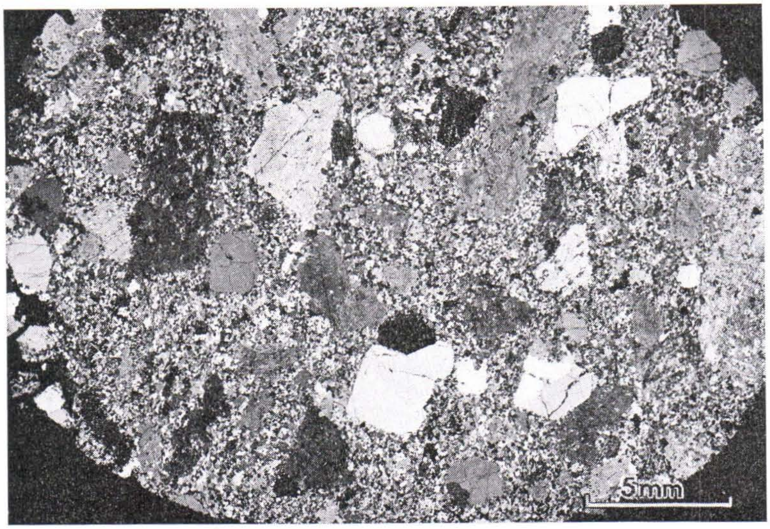

FIG. 12. Hiidenniemi porphyry. The phenocrysts are of alkali feldspar, quartz and plagioclase. Exposure No. 795 in Appendix 1. Hiidenniemi, Lappeenranta. Crossed nicols.

clusters, which have the same grain size as the groundmass. These presumably represent recrystallized glass inclusions in the phenocrysts. Biotite, chlorite, epidote and opaque mineral grains likewise occur as inclusions. Also large flakes of muscovite have been observed penetrating the orthoclase. Some drop-quartz inclusions are also met with.

In places, the quartz phenocrysts, which are from 1 to 4 mm in diameter, show a tendency to undergo idiomorphism, while in other places they appear, like those of potash feldspar, to be crystal splinters. In places, the quartz phenocrysts form cumuli of two or more individuals. Most of the phenocrysts show a weak to moderate undulatory extinction. The margins against the groundmass are mostly sutured. Corrosion embayments, which are a common occurrence in the quartz of rapakivitic quartz porphyry dikes, have not been found with certainty in the quartz phenocrysts.

Plagioclase phenocrysts are not so common as the other two minerals. Like the potash feldspar, they also contain groundmass minerals as inclusions, the texture in places being poikilitic. The composition of the plagioclase varies greatly from sample to sample. Mostly it is andesine-labradorite. The poikilitic phenocrysts are often conspicuously altered (sericite, epidote), in many instances also replaced by quartz. The original idiomorphic texture is in places preserved.

Towards the south, e.g., in exposure No. 795, the rock exhibits a reddish tint, being otherwise identical with the typical Hiidenniemi porphyry. Still further southwest, just outside the area marked as porphyry in Appendix 1, this porphyry variety still occurs penetrating the hornfelsic country rocks and grading over into an inhomogeneous, strongly contaminated, reddish marginal »felsite» porphyry. This rock is met with in most of the outcrops adjacent to the southwestern border of the Hiidenniemi porphyry. Compared with the typical Hiidenniemi porphyry, this marginal porphyry shows a slightly smaller grain size and fewer phenocrysts. Mostly, its biotite is completely chloritized. Some highly contaminated samples contain hornblende. In places, the rock is rich in carbonate minerals; in places, there is also a considerable sphene content. The variation in grain size is quite irregular. The reddish colour is due to oxide pigment, which is not evenly distributed in the rock. To the naked eye, the marginal modification resembles closely the red felsite porphyry described on p. 28.

Chemical composition

Table 2 gives the chemical composition of the Hiidenniemi porphyry from the type exposure No. 795 (anal. No. 1) as well as that of a reddish porphyry, exposure No. 794 (anal. No. 2), which is transitional between the marginal inhomogenous felsite porphyry and the Hiidenniemi porphyry proper. Both analyses show features typical of the rapakivitic suite (see, e.g., Vorma 1971, pp. 8—9 and p. 64). In respect of its alkaline content, however, the Hiidenniemi porphyry deviates somewhat from the typical rapakivitic composition; the K_2O/Na_2O ratio is much higher than in any chemically analysed granite sample from the Wiborg massif. The total iron content is lower than in the typical wiborgitic rapakivi, applied to which most of the other data fit well. In regard to such elements as Rb, Sr, Zr and Ba, the rapakivitic character is clear. Both analyses correspond closely — also in respect of the K_2O/Na_2O ratio — to the ones made of the volcanogeneous quartz porphyry, which is synchronous with the rapakivi emplacement, in the island of Hogland (see Wahl 1974, p. 296, Table III).

Emplacement

The tentative picture for the emplacement of the Hiidenniemi porphyry can be outlined as follows. An old subhorizontal fracture zone probably served as a magma conduit. During the early stages of emplacement of this subvolcanic sheet, its marginal parts suffered heavy contamination by the mainly argillaceous country rocks. Also

TABLE 2

Chemical composition of porphyries from the Ruoholampi roof pendant, northeastern part of Wiborg rapakivi granite massif.[1])

	1.	2.	3.	4.	5.	6.	7.
SiO_2	69.63	69.98	68.50	70.33	71.10	67.78	66.40
TiO_2	.40	.39	.56	.83	.53	.57	.63
Al_2O_3	14.22	14.15	13.37	12.64	12.63	13.36	15.19
Fe_2O_3	1.93	2.16	4.59	4.56	1.89	2.62	2.31
FeO	1.87	1.44	1.03	1.80	3.08	3.85	3.92
MnO	.06	.04	.08	.05	.08	.09	.10
MgO	.50	.54	.52	.43	.95	.97	.85
CaO	2.11	1.43	.93	1.32	1.94	2.08	2.31
Na_2O	.83	1.63	2.18	2.18	1.66	.73	1.10
K_2O	7.18	6.76	6.90	5.56	4.86	6.16	6.25
P_2O_5	.10	.10	.11	.17	.10	.12	.11
CO_2	.00	.09	.00	—	.08	.00	.00
H_2O+	.68	.75	.55	.38	.69	.64	.51
H_2O-	.02	.05	.05	.07	.01	.06	.05
Cl	.00	.00	.00	—	.00	.09	.12
F	.18	.27	.09	—	.20	.16	.10
S	—	—	—	—	—	.00	.00
Li_2O	.006	.006	.004	—	.009	.007	.003
Cs_2O	.003	.002	.001	—	.003	.001	.001
Rb_2O	.028	.028	.019	—	.024	.036	.028
SrO	.018	.27	.014	—	.025	.014	.021
ZrO_2	.065	.65	.080	—	.071	.081	.106
BaO	.20	.20	.18	—	.16	.10	.38
	100.03	100.11	99.76	100.32	100.09	99.52	100.49
—O=Cl,F	.08	.11	.04	—	0.08	.09	.07
	99.95	100.00	99.72	100.32	100.01	99.43	100.42

[1]) Anal. Nos. 1—3 and 5 by Pentti Ojanperä with XRF-analyses of Rb, Sr, Zr and Ba by V. Hoffrén, Nos. 6 and 7 by Risto Saikkonen with XRF-analyses of Rb, Sr, Zr, and Ba by Maija Hagel.

1. Gray Hiidenniemi porphyry. Type locality. No. 795. Hiidenniemi, Rutola, Lappeenranta.
2. Reddish Hiidenniemi porphyry. No. 794. Hiidenniemi, Rutola, Lappeenranta.
3. Red felsite porphyry. Type locality. No. 24. Tapavainola, Lappeenranta.
4. Red felsite porphyry. Tapavainola, Lappee (Hackman 1934, p. 79, anal. 14).
5. Gray felsite porphyry with reddish potash feldspar phenocrysts. No. 773. Selkäharju, Lappeenranta.
6. Gray felsite, thermally metamorphosed. No 35-A. Tapavainola, Lappeenranta.
7. Gray felsite porphyry, thermally metamorphosed. No. 35-C. Tapavainola, Lappeenranta.

country rock screens were left in the porphyry. The inhomogenous, slightly banded marginal modification crystallized before the core. Simultaneously with the thermal metamorphism of the enveloping rocks, the contaminated margins, the screens included, were thermally metamorphosed by the hot material flowing along the inner part of sheet. Later on, when he Ruoholampi fragment sunk into the rapakivi mass, the rock underwent thermal metamorphism anew. During this episode, the groundmass was recrystallized and many of the original features obliterated.

Felsite porphyry and associated rocks

Two red felsite porphyry occurrences were described briefly by Hackman (1934, pp. 62—63). The rock of the Tilsala occurrence corresponds to the inhomogeneous marginal variety of the Hiidenniemi porphyry. The rock occurring at Tapavainola is evidently the same as the porphyry immediately to the north of Tapavainola as marked on the map in Appendix 1. Hackman also mentioned the felsite porphyry met with slightly to the north from his Tapavainola occurrence, corresponding to outcrop No. 59 in Appendix 1.

Geological setting

It is highly probable that the felsite porphyry belongs to the rapakivi suite. The present author regards the rock as a volcanic equivalent of the rapakivi granite. Possibly extrusions of rhyolitic lava flows and ignimbrite eruptions took place accompanied by large-scale volcano-tectonical subsidence of the roof of the rapakivi magma chamber. During this episode, the rapakivitic felsite porphyries are assumed to have been thermally metamorphosed.

The felsite porphyry of the Tilsala area, to be sure, represents a marginal facies of the Hiidenniemi porphyry. Elsewhere, the felsite porphyry or felsite has not been found in direct contact with rapakivi proper.

If the felsite of outcrop No. 59 (Appendix 1), to be discussed later in the text, and brecciating the hybridized diabase, is genetically related to the red felsite porphyry of the same exposure, the red felsite porphyry can be regarded as younger than the diabase. Figs. 13 and 33 show the breccia between the felsite and the diabase. Fig. 14 shows, on the other hand, subangular arenaceous hornfels fragments in the felsite porphyry. Also other rock fragments, so small as to have been detected only under the microscope, are occasionally encountered as inclusions in the felsite porphyry. Quartzite (Fig. 15) and »anorthosite» (outcrop 35) fragments have been met with on a microscopic scale.

In places, the felsite porphyry is massive in texture. In other places, however, a faint, steeply dipping banding can be seen on weathered surfaces, as illustrated by Fig. 16. In the very southeastern corner of the Ruoholampi roof pendant, in exposure No. 35, between Tapavainola and Montola, gray felsite porphyry occurs on the eastern slope of

FIG. 13. Fragments of hybridized diabase in matrix of felsite. Exposure No. 59 in Appendix 1. Tapavainola, Lappeenranta.

FIG. 14. Fragments of argillaceous hornfels in felsite porphyry. Possibly this porphyry is a marginal facies of the Lappee granite. Exposure No. 28 in Appendix 1. Tapavainola, Lappeenranta.

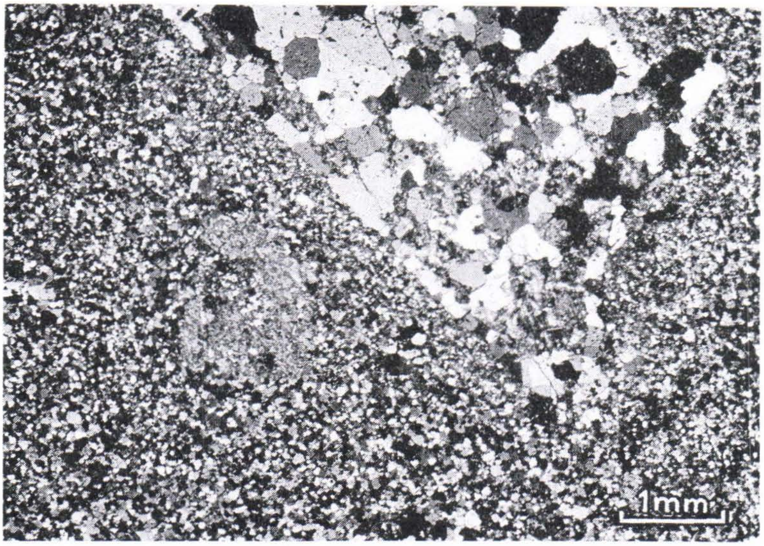

FIG. 15. Quartzite fragment in felsite porphyry. Note the secondary quartz rim around the fragment. Exposure No. 771 in Appendix 1. Southeast of Hiidenniemi, Lappeenranta. Crossed nicols.

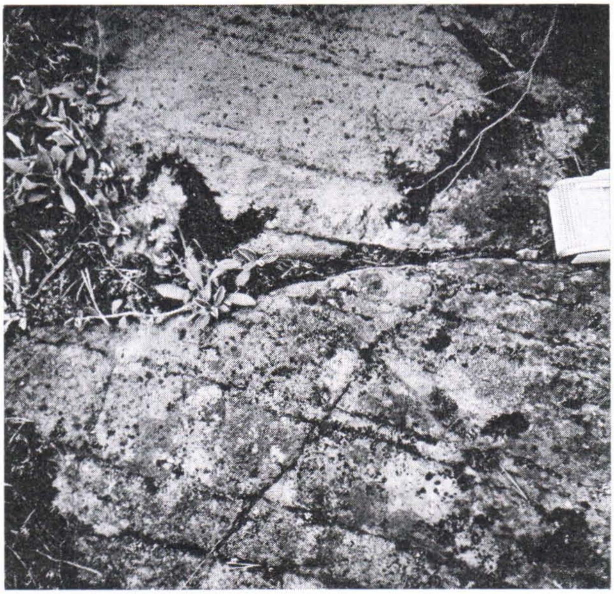

FIG. 16. Faint banding in a properly weathered felsite porphyry, Exposure No. 59 in Appendix 1. Tapavainola, Lappeenranta.

a small hill. West of this hill, andalusite hornfels is met with but the contact between the two rocks is, however, covered by till. In the porphyry proper, there are bands in which the potash feldspar phenocrysts are small and sparse (*cf.* Table 2, anal. No. 6), and there are bands within which they are densely present (*cf.* Table 2, anal. No. 7). The rock was metamorphosed thermally by the adjacent rapakivi. The gray felsite (porphyry) is cut and brecciated by irregular bands, about 10—20 cm broad, consisting of a fine-grained (0.05 mm) allotriomorphic-granular mass of quartz, potash feldspar, biotite, plagioclase and opaque minerals. In these bands, the biotite typically has a decussate arrangement. In addition, pegmatitic rapakivi dikes, up to 1 m in breadth, cut the felsite porphyry. Also narrow winding veins of granitic material are quite common. In places, they have led to the growth of potash feldspar aggregations.

Some of the rocks regarded as volcanic or subvolcanic felsite porphyries might in fact be marginal facies of rapakivi granites. Thus, e.g., the porphyry from the outcrops Nos. 28 and 30 (Appendix 1) could well be interpreted as such.

Petrography

The texture of the typical felsite porphyry is illustrated in Figs. 17, 18 and 32. The chemically analysed specimen from outcrop No. 24 is described here as a type specimen:

In an aphanitic groundmass (grain size 0.05 mm) predominantly composed of potash feldspar, quartz and plagioclase, there are scattered phenocrysts of potash feldspar and plagioclase, both up to 3 mm in diameter, reaching in exceptional instances 1 cm. It is noteworthy that quartz phenocrysts, which are typically present in rapakivi granite porphyries, are lacking. In a hand specimen, the phenocrysts show idiomorphic shapes. Under the microscope, most of them reveal quite sutured margins; phenocrysts with smooth surfaces against the groundmass are exceptions only. The potash feldspar phenocrysts are heavily clouded by iron oxide pigment. A well developed perthite texture is seldom observed. Also the plagioclase phenocrysts (An_{31-33}) are turbid. In places, an antiperthite texture is to be seen. Coarse crystals and aggregates of epidote as well as sericite flakes occur as inclusions.

In addition to the major minerals already noted, the allotriomorphic-granular groundmass also contains some chlorite, muscovite, opaque minerals, leucoxene, epidote and apatite.

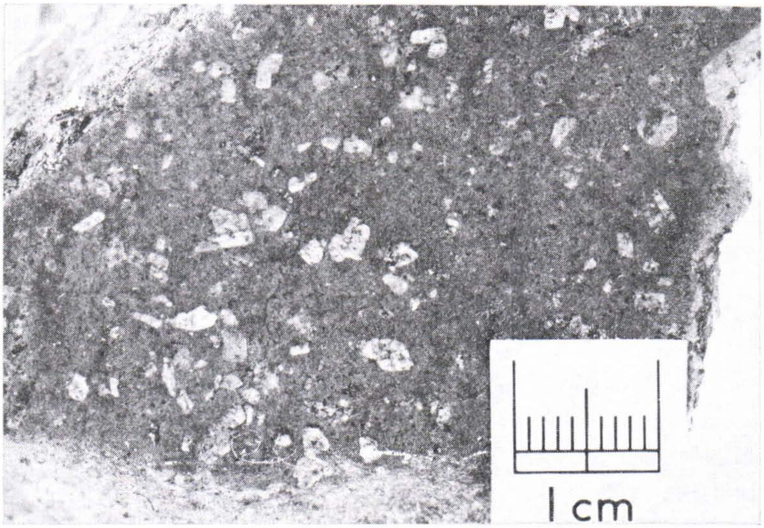

FIG. 17. Red felsite porphyry from type locality No. 24 in Appendix 1. Tapavainola, Lappeenranta.

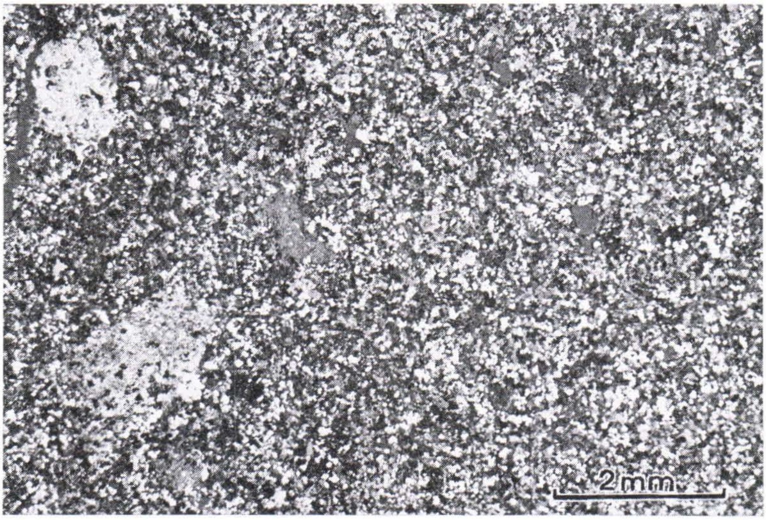

FIG. 18. Microphotograph of the red felsite porphyry illustrated in Fig. 17. Crossed nicols.

The other felsite porphyries show a similar petrography. Small local deviations occur, however. Thus the porphyry of exposure No. 59 contains muscovite as late poikiloblasts. In the gray, thermally metamorphosed felsite of outcrop No. 35, biotite is met with often in knots with magnetite in a typical decussate arrangement. The late biotite flakes measure from 0.1 to 0.5 mm in diameter, while the groundmass biotite has the same grain size (0.05 mm) as the other groundmass minerals. As is characteristic of the hornfelses of the area, some plagioclase occurs in the fine-grained (0.01 mm) intergranular matrix.

The porphyry from exposures Nos. 28 and 30 deviates more markedly from the felsite porphyries described in the foregoing. The granophyre texture is well developed in places. Both the potash feldspar and the plagioclase phenocrysts are clearer than in the type specimen No. 24; nor is the potash feldspar so heavily clouded by iron oxide pigment. The anorthite content of the plagioclase is higher (An_{45}). Quartz likewise occurs as phenocrysts. Biotite is present, even though partly altered into cholorite. As in the felsite porphyry proper, muscovite and epidote occur, too. Oxide grains are common but not accompanied by leucoxene as in the other felsite-porphyry occurrences. Fluorite, apatite and zircon are also encountered. The grain size of the groundmass is somewhat coarser than in the felsite porphyry proper, viz. 0.1—0.2 mm. As a whole, everything agrees well with the assumption that this rock represents a marginal facies of the Lappee granite.

Chemical composition

Analysis No. 3 in Table 2 gives the chemical composition of the red felsite porphyry from the type locality, outcrop No. 24 at Tapavainola. In the same Table, analysis No. 4 is after Hackman (1934), an analysis of the red felsite porphyry also from Tapavainola. In respect of every oxide, the composition fits the rapakivitic suite well. The state of oxidation is only higher than in any other analyzed rapakivi sample from the Wiborg massif or its satellite massifs. The high oxidation state, however, fits in well with that of the quartz porphyry dikes cutting the rapakivi (see, e.g., Vorma 1971, p. 8, anal. 15 and Savolahti 1956, p. 77 anal. 12).

Analysis No. 6 is of the gray felsite porphyry, which is poor in phenocrysts, and analysis No. 7 of the gray felsite porphyry, which is richer in potash feldspar phenocrysts, both being from the previously discussed outcrop No. 35. Comparison with analyses Nos. 1—5 shows that the gray porphyries correspond closely in composition to the Hiidenniemi porphyry and to the red felsite porphyry. The state of oxidation of the iron determines the colour of the rock. The Hiidenniemi porphyry without doubt belongs to the rapakivi suite. The K_2O/Na_2O ratio in the gray felsite porphyry is similar to that of the Hiidenniemi porphyry. The total iron content and the magnesium content are higher in the gray felsite porphyry than in the Hiidenniemi porphyry. The former, however, is somewhat more basic than the latter. When the Rb, Sr, Zr and Ba contents are compared with those of the rapakivi granites (see Vorma 1971, p. 8), additional support is received for the concept that the type of magma from which the felsite porphyries crystallized was of a rapakivitic nature.

As in the case of the Hiidenniemi porphyry, also a correlation in the composition of the felsite porphyry with that of the quartz porphyry of the island of Hogland is evident. Comparison with the analyses in Wahl's Table III (1947, p. 296) reveals close similarities and point significantly to the rapakivitic origin of the felsite porphyries of the Ruoholampi roof pendant.

Discussion

After discussing the similarity in chemical composition between the red felsite porphyry and the typical rapakivi, Hackman (1934, p. 63) states: »Diese Übereinstimmung führt unwilkürlich den Gedanken darauf, dass das Gestein mit Rapakiwi zusammengehören könne. Gegen eine solche Annahme sprechen doch wiederum das geologische Auftreten des Porphyrs in, wie es scheint, intimer Vergesellschaftung mit den pyroklastischen Leptitschiefern sowie der äussere Habitus des Gesteins, der schon auf ein höheres Alter schliessen lässt, allerdings nicht in dem Masse, dass man mit Bestimmtheit sich für Annahme eines solchen entscheiden wurde. Wir haben das Gestein auf der Karte immerhin dem Archäikum zugerechnet, doch mag die Altersfrage und die Frage der Zugehörigkeit zum Rapakiwi noch offen bleiden.» The question of the »habitus» of the felsite porphyry can easily be solved if it be simply assumed that thet rock became thermally metamorphosed by the surrounding rapakivi concurrently with the subsidence of the roof pendant into the solidifying rapakivi beneath, with deuteric reactions possibly also taking place while the body was cooling. The occurrence of the Tilsala felsite porphyry as a marginal facies of the definitively rapakivitic Hiidenniemi porphyry also supports the view of the rapakivitic origin of the felsite porphyries.

The absence of quartz phenocrysts in the felsite porphyries can be explained on the basis of experimental data. According to Tuttle and Bowen (1958), the early crystallization of quartz is favoured by high water pressure. Assuming the felsite porphyries to be volcanic equivalents or rapakivi granites, it might be supposed that they crystallized from a drier melt than the rapakivi granites proper. A drier melt of granitic composition, as is well known, is more likely to reach the surface than the more hydrous granitic melts (see, e.g., Cann 1970). In the case of felsite porphyries, one need only assume that their extrusion took place before the feldspar-quartz join in the albite-orthoclase-quartz system was reached during the crystallization.

Hybridization

This chapter deals with the interaction between diabase and rapakivitic magma. So far, hybridization phenomena caused by the rapakivitic magma in basic rocks have received little attention in connection with studies of Finnish rapakivis. The few papers dealing with this problem are more concerned with the contamination of the rapakivi during hybridization than with the processes taking place in the rocks subjected to infiltration of fluids from rapakivi. As an example of this is the tirilite rapakivi, which was interpreted by Wahl in 1925 as a mixture of rapakivi and diabase.

The hybridization phenomena will be illustrated in the following by some case histories.

Case history 1

The small peninsula (outcrop No. 760 in Appendix 1) on the northern shore of Ruoholampi is composed of diabase, of quite ordinary appearance, with perhaps a slightly higher than usual degree of recrystallization and epidotization of the rock. Sligt inhomogeneity is produced by some N30W-trending bands of fine-grained diabase c. 0.5 m broad and, in the southwestern part of the outcrop, by a zone at least 2 m broad of fine-grained reddish porphyry, which also trends N30W.

Between the porphyry and the diabase, there occurs a zone of reddish hybrid rock about 2 m broad with an irregular nodular texture, in which amygdules resembling nodules are possibly of a replacement origin. The contact towards the porphyry is quite sharp, and towards the diabase gradational.

Fig. 19 illustrates the typical diabase just outside the nodular zone. The mineral composition is plagioclase (An_{40-50}, strongly sericited; occurs both as phenocrysts and in the groundmass), biotite, sphene, diopside, hornblende, »intersertal» quartz, opaque minerals, chlorite,

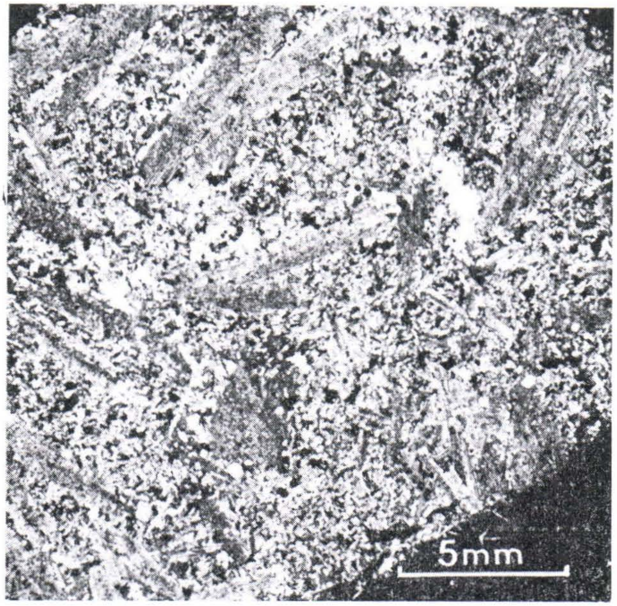

Fig. 19

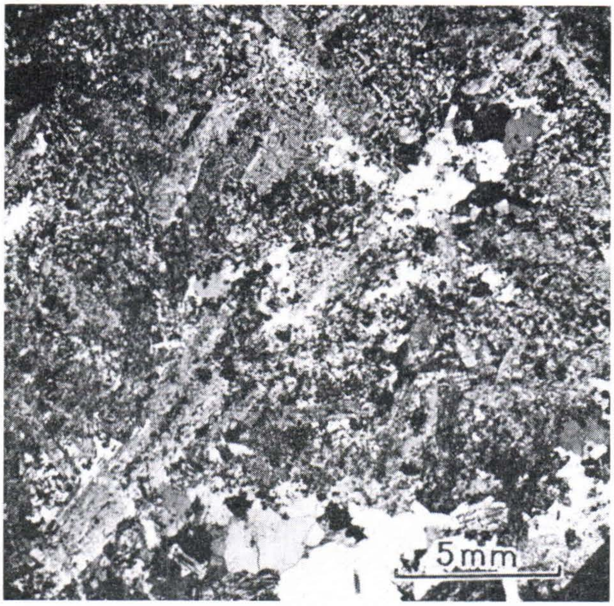

Fig. 20

Fig. 19—22. Hybridization of diabase by rapakivi porphyry. For details, see text.

FIG. 21

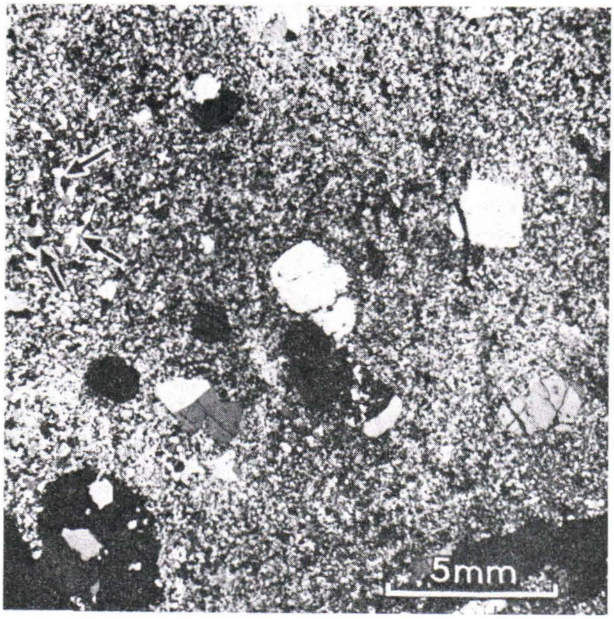

FIG. 22

Exposure No. 760 in Appendix 1. Ruoholampi, Lappeenranta. Crossed nicols.

sericite, epidote and apatite. Fig. 20 illustrates the diabase transitional between the diabase proper (Fig. 19) and the nodular zone. The mineral composition is approximately the same as in the intact rock. The biotite is, however, almost completely replaced by chlorite. As a whole, the rock seems to be somewhat richer in quartz than the diabase proper. In addition, the photograph reveals a portion of a quartz-rich nodule.

Fig. 21 illustrates the rock from the centre of the nodular zone. The original groundmass is recrystallized and the plagioclase phenocrysts are mostly replaced by potash feldspar. The plagioclase remnants are rich in epidote and sericite. Owing to the heavy clouding, the determination of the plagioclase composition is difficult. The biotite has completely disappeared. Chlorite occurs instead. Potash feldspar is present as allotriomorphic grains replacing both the groundmass and the phenocrysts. The composition of the coarse-grained accumulation — nodule — in the upper margin of the photo is of potash feldpar with epidote, sphene, chlorite, opaque minerals and an aggregate of actinolitic hornblende; otherwise the rock contains no hornblende.

Fig.22 illustrates the porphyry occurring about 0.5 m from the diabase contact. Quartz occurs both as phenocrysts and in the groundmass. In addition, quartz forms lenticles, some of which are marked by arrows in the photograph. The hypidiomorphic-granular groundmass (0.1—0.2 mm in grain size) is composed of quartz, potash feldspar, plagioclase, epidote, chlorite, sericite, opaque minerals and some apatite. In addition, late muscovite occurs as flakes. Some chlorite-filled microfractures can also be seen. Remarkable is the richness of the rock in epidote as well as its complete lack of potash feldspar phenocrysts, which first appear in the rock farther off from the contact.

Figs. 23 and 24 are partial enlargements of the plagioclase phenocrysts from the centre of Fig. 21. The »phenocrysts» demarcated in the two photos are seen to be composed of a fine-grained plagioclase-potash feldspar mass with some quartz. It is evident that, after the partial replacement of plagioclase by potash feldspar, recrystallization took place in the phenocrysts.

In this case history, the porphyry shown in Fig. 22 is evidently a highly contaminated rapakivi porphyry. Adjacent to this porphyry, the porphyritic texture of the diabase (Fig. 21) is destroyed, and now only a relict porphyritic texture can be seen. This type of texture is observed quite often in rocks formerly regarded as acid tuffitic rocks.

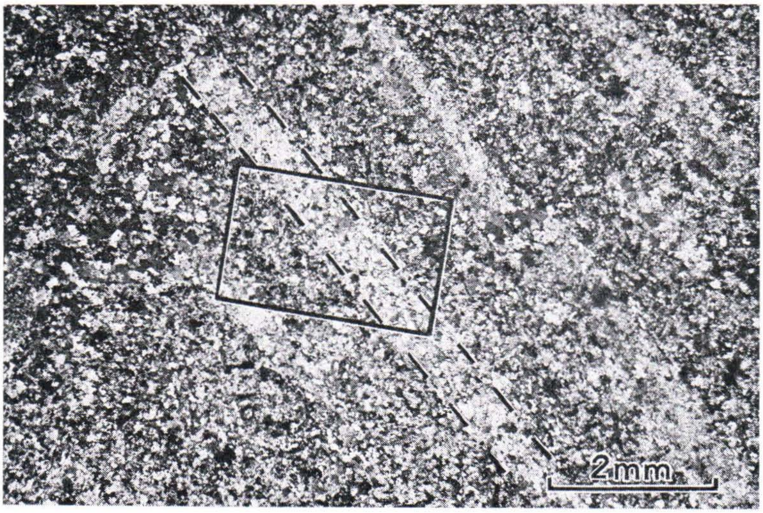

FIG. 23. Partial enlargement of the plagioclase phenocrysts illustrated in the centre of Fig. 21. Crossed nicols.

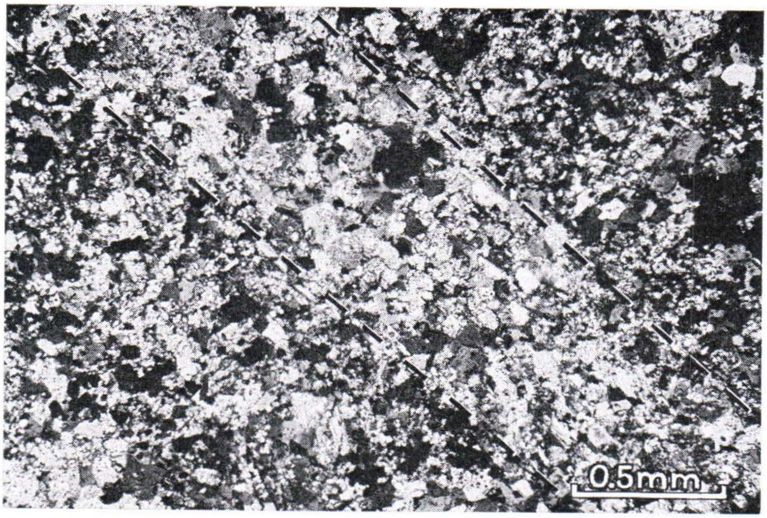

FIG. 24. Enlargement of the demarcated area of Fig. 23 showing the »plagioclase laths» to be composed of an allotriomorphic-granular mass of potash feldspar and plagioclase with some quartz. Crossed nicols.

Case history 2

The main part of outcrop No. 60, to the south of Selkäharju (Appendix 1), is composed of a fine-grained rapakivi porphyry. In the northwestern corner of the outcrop, a small-grained diabase is met with. The contact between the rocks is sharp. Close to the contact, there are subangular fragments of diabase in the porphyry (Fig. 25).

The texture of the rapakivi porphyry is illustrated in Fig. 26. In a hypidiomorphic-granular, almost allotriomorphic-granular groundmass (grain size 0.1 mm) of quartz, potash feldspar, partly chloritized biotite, strongly sericitized plagioclase, opaques, apatite and zircon, there are poikiloblasts of late muscovite (0.2—1 mm in diameter)and phenocrysts of quartz and potash feldspar, from 1 to 5 mm in diameter, many with sutured margins. The potash feldspar shows in places clear cross-twinning and contains an abundance of quartz inclusions. Note should be taken of the quartz aggregate in the right lower corner of the photograph. Under the microscope, the rock is almost identical with the Hiidenniemi porphyry.

The texture of the diabase is illustrated in Fig. 27. The phenocryst plagioclase is zoned. The groundmass has an intergranular texture built of plagioclase laths 0.1—0.2 mm long accompanied by biotite, hornblende, quartz, opaque minerals and sphene, with some sericite and apatite. The rock also contains some small ocelli of granoblastic quartz, 0.4 mm in diameter, plagioclase, hornblende, biotite and opaque minerals. A few of the ocelli are concentric in structure, with quartz constituting the marginal zone.

The contact between the rapakivi porphyry and the diabase is shown in Fig. 28. In the figure, the contact line dips to the right. The lower part of the figure shows the marginal portion of the rapakivi porphyry. Here the aphanitic groundmass (grain size 0.01 mm in the most fine-grained portions) displays a weak flow(?) banding parallel to the contact. Rounded quartz phenocrysts characterize the marginal zone, in which no potash feldspar phenocrysts are present. The occurrence of quartz aggregates and lenticles is noticeable in this case, too.

The margin toward the diabase consists of a darkish rim about 1 mm thick composed of biotite and magnetite with minor amounts of leucocractic minerals. Also behind this reaction rim, the diabase is entirely recrystallized. In this connection, only two features are worth emphasizing, viz., the relict porphyritic texture and the ocellar texture. The relict porphyritic texture characterizing case history 1 is very faintly visible, while the ocellar texture is beautifully developed (see

Fig. 25. Fragments of hybridized diabase in porphyry. Exposure No. 60 in Appendix 1. South of Selkäharju, Lappeenranta.

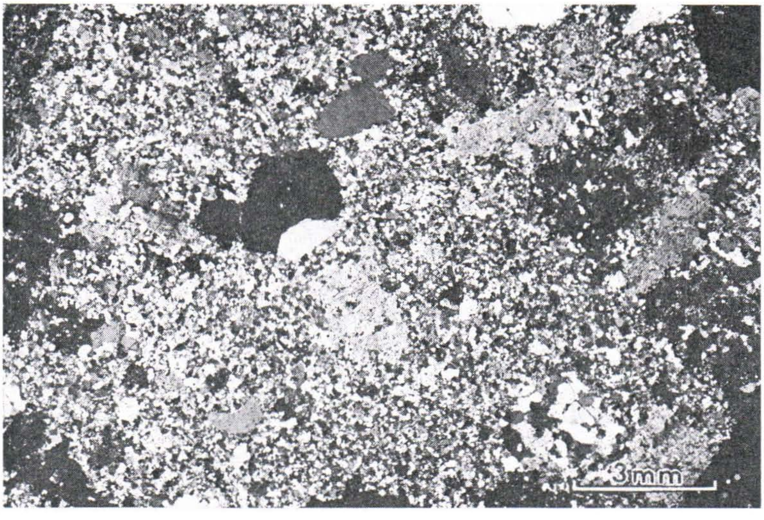

Fig. 26. Rapakivi porphyry from the breccia illustrated in Fig. 25. For details, see text. Crossed nicols.

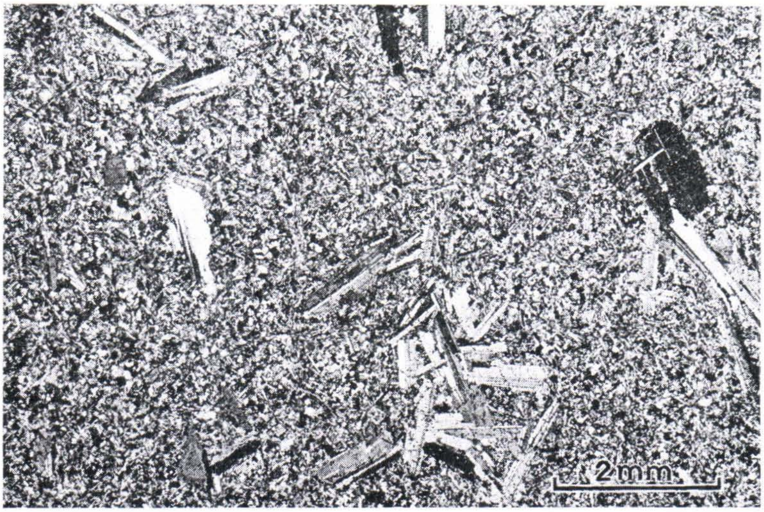

FIG. 27. Diabase from the same exposure as Fig. 25 but outside the breccia zone. For details, see text. Crossed nicols.

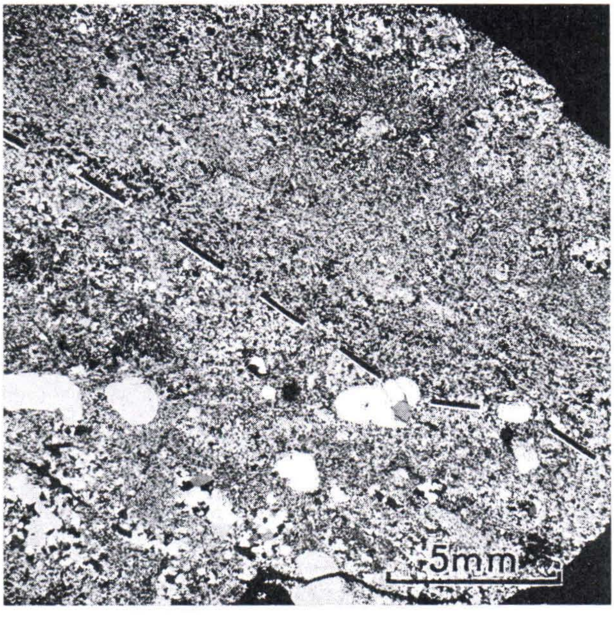

FIG. 28. Contact between rapakivi porphyry illustrated in Fig. 26 and diabase illustrated in Fig. 27. The hybridized diabase — upper part of the figure — shows a well-developed ocellar texture. For details, see text. Crossed nicols.

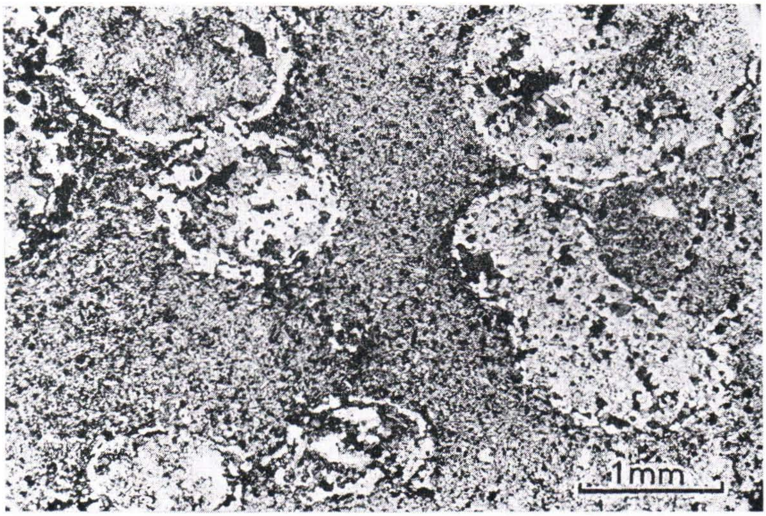

FIG. 29. Ocellar texture in hybridized diabase. Same thin section as in Fig. 28. Parallel nicols.

the upper part of Fig. 28 and Fig. 29). Almost invariably a concentric structure is to bo seen in the ocelli. The margin is composed of a narrow rim of allotriomorphic-granular quartz. The centre in some of the ocelli is composed of biotite, in most of the ocelli of a plagioclase-biotite-quartz aggregate with some accompanying muscovite.

Fig. 30 illustrates the texture of a diabase fragment in the porphyry (Fig. 25). The fragmented rock is almost completely recrystallized and strongly hybridized by an allotriomorphic-granular quartz-rich neosome. The paleosome, with the addition of potassium, is represented by biotite schlieren, in which most of the biotite flakes have a definite orientation transverse to the strike of the schlieren. Also some plagioclase occurs there as very minute grains. In places, especially where the biotite content is at its highest, the quartz infiltration has produced poikiloblasts of quartz. The lower part of the photograph in Fig. 30 shows a slightly better preserved diabase. Here a faint relict porphyritic texture is visible. Also some irregularly developed ocelli are to be found. Fig. 31, showing the same specimen, illustrates a plagioclase phenocryst partly replaced by potash feldspar and quartz.

In the vary southern part of the outcrop, separated by quaternary deposits from the major exposure, hybrid rocks are met with in which both ocellar and relict porphyritic textures are encountered. Otherwise these rocks are quite felsitic and could well have been regarded as acid tuffaceneous rocks. However, the textures referred to suggest their hybrid origin.

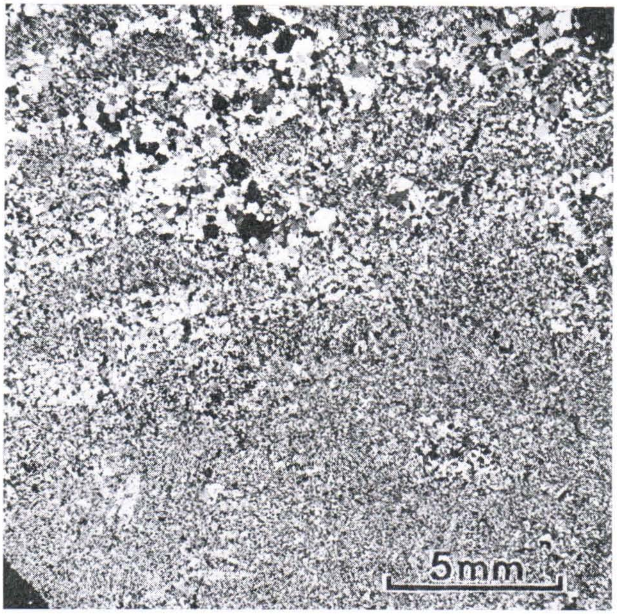

FIG. 30. Hybridized diabase from one of the fragments illustrated in Fig. 25. For details, see text. Crossed nicols.

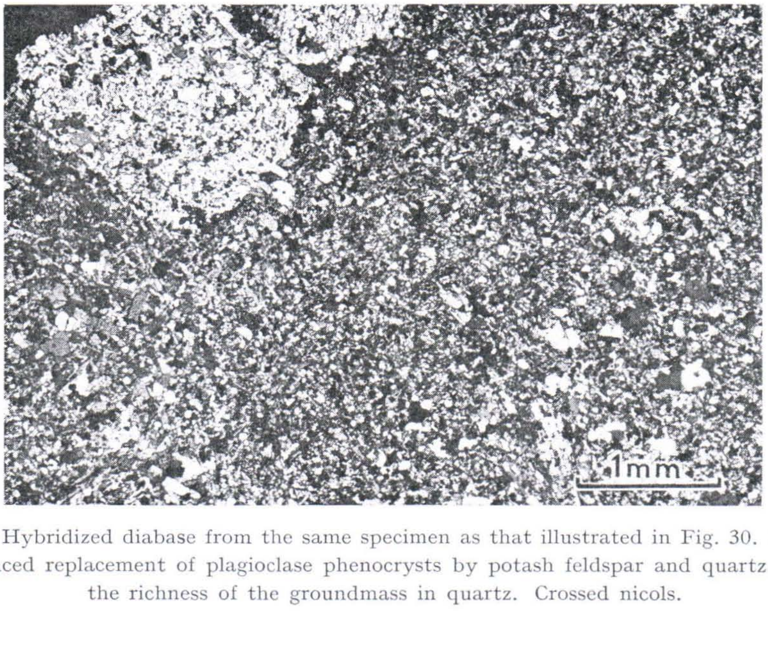

FIG. 31. Hybridized diabase from the same specimen as that illustrated in Fig. 30. Note the far-advanced replacement of plagioclase phenocrysts by potash feldspar and quartz and also the richness of the groundmass in quartz. Crossed nicols.

Case history 3

Northwest of Tapavainola, in outcrop No. 59, the third example is found. Most of the outcrop is composed of a reddish felsite porphyry (Figs. 16 and 32). In the northwestern part, there is an exposed breccia between felsite and altered diabase (Figs. 13 and 33). On a weathered surface, the felsite brecciating the diabase is a white, in places reddish, aphanitic rock, the diabase being grayish.

Fig. 34 reproduces a microphotograph of a thin section made of diabase intensively penetrated by felsite. The finer-grained rock with remnants of partly replaced plagioclase phenocrysts is hybridized diabase, the coarser rock being felsite.

The groundmass of the diabase is aphanitic with a grain size of 0.01—0.05 mm. It is composed of a granoblastic mass of plagioclase, quartz, biotite, potash feldspar and magnetite. In the mass, relict plagioclase exhibits a relict porphyritic texture. The plagioclase phenocrysts are in part replaced by quartz and potash feldspar. Characteristic of the altered diabase is the frequent occurrence of biotite aggregations measuring 0.2—0.5 mm in diameter. When the aggregations are bigger, 0.5—1 mm in diameter, they have a core of allotriomorphic-granular quartz (see Fig. 35). Also some quartz aggregations are present without any biotite rim at all. As a whole, this case represents a hybridization with production of somewhat different ocelli from the ones described

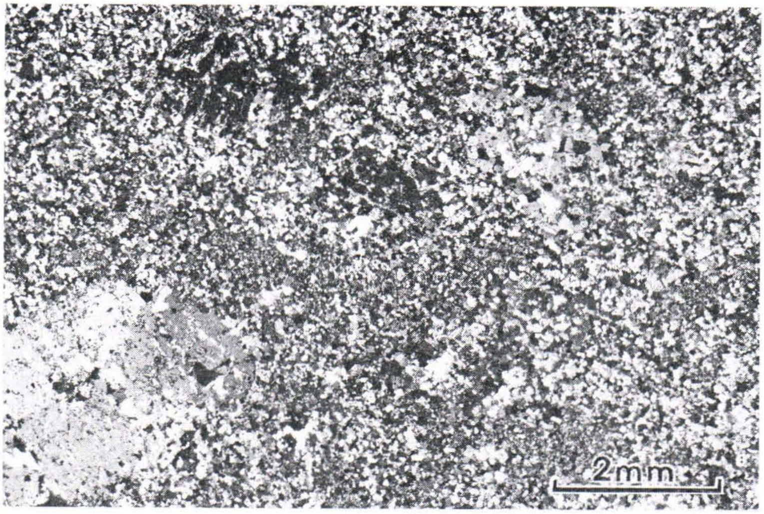

FIG. 32. Texture of the red felsite porphyry illustrated in Fig. 16. The phenocrysts are of alkali feldspar. North of Tapavainola, Lappeenranta. Crossed nicols.

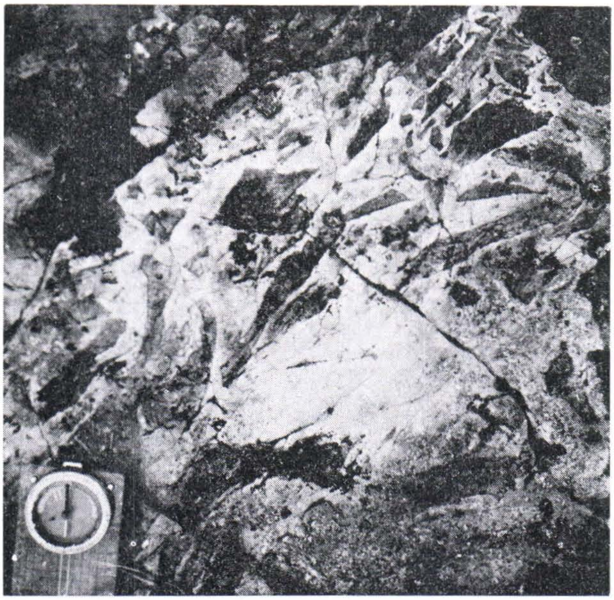

FIG. 33. Hybridized diabase brecciated by felsite. Exposure No. 59 in Appendix 1. North of Tapavainola, Lappeenranta.

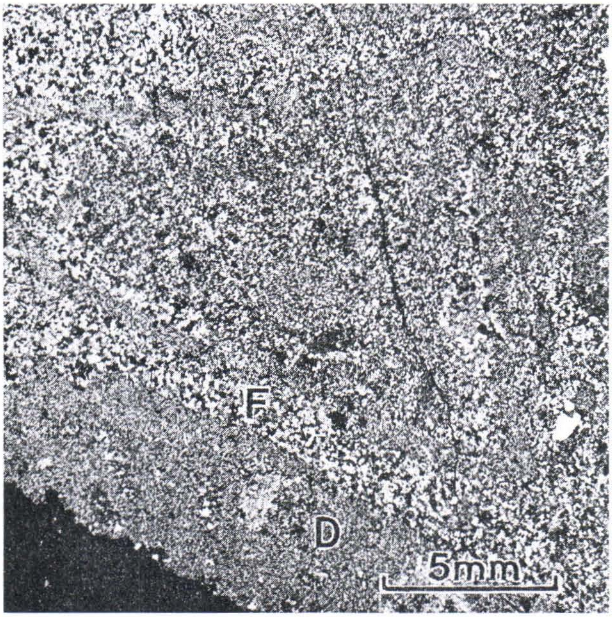

FIG. 34. Hybridized diabese (D) intensively penetrated by felsite (F); from the breccia illustrated in Fig. 33. For further details, see text. Crossed nicols.

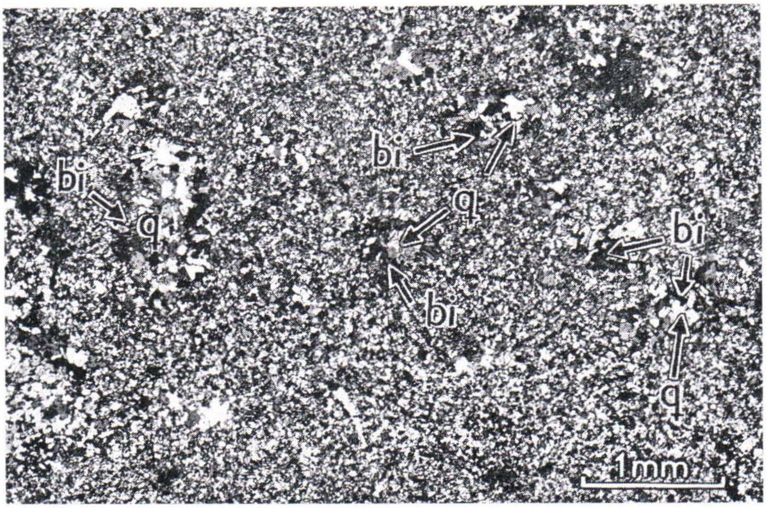

Fig. 35. Hybridized diabase with biotite (bi) and biotite-quartz (q) aggregates. Forde tails, see text. Same thin section as illustrated in Fig. 34. Crossed nicols.

in case history 2. In connection with the alteration of the diabase (No. 59), silicification and potassium influx seem to have stood for the major compositional changes.

The felsite component of the breccia is mainly composed of almost granoblastic quartz (grain size 0.1 mm) accompanied by minor amounts of potash feldspar, epidote and biotite. The plagioclase and muscovite contents are small. It should be emphasized that a transition from this felsite to the red felsite porphyry has not been proved definitely in the exposure in question.

Case history 4

The last example representing the hybridization of the diabase by porphyry comes from outcrop No. 773 in Selkäharju. A small-grained diabase occurs there in contact with a hybrid, tuffaceous-looking, slightly banded acid rock. The contact line itself is poorly exposed. It is assumed that the contact surface is here subhorizontal, with the diabase overlying the acid rock.

The acid rock contains grayish felsite porphyry bands with an aphanitic (grain size 0.05 mm and less) allotriomorphic-granular groundmass of quartz, potash feldspar, plagioclase, partly chloritized biotite, chlorite, late muscovite and opaque minerals (with accessory apatite and epidote). Also there are red phenocrysts of potash feldspar, up to one cm in diameter, and oligoclase-andesinic plagioclase replaced partly by potash feldspar and quartz. In the light of chemical analysis, No. 5 in Table 2, this rock could be interpreted as a somewhat contaminated rapakivi porphyry. When the high SiO_2 content is taken into account, it can be deduced that the rapakivitic magma has been slightly enriched in Mg, Fe and Ca.

The rock illustrated in Figs. 36 and 37 occurs as irregular bands in the felsite porphyry. The rock is predominantly composed of quartz with andesinic plagioclase, biotite, often observed in aggregates, opaque minerals, potash feldspar and chlorite with apatite and zircon as accessories. Late muscovite occurs as flakes. The texture is allotriomorphic-granular and the grain size varies greatly. Some of the andesine crystals can be regarded as phenocrysts. Potash feldspar occurs in many places as augens (see Fig. 36). As a whole, the rock gives an impression of having been partly mylonitized, after which felsitic material infiltrated into the rock.

Fig. 38 illustrates a hybrid diabase from a nearby exposure. The diabase has been infiltrated by fluids, causing crystallization of the potash feldspar and quartz, in many places in the form of lenticles. Plagioclase phenocrysts (Fig. 39), for the most part replaced by the afore-mentioned minerals, still bear the basic composition; in the case illustrated, An_{75}, (in another similar sample, An_{60}). Mixed with the

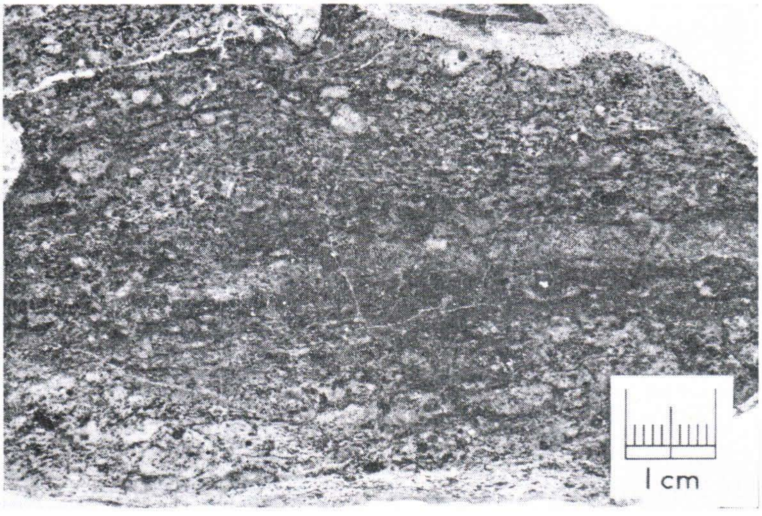

FIG. 36. Hybrid rock from exposure No. 773 in Appendix 1. For details, see text. Selkäharju, Lappeenranta.

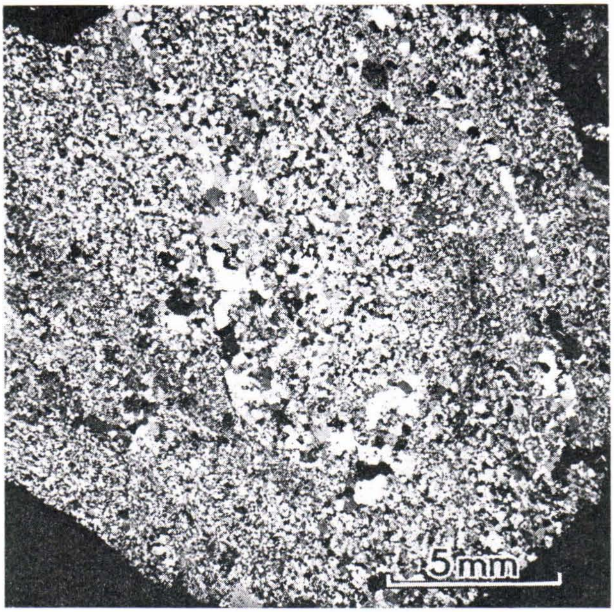

FIG. 37. The texture of the hybrid illustrated in Fig. 36. Crossed nicols.

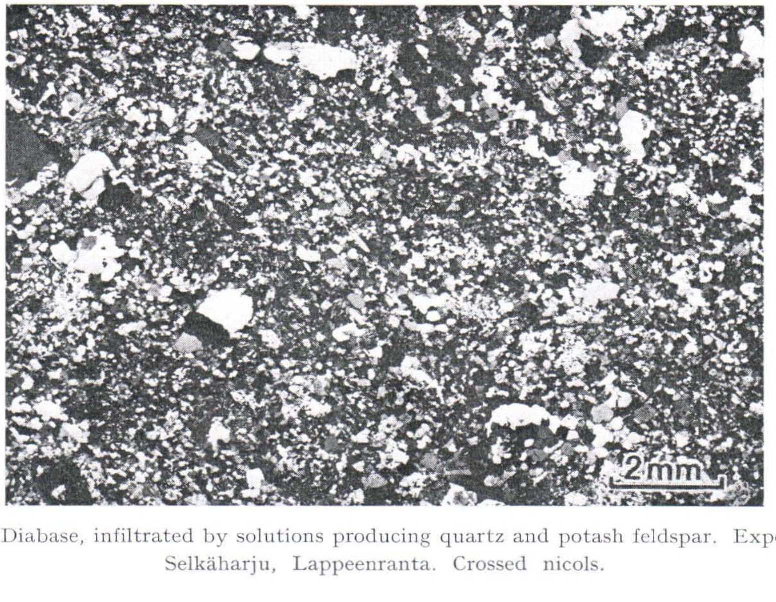

FIG. 38. Diabase, infiltrated by solutions producing quartz and potash feldspar. Exposure 63. Selkäharju, Lappeenranta. Crossed nicols.

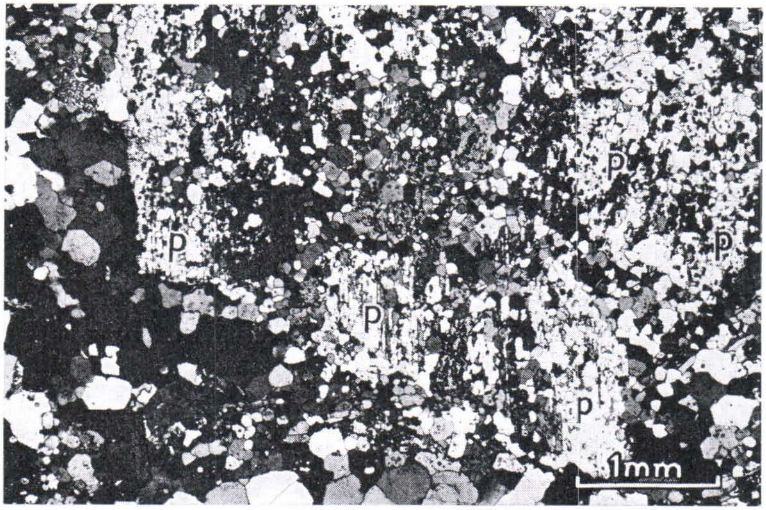

Fig. 39. Relict porphyritic texture in the hybrid diabase illustrated in Fig. 38. The plagioclase (p) phenocrysts, replaced by quartz and potash feldspar, in a matrix predominantly composed of quartz and potash feldspar. Parts of quartz lenticles shown in the left and lower parts of the figure. Crossed nicols.

altered diabase, an aphanitic felsite similar to that described from outcrop No. 35, in the southeastern corner of the Ruoholampi roof pendant, occurs in places.

Discussion on hybridization

In all the foregoing case histories, the diabase was subjected to infiltration of fluids from rapakivi. In relation to other rapakivitic constituents, the rock causing the hybridization is quite enriched in quartz. Also the hybridized rock seems to have been enriched in quartz, silicification being thus an essential factor in the hybridization. The appearance of potash feldspar when the relict porphyritic texture is produced and the occurence of biotite in large amounts instead of hornblende or pyroxene in its turn are indications of an increase in the amount of potassium.

The ocelli described in case histories 2 and 3 deviate somewhat from those described in the literature. In the case of the Ruoholampi roof pendant, all the ocelli studied are composed of aggregates. A concentric structure is frequently met with; some of the ocelli have marginal quartz rims and some a quartz core. Their manner of occurrence shows without doubt that they are products of hybridization.

In connection with a study on the ocellar hybrids from the Tyrone Igneous Series, Ireland, Angus (1962) gave a review of ocellar hybrids occurring elsewhere. There is no need to repeat his description. A point worth mentioning is that, in most cases involving a hybrid between basic rock and acid rock and where the ocellar texture was observed, the ocelli consisted mostly of a single quartz crystal surrounded by melanocratic minerals, usually hornblende. In the diabase/rapakivi porphyry hybrids, the core of the ocelli is composed of mineral aggregates. The difference between the ocelli described by Angus and those in the present paper is obviously due to different nucleation and growing rates. It should be emphasized that all the ocelli described in the hybridized diabase are from the close proximity of the contact line with rapakivi porphyry. The composition of the melanocratic rim around the ocelli certainly very much depends on the supply of alkalies during the growth of the ocelli.

A feature peculiar to the hybrid rocks in the Ruoholampi area is the common occurrence of lenticles, elongated ovals and tongues of granoblastic quartz both in the hybridizing rock and in the hybridized rock. The growth of these aggregates seems to have taken place simultaneously with the growth of the ocelli in the diabase while the acid magma was still able to flow.

Characteristic of rapakivi granites and their subvolcanic equivalents, viz. the quartz porphyry dike rocks, is the common occurrence of quartz phenocrysts. Also in subvolcanic dike rocks, potash feldspar is a common phenocryst mineral. In the previous examples, the acid rock responsible for the hybridization does not strictly obey these rules. In cases 1 and 2, the rock causing hybridization is a porphyry of the Hiidenniemi type, i.e., it is rich in both quartz and feldspar phenocrysts; but in the contact samples against the diabase, no potash feldspar phenocrysts are present. Quartz phenocrysts and lenticles, on the other hand occur abundantly. In case 3, the red felsite porphyry contains no quartz phenocrysts. Potash feldspar does occur. The rock that brecciates and hybridizes the diabase there does not contain either quartz or potash feldspar phenocrysts.

OROGENIC COMPLEX

By far the greatest part of both the Hyvärilä and Ruoholampi roof pendants is composed of rocks belonging to the Svecokarelidic orogenic complex. In the Hyvärilä roof pendant, metamorphosed argillaceous rocks predominate over the porphyroblastic granodiorite. In the Ruoholampi roof pendant, the granodioritic rocks prevail over supracrustal rocks. Also arenaceous rocks occur in small amounts in the area of the Ruoholampi roof pendant. Evidently, these rocks, together with the Subjotnian basic volcanic rocks, their subvolcanic equivalents and rapakivitic volcanic rocks, constituted the roof of the rapakivi massif. When rapakivitic ash flow eruptions took place, similar to those among the Dala volcanics formation in western Sweden, large-scale collapse structures were probably produced. The thermal metamorphisn, to which the Ruoholampi roof pendant rocks were subjected, is believed to be in part contemporaneous with this episode, viz., with the subsidence of the roof pendant into the rapakivi magma. Thermal metamorphism also took place during the stage when the Hiidenniemi porphyry metamorphosed its envelope.

In the following description, all the examples to be given are from the area of the Ruoholampi roof pendant.

Argillaceous hornfelses

Svecokarelidic mica gneisses occur in both the Hyvärilä and the Ruoholampi roof pendants. These are fine-grained to medium-grained, gray, weakly banded rocks, which are veined in places by granitic material. Foliation is marked and nearly vertical.

A thin section study of a mica gneiss located next to the andalusite hornfels zone, east of Ruoholampi, (Appendix 1) shows the rock to be composed of quartz, plagioclase, potash feldspar, biotite, muscovite and cordierite. The grain size varies from 0.1 to 1 mm. Some of the biotite occurs as porphyroblasts up to 4 mm in diameter. In places, the biotite exhibits a well-developed decussate arrangement; in places, it is aligned parallel to the foliation. Quartz often occurs in lenses and lenticles; in places, it also forms poikiloblasts. As a whole, the rock gives an impression of weakly thermally metamorphosed mica gneiss, the thermal metamorphism having possibly been caused by the rapakivitic rocks.

The rock is banded by a fine-grained, granoblastic, cordierite-bearing quartz-plagioclase gneiss (leptite) with minor amounts of partly chloritized biotite and muscovite.

From these rocks, the hornfels envelope of the Hiidenniemi porphyry was produced. Also the hornfelses in Rutola, southwest of Ruoholampi, as well as those in Tapavainola were produced mainly from argillaceous rocks, and will be described in this chapter. The hornfelses southwest of the Hiidenniemi porphyry possibly have a different parent rock and will therefore be described separately (p. 64).

Envelope of the Hiidenniemi porphyry

The andalusite hornfelses, andalusite-cordierite hornfelses (Figs. 40 and 41) and cordierite hornfelses form a zone about 100 m broad around the Hiidenniemi porphyry, northeast of Ruoholampi. No zonal distribution of andalusite and cordierite hornfelses can be distinguished. The occurrence of these minerals seems to have been controlled by the rock composition, as shown by the occurrence in one and the same exposure of bands rich in cordierite and bands rich in andalusite.

Characteristic of the hornfelses is a fine-grained mass of leucocratic minerals containing aggregations and lenticles, built of minerals coarser in grain. Andalusite crystals, in particular, form aggregates or have grown into poikiloblasts. In places, the andalusite is zoned and has a pleocroic core. In places, the mineral is diablastically intergrown with late biotite (Fig. 42), and in places with late muscovite. Partial replacement of the andalusite by muscovite has also been observed.

Andalusite hornfelses occur also as screens in the Hiidenniemi porphyry. It is difficult to say which of the rocks — porphyry or hornfels — prevails in the area marked as porphyry in the area northeast of Ruoholampi. Owing to contamination, the porphyry itself contains in places abundant andalusite and sheaves of fibrolite.

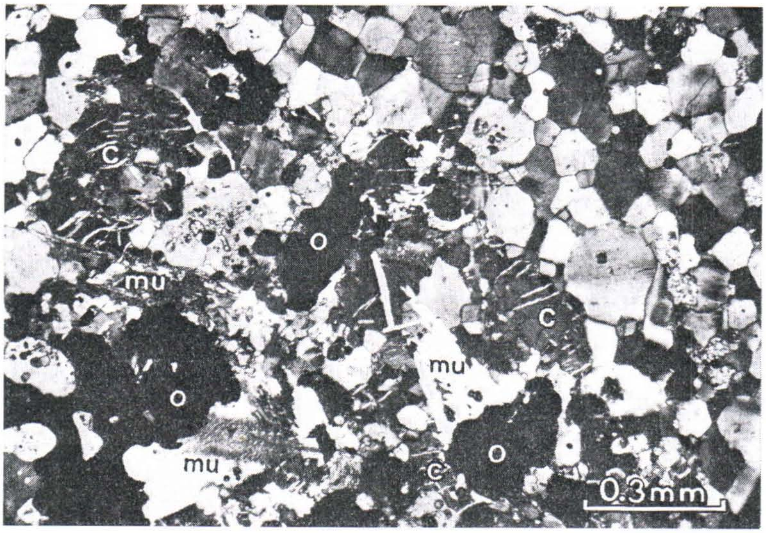

FIG. 40. Cordierite from an andalusite-cordierite hornfels. c = cordierite, mu = muscovite, o = opaque minerals, others are of potash feldspar and quartz with a minor amount of plagioclase. Exposure No. 764 in Appendix 1. Northeast of Ruoholampi, Märkälä, Lappeenranta. Crossed nicols.

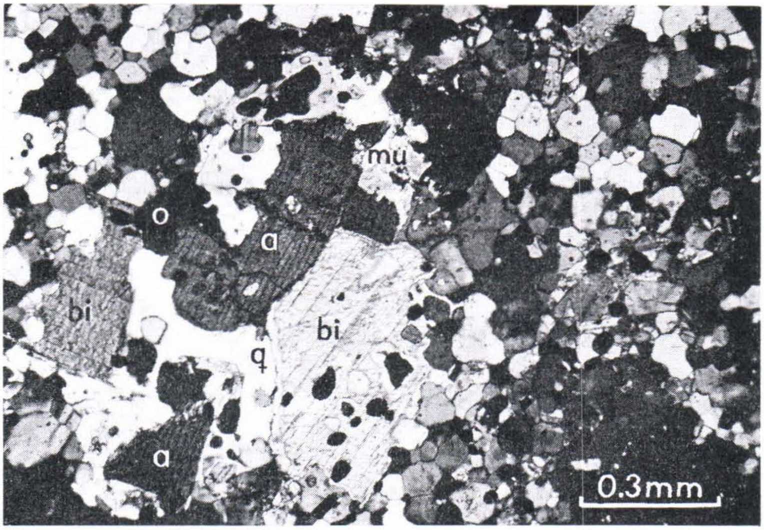

FIG. 41. Andalusite from the same hornfels as illustrated in Fig. 40. a = andalusite, b = biotite, mu = muscovite, q = quartz, o = opaque minerals. Crossed nicols.

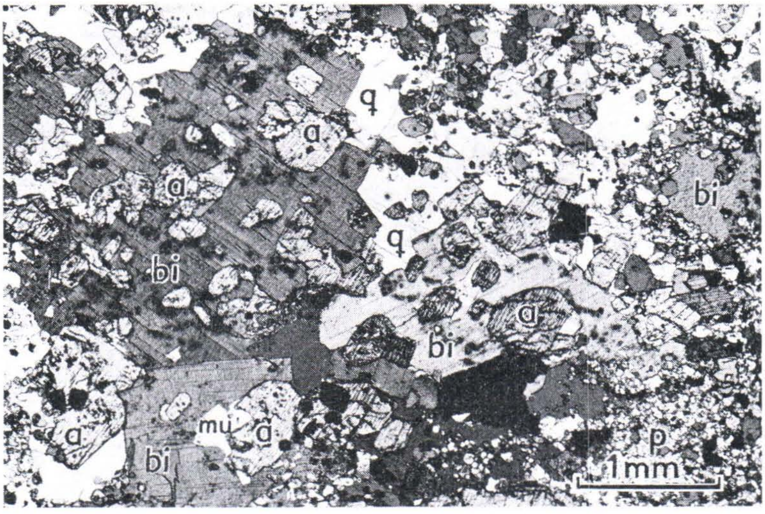

FIG. 42. Diablastic intergrowth of andalusite (a) and biotite (bi) from the injection hornfels, exposure No. 767 in Appendix 1. q = quartz, p = plagioclase (anorthite) in the intergranular matrix, mu = muscovite. Northeast of Ruoholampi, Lappeenranta. Crossed nicols.

In many of the andalusite-bearing hornfels specimens, fibrolite has been encountered either as clusters in muscovite or as sheaves among the leucocratic minerals.

Cordierite often coexists with andalusite. If andalusite is missing but cordierite is present, sillimanite has not been encountered in the argillaceous hornfelses around the Hiidenniemi porphyry. The cordierite occurs mostly as small poikiloblasts (Fig. 40). Often it is seen to be quite well preserved; in some places, however, it is strongly pinitized. Biotite, when present, occurs both as small flakes and as late large poikiloblasts, in both cases mostly in a decussate arrangement. In many of the samples, biotite forms knots. The manner of occurrence of the muscovite is similar to that of the biotite. The leucoratic minerals are quartz, potash feldspar and plagioclase, although both feldspars are not present simultaneously in all the thin sections. Worth noting is the fact that in many of the specimens potash feldspar is in equilibrium with andalusite and/or cordierite, indicating the conditions of pyroxene-hornfels facies (see Turner 1968, p. 225).

Quartz often occurs aggregated as lenticles and ovals. It also occurs in the fine-grained quartz-feldspar mass. In certain places, a healed flaser texture in the rock can be imagined. In many of the hornfels specimens, plagioclase very rich in the anorthite component occurs in narrow string or aggregates as very minute grains (often as small as 0.01 mm in diameter) in the intergranular matrix. According to a partial micro-probe analysis, the plagioclase illustrated in Fig. 42 is anorthite (CaO 17.9, Na_2O 0.4 %).

Opaque minerals (magnetite) are common. In places, the distribution of magnetite accentuates the old foliation.

Hackman (1934, p. 79, anal. No. 17) published a chemical analysis of the andalusite-bearing cordierite hornfels enveloping the Hiidenniemi porphyry. The analysis is included in Table 3 (No. 1). The minerals of the rock are quartz, biotite, muscovite, cordierite, andalusite, plagioclase, magnetite, apatite and zircon. Hackman (*op.cit.*, p. 61) correlated this rock with the cordierite- and andalusite-bearing rocks of the Orijärvi area (see Eskola 1914). Compared with typical biotite gneisses and other metamorphosed argillaceous rocks, the alkaline content, especially that of sodium, is quite low, a feature characteristic of all the rocks of the Ruoholampi roof pendant area so far analyzed (see Tables 1—4).

Exposure No. 10, east of Ruoholampi, is characterized by a beautiful andalusite (-cordierite) hornfels, in which fibrolite sheaves are abundantly present. Peculiar to this argillaceous hornfels is its occurrence as angular fragments, about 10—20 cm or more in diameter,

TABLE 3

Chemical composition of hornfelses from the Ruoholampi roof pendant.

	1.	2.	3.	4.
SiO_2	67.36	66.40	74.42	61.94
TiO_2	.93	.64	.56	.79
Al_2O_3	16.91	15.69	12.76	18.56
Fe_2O_3	.12	4.09	.60	.96
FeO	5.39	3.29	3.05	4.89
MnO	.10	.11	.04	.07
MgO	2.77	.57	.52	.66
CaO	.62	5.83	1.34	1.02
Na_2O	1.09	.38	.68	1.00
K_2O	2.45	1.67	4.43	7.93
P_2O_5	.07	.12	.07	.14
CO_2	—	.08	.00	.00
H_2O+	2.41	.81	.97	1.11
H_2O-	.12	.01	.08	.08
Cl	—	.00	.16	.18
F	—	.31	.11	.09
S	—	—	.35	.16
Li_2O	—	.005	.006	.013
Cs_2O	—	.002	.000	.000
Rb_2O	—	.005	.024	.040
SrO	—	.015	.014	.028
ZrO_2	—	.088	.084	.132
BaO	—	.09	.32	.61
	100.33	100.21	100.59	100.40
—O=Cl,F,S	—	.13	.26	.16
	100.33	100.08	100.33	100.24

1. Cordierite hornfels. Ruoholampi, Lappeenranta. Anal. L. Lokka (Hackman 1934, p. 79, anal. No. 17).
2. Somewhat calcareous arenaceous hornfels interbed(?) in argillaceous hornfels. Exposure No. 776. Rutola, Lappeenranta. Silicate analysis by Pentti Ojanperä with XRF-analysis of Rb, Sr, Zr and Ba by Väinö Hoffrén.
3. »Aphanitic» hornfels, metasomatically altered, specimen C from exposure No. 786. South of Ruoholampi, Lappeenranta. Silicate analysis by Risto Saikkonen with XRF-analysis of Rb, Sr, Zr and Ba by Maija Hagel.
4. Hornfels, metasomatically altered, specimen D from exposure No. 786. South of Ruoholampi, Lappeenranta. Silicate analysis by Risto Saikkonen with XRF-analysis of Rb, Sr, Zr and Ba by Maija Hagel.

in a fine-grained, gray intrusive rock. The whole rock is an eruptive breccia. The brecciating rock is rich in quartz and contains minor amounts of untwinned An-rich plagioclase and potash feldspar. The texture is granoblastic and the grain size 0.05—0.2 mm. Small amounts of biotite and muscovite are present and they occur in a decussate arrangement. Opaque minerals and monazite are present as accessories. The muscovite flakes are partly replaced by fibrolite. The fibrolite originated either through metasomatism or by contamination. The breccia — »aplite» brecciating argillaceous gneiss — is probably older than the thermal metamorphism that produced the andalusite hornfels, the recrystallization of the aplite and the growth of fibrolite in the aplite. The undeformed fragments show that static conditions prevailed during the thermal metamorphism.

Rutola

The hornfelses exposed at outcrop No. 776, southwest of Rutola, are of special interest because this is the only place where robust sillimanite is found in argillaceous hornfelses in the study area. The position of the hornfelses, as compared to that of the nearby diabase, suggests that the diabase overlay the hornfelses. Possibly the thermal metamorphism, at least one episode of it, is related to the emplacement of the diabase.

Figs. 43—47 illustrate some of the intergrowths and textures recorded here. Figs. 43—46 are from a hornfels containing andalusite, cordierite, robust sillimanite (Figs. 43—44), quartz, plagioclase, potash feldspar, biotite, muscovite, fibrolite after biotite (Fig. 46), opaque minerals and zircon. Characteristic are the parallel intergrowth of robust sillimanite with andalusite (Fig. 44), zoning in the andalusite (Fig. 45), replacement of the biotite by sheaves of fibrolite (Fig. 46) and the presence of potash feldspar. The occurrence of robust sillimanite indicates higher temperatures than in the hornfelses around the Hiidenniemi porphyry, where no robust sillimanite has so far been found. The parallel intergrowth of andalusite with sillimanite and the zoning in the andalusite suggest that the thermal metamorphism took place in many phases. Some of the thin sections from the exposure also show late biotite and late muscovite as porphyroblasts, indicating that the crystallization continued also along with a decreasing temperature. Possibly the growth of late biotite and muscovite was catalyzed by migrating alkali-rich fluids.

Fig. 47 illustrates the hornfels texture in a specimen from the same outcrop, No. 776. This specimen is devoid of andalusite and robust sillimanite. The mineral composition is quartz, muscovite, biotite, plagioclase, some cordierite porphyroblasts, potash feldspar, some sheaves of fibrolite, opaque minerals and epidote. Plagioclase occurs in the fine-grained portion of the rock. Its relief under the microscope shows it to be quite rich in anorthite. Quartz occurs mainly in the coarse-grained aggregates. Some of the muscovite and biotite are of a late origin. A chemical analysis of this rock is given in Table 3, anal. No. 2. The rock has probably undergone a strong metamorphic or

FIG. 43. Robust sillimanite in argillaceous hornfels. s = sillimanite, a = andalusite, mu = muscovite. Other minerals present are quartz, plagioclase, potash feldspar, biotite and opaque minerals. Exposure No. 776 in Appendix 1. Rutola, Lappeenranta. Crossed nicols.

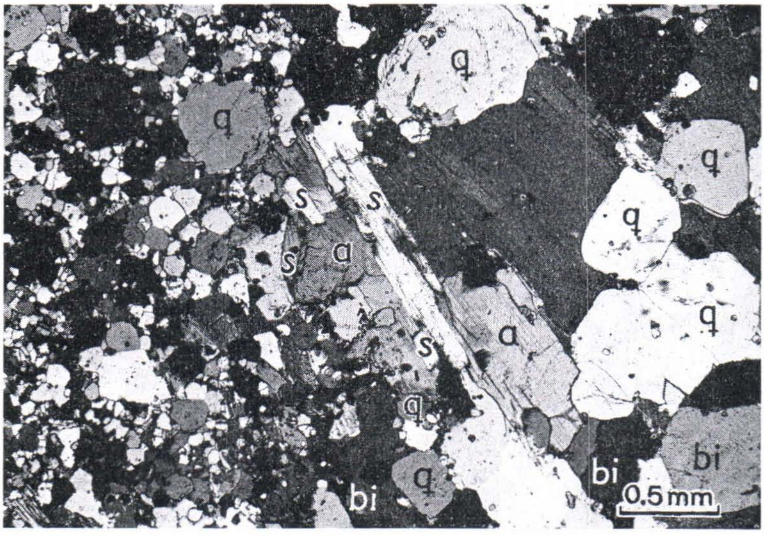

FIG. 44. Oriented intergrowth of robust sillimanite with andalusite. s = sillimanite, a = andalusite, q = quartz, bi = biotite. Same thin section as in Fig. 43. Crossed nicols.

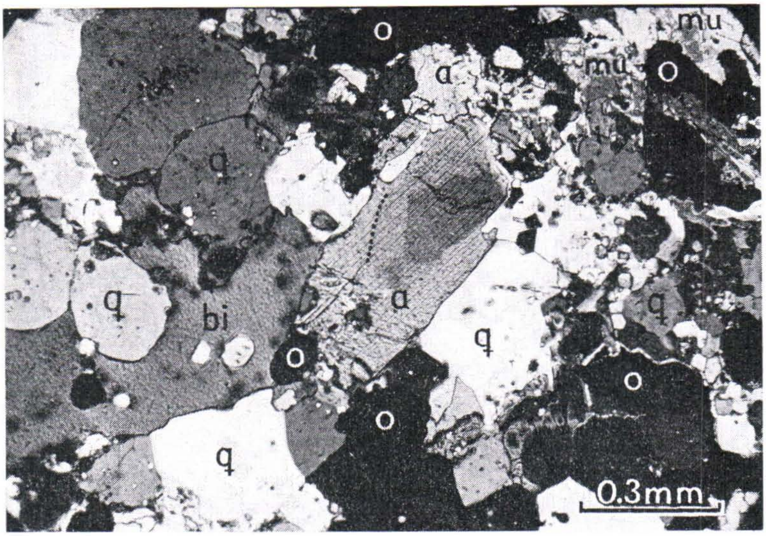

FIG. 45. Zoned andalusite showing three distinct zones. a = andalusite, q = quartz, bi = biotite, mu = muscovite, o = opaque minerals. Same thin section as in Fig. 43. Crossed nicols.

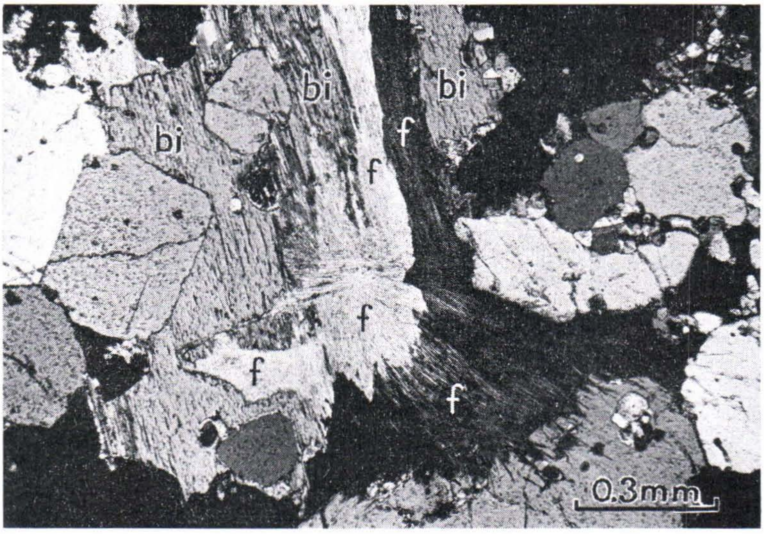

FIG. 46. Fibrolite (f) after biotite (bi). Same specimen as in Fig. 43. The photograph is, however, from a polished thin section without cover glass. Crossed nicols.

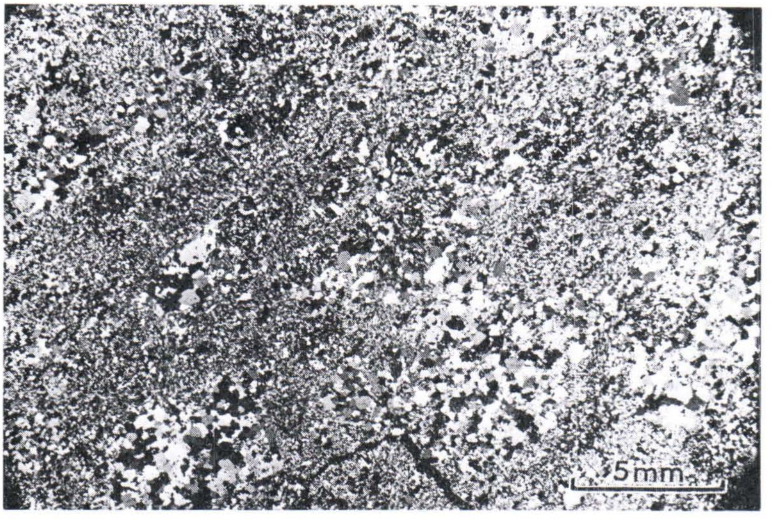

FIG. 47. A hornfels illustrating the typical grain size variation in hornfelses in the Ruoholampi area. For mineral composition, see text. The same exposure, No. 776, as in Figs. 43—46. Crossed nicols.

metasomatic differentiation. The extremely small sodium content is striking; this feature will be discussed more closely in connection with granodiorite hornfelses (p. 81).

Tapavainola

In the very southeastern corner of the Ruoholampi roof pendant, andalusite hornfelses are met with in some exposures. Potash feldspar is in equilibrium with andalusite also in these rocks. As in the hornfelses around the Hiidenniemi porphyry here, too, late biotite and muscovite occur as poikiloblasts. Cordierite is occasionally present.

Arenaceous hornfelses

Quartzites, arkose quartzites and leptite occur in the study area in isolated outcrops. Hence their relation to the other rocks is uncertain. Even their assumed Svecokarelidic age can be questioned. The thermally metamorphosed arkose quartzite occurring as fragments in the tectonic breccia underlying the Hiidenniemi porphyry will be described in connection with the breccia. The arenaceous rocks occurring as intercalations in argillaceous rocks will be described briefly in connection with the latter.

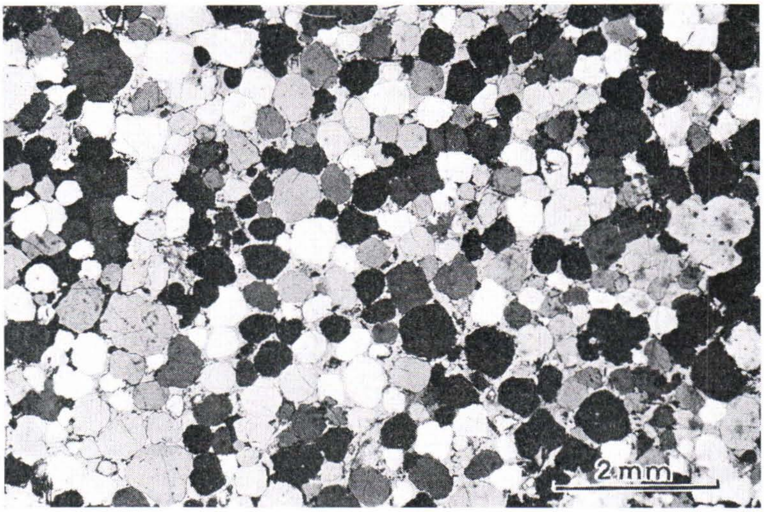

FIG. 48. Well-preserved blastoclastic texture in a thermally metamorphosed quartzite. The matrix is of orthoclase and sillimanite with a minor amount of cordierite. Exposure No. 82 in Appendix 1. Drainage channel, Töröla, Lappeenranta. Crossed nicols.

Töröla quartzite

Northeast of Töröla (Appendix 1), along the edges of a narrow drainage channel, a light gray quartzite is met with. Its contacts against the country rock are not exposed. The adjacent outcrops contain tirilite rapakivi. Towards the north and the south, the bedrock is hidden under loose earth. It is possible that the quartzite represents a small subsided roof remnant distinct from that of Ruoholampi.

Under the microscope, the quartzite shows in patches a blastoclastic texture with well-rounded quartz and a few plagioclase (An_{30}) grains (Fig. 48). In some spots, where the quartzite has recrystallized thoroughly, a granoblastic texture is to be seen. The matrix is mainly composed of orthoclase and sillimanite with minor amounts of partly pinitized cordierite and some magnetite. Large flakes of late biotite and muscovite penetrate the matrix.

The quartzite was presumably subjected to a sudden rise in temperature when it fragmented and subsided into the rapakivi magma. The original clayey matrix produced orthoclase and sillimanite with some cordierite under the conditions of pyroxene-hornfels facies of contact metamorphism. The formation of muscovite and biotite flakes is a later process, which took place when the conditions of the hornblende-hornfels facies were reached along with the decreasing temperature.

In this paper, the Törölä quartzite is grouped among the rocks of the orogenic complex. The well-preserved blastoclastic texture points to a very weak regional metamorphism, or to no regional metamorphism at all, which is, however, a feature uncommon to the rocks of the Svecofennidic belt of the Svecokarelidic orogeny. The rock might be Subjotnian in age, as well.

Leptites

Rocks marked leptites on the map in Appendix 1 are inhomogeneous, fine-grained light-coloured rocks. Originally, they were possibly arenaceous sediments (siltstones) or welded tuffs. A possible regional metamorphism, cataclastic deformation, and thermal metamorphism in connection with rapakivi emplacement, however, hinder the drawing of definite conclusions about their origin.

Hackman (1934) interpreted the leptites of the Ruoholampi area as thermally metamorphosed tuffites. Some of Hackman's tuffites are with certainty thermally metamorphosed argillaceous rocks, e.g., those north of Tapavainola, and some hybrid rocks formed from diabase and felsite porphyry (see pp. 35—51), but some might really have been welded tuffs.

The two localities in Appendix 1 — No. 771 near the shore in the southeastern part of Ruoholampi and No. 5 southeast of Kärjenlampi — marked as leptites, show an almost horizontal foliation. Whether this is due to the original bedding or to shearing is not clear. Thermal metamorphism has healed the rock. The quartz does not show any undulatory extinction caused by strain. The flaser-like texture, however, suggests a mylonite or welded tuff origin for these rocks.

The mineral composition is quartz, potash feldspar, basic plagioclase, minor amounts of biotite, partly of late origin, muscovite, also partly of late origin, opaque minerals, apatite and zircon. Late cordierite occurs as poikiloblasts in some of the rock specimens of exposure No. 5, where also bundles of fibrolite are met with.

Fig. 49 shows the texture of a leptite specimen from outcrop No. 5. In the aphanitic groundmass formed by the aforementioned minerals, there occur largish fragments of quartz, quartzite and potash feldspar. Plagioclase occurs mostly as very small grains in the intergranular matrix. Fig. 50 shows how the small-grained plagioclase strings wind along and around bigger grains, lenses and pools built in the main of quartz. Biotite and cordierite occur as small poikiloblasts. Fig. 51, furthermore, illustrates a leptite with a faint flaser-like texture. In the

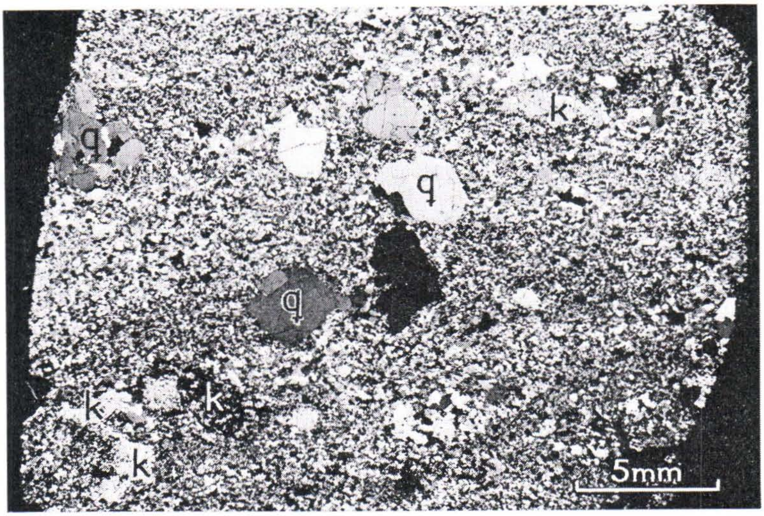

FIG. 49. Thermally metamorphosed siltstone(?). k = potash feldspar, q = quartz. Exposure No. 5 in Appendix 1. Southeast of Kärjenlampi, Lappeenranta. Crossed nicols.

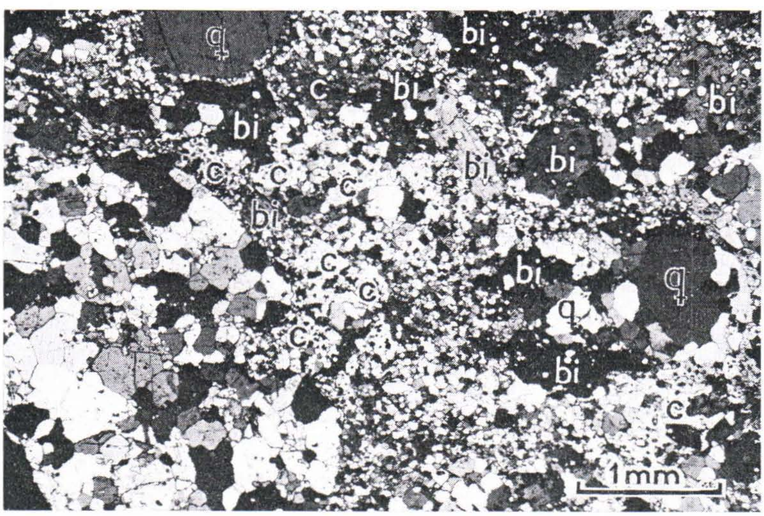

FIG. 50. Thermally metamorphosed arenite(?). Plagioclase, occurs mostly in the fine-grained strings which wind along and around the bigger grains, lenses and pools of quartz (for the major part) aggregates: q = quartz, bi = biotite, c = cordierite. Same exposure, No. 5, as in Fig. 49. Crossed nicols.

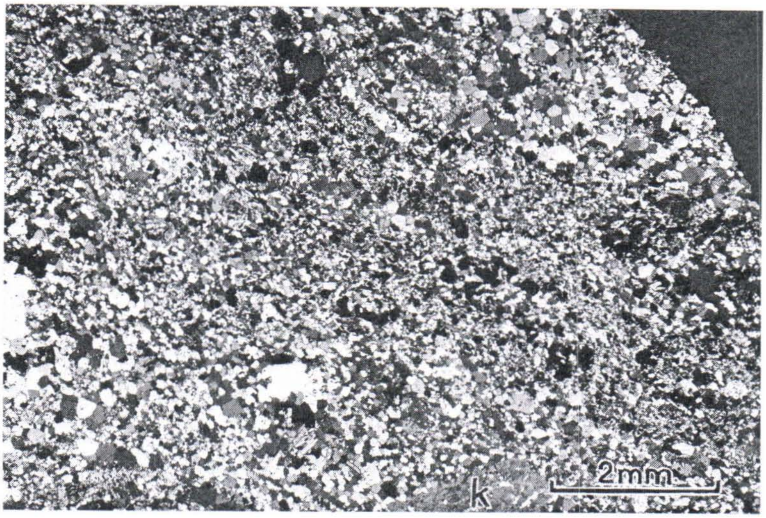

FIG. 51. Leptite, intimately associated with the felsite porphyry. The photograph shows a faint flaser (healed) or fluidal texture. The mineral composition is of quartz, plagioclase, biotite, chlorite, potash feldspar, with some epidote, fluorite and opaques. The fluidal texture is supported by the potash feldspar phenocrysts (k), which are quite similar to those in the felsite porphyries. Exposure No. 771 in Appendix 1. South of Ruoholampi, Lappeenranta. Crossed nicols.

exposure from which the specimen was taken, the leptite is intimately mixed with felsite porphyry. The illustrated texture is either a flaser texture healed through thermal metamorphism and accompanied by hybridization by the felsite porphyry, or it is a fluidal texture indicating that the rock is a welded tuff in origin. In the latter case, the rock would be a thermally metamorphosed welded tuff of the rapakivitic suite.

Miscellaneous hornfelses

The rocks marked as hornfelses, southwest of the Hiidenniemi porphyry, probably derived in part from cataclastically deformed granodiorite and in part from regionally metamorphosed, also cataclastically crushed migmatites. In many exposures, especially those close to the porphyry contact, the marginal variety of the porphyry penetrates the hornfelses. Metasomatic alteration of the country rock is to be observed here. As pointed out on p. 22, it is probable that the present erosion surface coincides closely with the original contact surface of the Hiidenniemi porphyry against its country rocks.

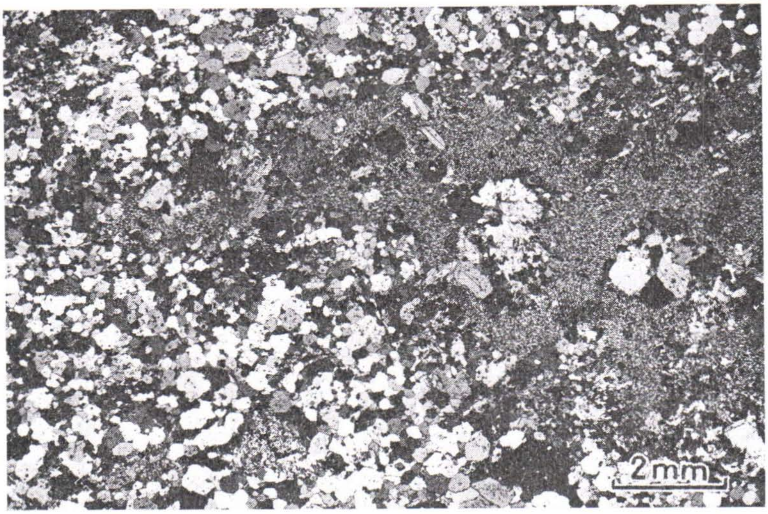

FIG. 52. A tail of a fine-grained »flame» in cordierite-bearing contact quartzite enveloping the Hiidenniemi porphyry. For details, see text. Contact exposure; southeast of exposure No. 795 in Appendix 1. Hiidenniemi, Lappeenranta. Crossed nicols.

»Flame rocks»

Among the hornfelses situated next to the southeastern contact line of the Hiidenniemi porphyry, injection hornfelses are met with. Some of these are characterized by a peculiar flame structure. The flames are slightly darker-coloured than their »matrix». They vary in thickness from a few millimeters to several centimeters. In many respects, the flames resemble petrographically the intergranular An-rich plagioclase matrix of the hornfelses discussed on preceeding pages.

Fig. 52 illustrates the tail of a flame. The host of the flames, a cordierite-bearing contact quartzite envelopes the small-grained flame in which the grain size is only about 0.01 mm. The fine-grained mass is mainly anorthite (CaO 18.5, Na_2O 0.7 % according to micro-probe analysis). The same plagioclase occurs as extremely abundant inclusions in quartz poikiloblasts (up to 0.3 mm in diameter), not shown in the picture. In addition, the flames contain aggregates of slightly coarser-grained plagioclase (CaO 17.4, Na_2O 0.6 %) with a grain size up to 0.1 mm, porphyroblasts and aggregates of late biotite, augens of potash feldspar, 0.1—0.3 mm in diameter, and grains of magnetite.

The flames in outcrop No. 13 are somewhat different. There the host rock is a contact quartzite in which portions rich and poor in potash feldspar alternate. Viewed with the naked eye, the rock gives an impression of being highly fragmented; the darker rock occurs flame-like in the light-coloured quartzite. The flames are composed of a mosaic of quartz, potash feldspar and anorthite (CaO 18.0, Na_2O 0.97 %) the grain size varying from 0.01 mm to 0.03 mm. In this aphanitic mosaic, late biotite and muscovite occur in a decussate arrangement as flakes measuring up to 0.1—0.6 mm in diameter. Occasionally they form knots. In addition, there occurs magnetite as scattered grains, 0.1—0.3 mm in diameter.

The third flame rock taken here as an example is from outcrop No. 15, southwest of the Hiidenniemi porphyry. At this outcrop, the typical Hiidenniemi porphyry grades over into the contaminated marginal variety. Ghost-like remnants of country rock are frequently observed. The country rock in the fragments is an inhomogeneous contact gneiss rich in potash feldspar. The rock is inhomogeneous in both mineral composition and grain size. In places, the small biotite flakes have a marked parallel alignment; in places, they form aggregates in which magnetite is in many instances abundantly present. Besides the quartz, potash feldspar is a dominant mineral. Plagioclase grains, measuring up to 0.3 mm in diameter, have been partly replaced by potash feldspar and quartz. Most of the plagioclase, however, occurs in the intergranular matrix. Occasionally grains of plagioclase are encountered in which the intergranular An-rich plagioclase can be postulated to have derived from the original larger grains by fragmentation and recrystallization. Quartz occurs both as small, 0.05—0.2 mm grains and as porphyroblasts up to 2 mm in diameter. The marginal parts of many of the porphyroblasts enclose small plagioclase grains. The rock also contains fluorite and calcite. Under the microscope, one can see flames, a few millimeters in thickness, which are composed mainly of small-grained andesine-labradorite (CaO 9.7, Na_2O 5.9 % according to micro-probe analysis), 0.05 mm in diameter, often as quite idiomorphic crystals. Fig. 53 shows a quartz porphyroblast embedded in the margin of a flame. The marginal parts of the quartz contain as inclusions rounded basic plagioclase grains 0.01—0.02 mm in diameter, similar to those occurring in the intergranular matrix of the host rock. Outside the poikiloblastic margin of the quartz, the flame material is plagioclase, much of which is idiomorphic and somewhat coarser in grain than the plagioclase occurring as inclusions in the quartz porphyroblasts. In many of these idiomorphic plagioclase grains, the core is more basic (bytownite; CaO 14.2, Na_2O 2.1 %) than the idiomorphic outer zone. The core is identical with the small, rounded plagioclase grains enclosed in the marginal parts of the quartz porphyroblasts and with those occurring in the intergranular matrix

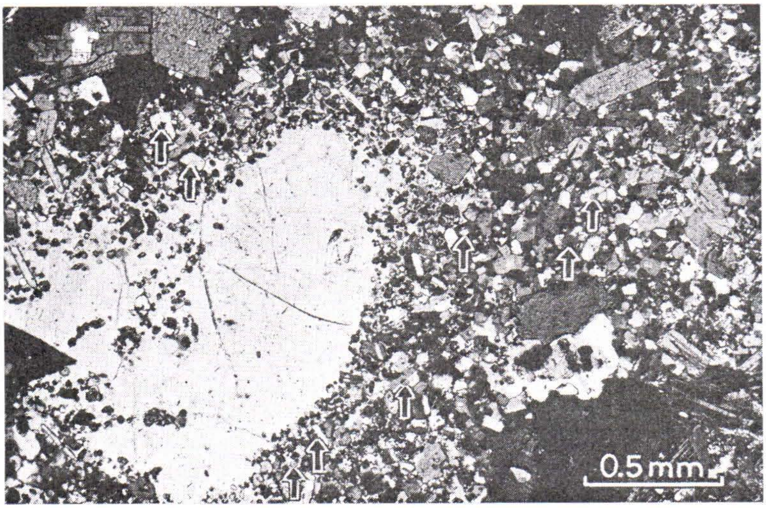

FIG. 53. A detail of a »flame» in an injection hornfels. For details, see text. Arrows indicate some of the minute An-rich cores of plagioclase crystals in the flame, referred to in the text. Exposure No. 15 in Appendix 1. South of Hiidenniemi, Lappeenranta. Crossed nicols.

elsewhere in the host rock. The flames also contain, in addition to the plagioclase, large flakes of late biotite in decussate arrangement.

The three described cases of flame structure are connected with the contact against the Hiidenniemi porphyry, as are also several other exposures showing flames. This structure has not been detected farther than a few meters from the contast. In the hornfelses farther away from the contact, small-grained basic plagioclase (grain size 0.01 mm) is common in the intergranular matrix. It seems that high temperatures, possibly also fluxes from the rapakivitic melt, were the essential factors in the formation of the flames. Possibly the anorthite-rich plagioclase represents a residue, equilibrated at high temperatures, when the rock was partially fused. In any case, the growth of the plagioclase richer in sodium as well as of the quartz poikiloblasts, the augens of the potash feldspar and the late biotite took place only after the temperature decreased.

Hornfelses of mylonite and migmatite

Farther away from the southwestern contact of the Hiidenniemi porphyry, the hornfels rock gives an impression of having derived from cataclastically deformed granodiorite or migmatites by thermal metamorphism. Also these rocks were interpreted by Hackman (1934)

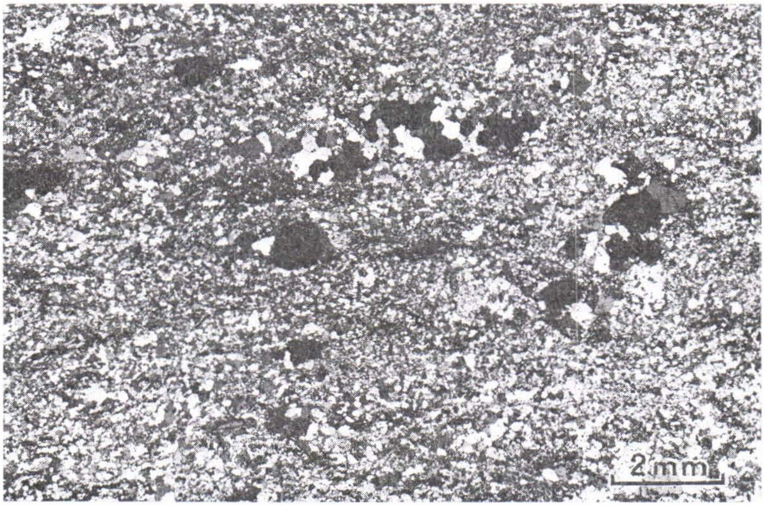

FIG. 54. A faint flaser texture in a thermally metamorphosed granodiorite-mylonite (?). Note the secondary quartz lenses and magnetite augens. Exposure No. 11 in Appendix 1. South of Hiidenniemi, Lappeenranta. Crossed nicols.

as volcanogeneous schists that have undergone a slight thermal metamorphism. Fig 54 illustrates one such rock. It is rather a mylonite, which became thermally metamorphosed. The flaser-texture is still faintly visible. Magnetite augens are abundantly present. The plagioclase is basic and occurs exclusively in the fine-grained intergranular matrix.

A thin section study revealed three components in a hornfels produced from migmatite: 1, biotite gneiss, rich in potash feldspar, the biotite being segregated into streaks and the plagioclase into the fine-grained intergranular matrix; 2, epidote-bearing arkose quartzite, poor in potash feldspar; and 3, quartz-bearing granoblastic bands rich in potash feldspar and in which components 1 and 2 occur as lenses and streaks.

Metasomatic metamorphism and/or welded tuffs

Owing to a faint, flat foliation, the rock in outcrop No. 786 looks somewhat inhomogeneous; gneissic portions alternate irregularly with »felsitic» portions. Both have been metamorphosed thermally, possibly also metasomatized hydrothermally. Two samples of the »felsitic» rock, some 30 cm apart, were taken for chemical analysis (Table 3, Nos. 3 and 4). To the naked eye, the only difference between the rocks is in their grain size; one is aphanitic (sample C) and the other (sample D) somewhat coarser in grain.

Texture of sample C is granoblastic. The grain size varies from 0.03 mm 0.5 mm with the exception of the plagioclase, which occurs in the fine-grained (0.01—0.02 mm) intergranular matrix as it does in most hornfelses. The mineral composition is: quartz, which in many cases forms lenticles, plagioclase, potash feldspar, biotite — partly altered into chlorite and present in many places in aggregates in which individual biotite flakes have a decussate arrangement — cordierite, muscovite, of which at least a part is of late origin (poikiloblasts), and pyrrhotite. A chemical analysis of the rock is given in Table 3, analysis No 3.

Also the other analyzed sample (D) is granoblastic in texture. Under the microscope, a faint foliation can be seen. The mineral composition is: quartz, potash feldspar, plagioclase, cordierite, biotite, muscovite and opaque minerals. The average grain size is 0.1 mm, although the largest poikiloblasts of cordierite, potash feldspar and biotite reach diameters of 2 mm. A chemical analysis of this rock is given in Table 3, analysis No. 4.

The two chemical analyses suggest that the rocks have undergone a metasomatic metamorphism. The qualitative mineral composition is almost the same in both rocks, but the quantitative mineral contents differ. Rock D is characterized by a high potash feldspar content and a very high K_2O content and K_2O/Na_2O ratio — both quite similar to those of the rapakivitic Hiidenniemi porphyry. The BaO is also very high. Barium was possibly expulsed with potassium from the melt out of which the Hiidenniemi porphyry crystallized and which infiltrated into the country rock. The MgO of rock D is quite low; yet, cordierite is abundantly present and must thus be an iron-rich variety. The high Al_2O_3 is possibly due to a high aluminium content in the original rock because the rapakivitic magma itself is poor in aluminium. On the other hand, the figure for ZrO_2 is quite high and correlates well with the rapakivitic composition (see Sahama 1945, p. 44). The ZrO_2 content suggets metasomatic enrichment of zirconium into the country rocks of the Hiidenniemi porphyry.

Analysis No. 3 differs from analysis No. 4, first of all, in the very high figure for SiO_2. Possibly it signifies a local silicification. Practically all the other figures are lower than in analysis No. 4. The relative values, however, are very similar in both the analyses, suggesting a common parent rock. Exceptions are the somewhat higher CaO and considerably higher S in analysis No. 3 as compared to those in No. 4. The sulfur was possibly derived from the magma out of which the adjacent Hiidenniemi porphyry crystallized. The quartz (silicification) may have derived from the porphyry, or it may be due to mobilization of the quartz in the rock itself during the contact metamorphism.

Study of the chemical analyses Nos. 3 and 4 in Table 3 does not reveal the origin of the hornfelses. Hackman (1934) regarded these rocks as thermally metamorphosed volcanogeneous schists. The mean of the two foregoing analyses — it is true — quite closely corresponds to the rapakivitic composition. If a mere mobilization of SiO_2 from rock D to rock C had taken place — as unlikely an event as it is — then the rock might originally well have been a welded tuff, comagmatic with the rapakivi suite. This interpretation is given some support by the texture of a hornfels specimen taken from the same outcrop as the analyzed samples. This specimen is from a band that is richer in biotite than the »felsitic» rocks chemically analyzed (C and D). The texture is illustrated in Fig. 55. The grain-size variation so typical of hornfelses in the Ruoholampi area is clearly seen. Mineral segregation into schlieren and lenticles gives an impression of a thermally metamorphosed welded tuff or a mylonite gneiss. The mineral composition is: quartz, potash feldspar (also as phenocrysts or porphyroblast), plagioclase (also as phenocrysts or porphyroblasts, conspicuously replaced by potash feldspar and quartz), biotite, which often forms

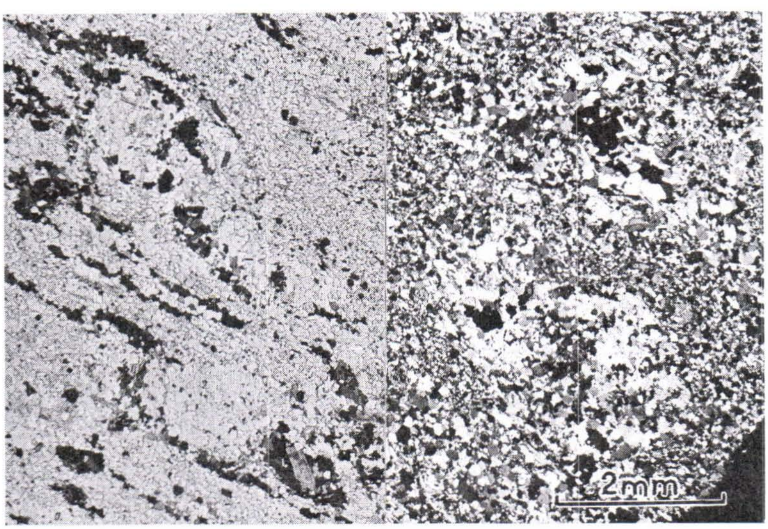

FIG. 55. The texture in a mylonite gneiss or welded tuff healed by thermal metamorphism. For further details, see text. Exposure No. 786 in Appendix 1. South of Hiidenniemi, Lappeenranta. Left, parallel nicols; right, crossed nicols.

schlieren and aggregates, and opaque minerals. In appearence, this rock is quite similar to that illustrated in Fig. 51, which is, perhaps, a rapakivitic welded tuff.

Hiidenniemi tectonic breccia

Geological setting

Hackman (1934, pp. 64—66) described a conglomerate south of Hiidenniemi (No. 100). The formation was later reinterpreted by Vorma (1965, p. 21) as a tectonic breccia. Extensions of the formation have later been found both northeast and south of the type locality.

The breccia zone underlies the Hiidenniemi porphyry. It is a subhorizontal formation at least a few meters thick, which tilts gently to the northwest. The fragements (Fig. 56) in the breccia are arkose quartzite, and the matrix is a thermally metamorphosed mylonite gneiss.

About 100 meters to the south from the type locality, close to the assumed porphyry contact, there is a small exposed area in which more competent arenaceous layers represent the initial stage of

FIG. 56. The Hiidenniemi tectonic breccia. For details, see text. Exposure No. 100 in Appendix 1. Hiidenniemi, Lappeenranta.

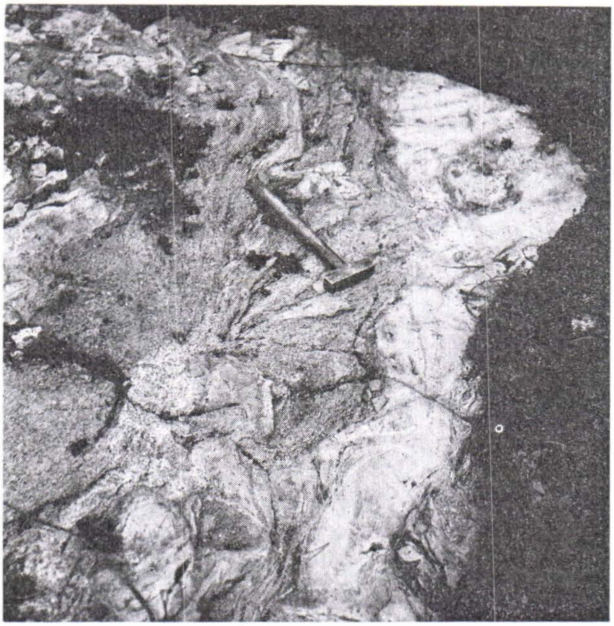

FIG. 57. Quartzite beds in the initial stage of fragmentation in a matrix of plastically behaving agrillaceous rock. Exposure No. 626 in Appendix 1. South of Hiidenniemi, Lappeenranta.

fragmentation (Fig. 57), the argillaceous layers being plastical. These arenaceous layers correspond closely to the fragments in the type locality and the argillaceous rock correspond to the matrix of the breccia.

About 100 meters to the northeast from the type locality, on the steep slope of the Hiidenniemi hill, next to the porphyry contact, the breccia zone is separated from the porphyry proper by a hybridized contact gneiss (injection hornfels) formation some meters thick. The breccia zone can be followed farther north in a couple of small outcrops. There the contacts against other rocks are not exposed, however.

In the present author's opinion, the breccia formation predates the emplacement of the Hiidenniemi porphyry. Possibly the old subhorizontal fracture zone served as a magma conduit for the emplacement of the porphyry.

Petrography

In the type locality, the quartzite fragments are composed of a mass of granoblastic quartz and potash feldspar with minor amounts of partly chloritized biotite, plagioclase, pinite chondrules, presumably after cordierite, and late muscovite. Opaque minerals and apatite occur as accessory minerals. The grain size varies from 0.2 mm to 0.6 mm. The texture is illustrated in Fig. 58.

In the other exposures, the fragments are highly similar to those in the type locality. In places, the amount of plagioclase is larger. The quartzite illustrated in Fig. 57 is somewhat smaller in grain than the type rock, viz. 0.05—0.1 mm; only in places does it reach 0.2 mm. This quartzite also contains epidote-rich portions in wich potash feldspar is virtually lacking. Epidote occurs as long narrow strings, indicating old shears (Fig. 59).

In the type locality, the matrix of the breccia could well be interpreted as a blastomylonite. The features characteristic of cataclastic rocks (see, e.g., Higgins 1971), however, are not easily identifiable because of the effects of thermal metamorphism produced by the adjacent porphyry and the circulation of alkali-rich fluids. Fig. 60 illustrates the granoblastic quartz — potash feldspar — biotite matrix. The strings formed by very small-grained minerals are composed of plagioclase. Note also the subhedral potash feldspar inset near the lower left corner. The same thin section also contains large poikiloblasts of plagioclase as well as lenticles and pools of quartz-potash feldspar aggregates. A tail of one of the lenticles can be seen in the figure.

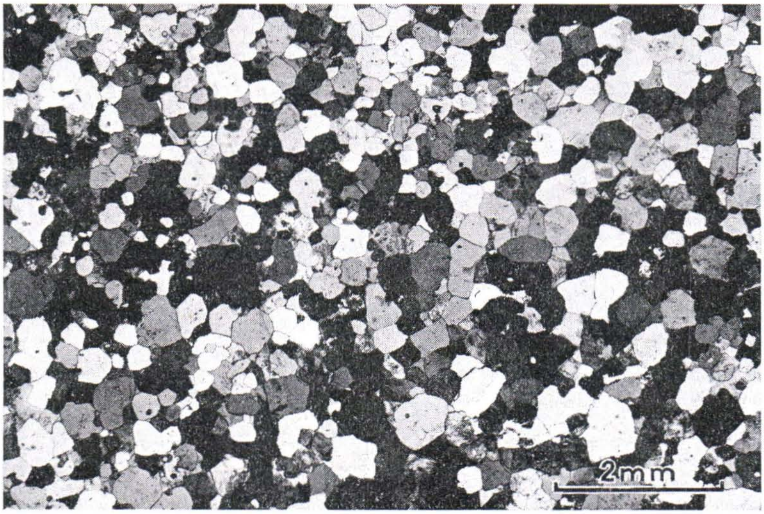

Fig. 58. Arkose quartzite from a fragment in the Hiidenniemi breccia. The granoblastic mass is of major quartz and potash feldspar with minor amounts of plagioclase, biotite, chlorite and late muscovite. Exposure No. 100 in Appendix 1. Crossed nicols.

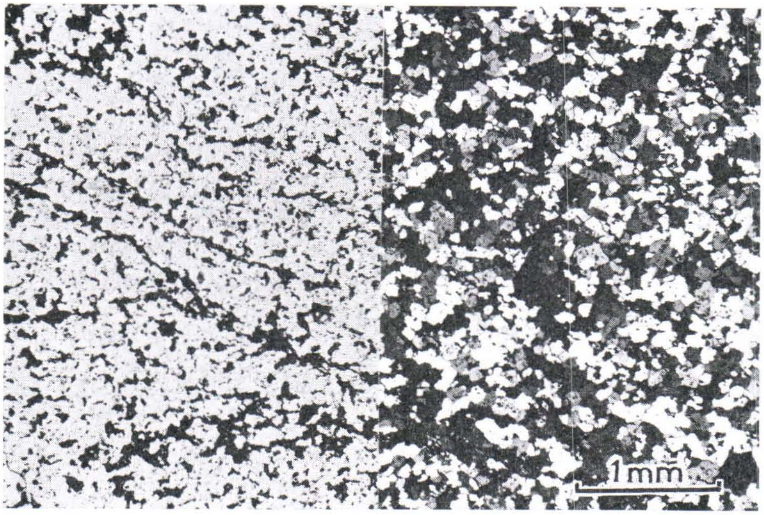

FIG. 59. Arkose quartzite with epidote-filled shears. Exposure No. 626 in Appendix 1. South of Hiidenniemi, Lappeenranta. Left, parallel nicols; right, crossed nicols.

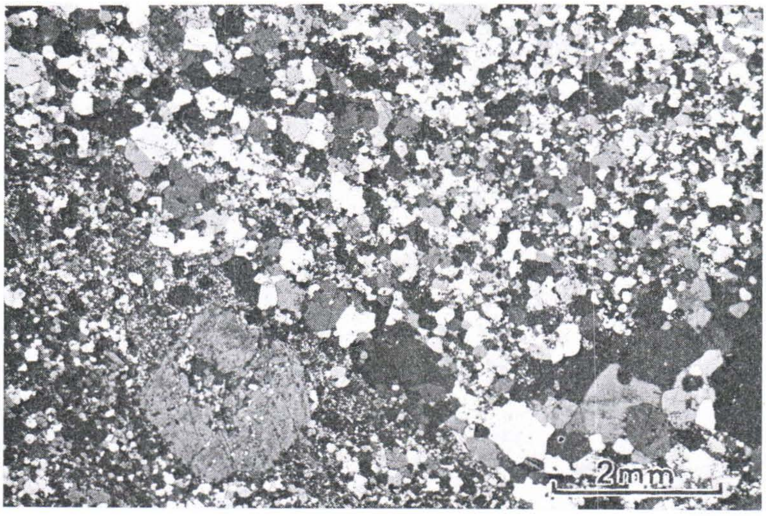

FIG. 60. A detail of the matrix of the Hiidenniemi tectonic breccia. See text. Exposure No. 100 in Appendix 1. Crossed nicols.

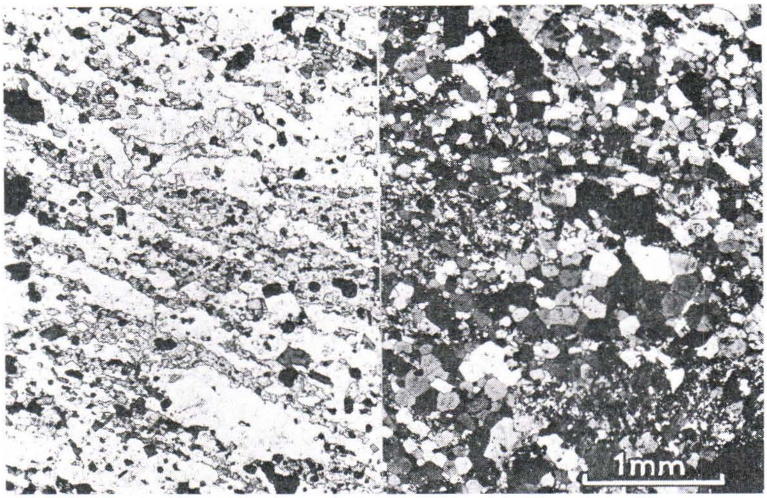

FIG. 61. Flaser texture, thermally metamorphosed, in matrix of Hiidenniemi breccia. The flasers are mostly of potash feldspar and quartz, the strings between flasers fine-grained plagioclase and biotite. Exposure No. 626 in Appendix 1. South of Hiidenniemi, Lappeenranta. Left, parallel nicols; right, crossed nicols.

Aggregates of biotite and muscovite, in which the minerals have a decussate arrangement, are common in another thin section from the type locality. A flaser texture can be distinguished in places, as, for instance, in Fig. 61. About 100 m to the northeast from the type locality, cordierite is found in the matrix of the breccia. Also poikiloblasts of plagioclase, measuring up to 3 mm in length, intergrown with quartz, and partly replaced by potash feldspar, are quite common in this locality. Biotite occurs as knots. Flames, similar to those discussed on pp. 65—67, are met with here as well.

Granodiorite and associated rocks

The granodiorites of the roof pendants have been counted among the synorogenic Svecokarelidic plutonic rocks. The two different granodiorite varieties have not been marked on the maps (Fig. 1 and Appendix 1). Mention should be made of the fact, however, that the two varieties, one even-grained and the other porphyroblastic, often occur intimately mixed.

Specimens taken east and south of Ruoholampi and south of Myllylampi (Appendix 1) have been studied. It was thought possible (p. 64) that a part of the hornfelses located southwest of the Hiidenniemi porphyry might well have been derived from cataclastically crushed granodiorite. This interpretation remains to be proved.

Petrography

Under the microscope, the granodiorite shows a hypidiomorphic-granular texture. The plagioclase (An_{30-38}) is polysynthetically twinned and clouded by sericite. In places, the zoning is well developed, as, for example, in the specimen from which the rock analysis No. 1 in Table 4 was made. The composition of this plagioclase is An_{30}, some grains having a core of An_{61}. The remarkable thing is that, in many of the specimens, some of the plagioclase occurs as very small grains in the intergranular matrix. Closer to the contacts against the rapakivitic rocks, this feature becomes more pronounced.

Potash feldspar occurs either as allotriomorphic grains or as quite idiomorphic porphyroblasts. X-ray powder determinations carried out on potash feldspar from eight granodiorite specimens showed the mineral to be monoclinic. Under the microscope, a faint cross-twinning is occasionally observable, indicating also a minor content of microcline. Vorma (1972) showed that, around the Wiborg rapakivi massif, there is a thermally metamorphosed aureole about 5 km broad in which the Svecokarelidic plutonic rocks contain orthoclase almost exclusively as their potash feldspar. Outside this aureole, microcline is the prevailing potash feldspar in similar rocks. The occurrence of orthoclase instead of microcline in the granodioritic rocks of the Ruoholampi roof pendant is likewise interpreted as a result of thermal metamorphism by rapakivi.

Quartz occurs as allotriomorphic grains; in places it also forms aggregates. Biotite, which is slightly chloritized in some specimens, recrystallized thoroughly during the rapakivi emplacement. In most of the specimens, a faint foliation is observable, having been caused by the aggregation of biotite in schlieren. In the aggregates themselves, the biotite flakes often have the decussate arrangement (Fig. 62).

Grains of cordierite are met with in most of the thin sections. Worth noting is the fact that the granodioritic rocks around the Wiborg massif contain practically no cordierite (see, e.g., Table 1, pp. 12—16 in Vorma 1972, in which the Fe-Mg silicate parageneses for more than 200 specimens of granitoid rocks around the Wiborg massif are given). In all probability, the formation of cordierite took place during the thermal metamorphism by rapakivi granite, the metamorphism having been more intense in the roof pendant rocks than around the massif itself.

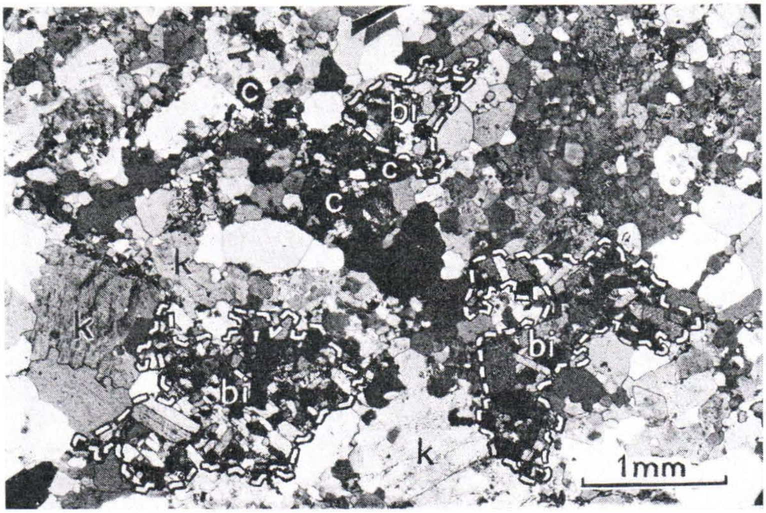

FIG. 62. Weakly thermally metamorphosed granodiorite. Biotite (bi) in aggregations and schlieren in the decussate arrangement: c = cordierite, k = potash feldspar. Small-grained matrix is of quartz and plagioclase. Exposure No. 791C in Appendix 1. South of Ruoholampi, Lappeenranta. Crossed nicols.

In many of the specimens, muscovite occurs as late flakes. Opaque minerals, apatite and calcite are the more important accessory minerals.

Thermal metamorphism

In hand specimens or on exposure, the granodiorite rock looks fresh and shows no signs of incipient alteration. Closer to the rapakivi contact, in the area marked as hornfels, between the lakes of Myllylampi and Kärjenlampi (Appendix 1), the rock has a faint, in places quite marked secondary(?) foliation, which is almost horizontal, or it dips slightly to the southeast. In some of the exposures, this direction becomes clearer owing to the presence of inhomogeneous banding. It is possible that this direction is parallel to the floor contact of the roof pendant against the rapakivi.

Most of the rocks marked as hornfelses are thermally metamorphosed, cordierite-bearing rocks, even though in grain size and outer appearence the lighter bands and streaks cannot be distinguished from the granodiorite proper.

Fig. 63 illustrates the texture of the lighter bands of the granodiorite. The rock is quite rich in cordierite. The polysynthetically twinned oligoclase-andesine is well preserved. Fig. 64 in its turn illustrates the

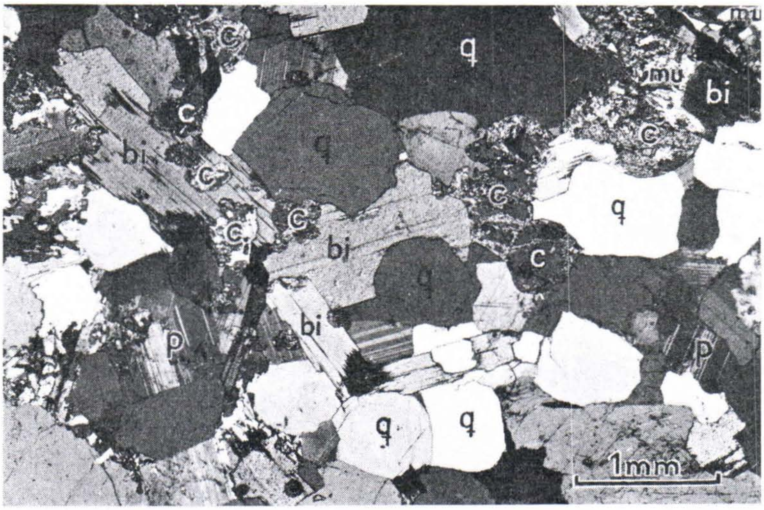

FIG. 63. Texture of cordierite-bearing granodiorite (weakly thermally metamorphosed granodiorite): q = quartz, p = plagioclase, c = cordierite, bi = biotite, mu = muscovite. Exposure No. 201A in Appendix 1. Between lakes Kärjenlampi and Myllylampi, Lappeenranta. Crossed nicols.

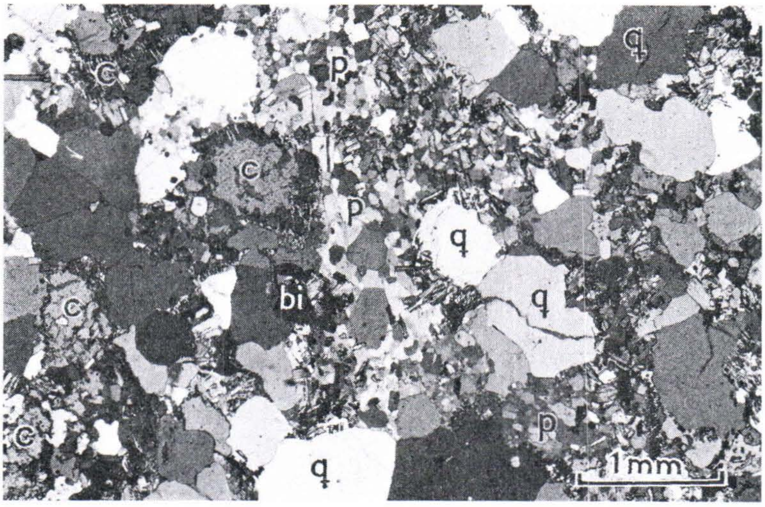

FIG. 64. Texture in darker bands, referred to in text, of granodiorite hornfels: q = quartz, c = cordierite, p = basic plagioclase in intergranular matrix, bi = biotite. Exposure No. 201A in Appendix 1. Between lakes Kärjenlampi and Myllylampi. Crossed nicols.

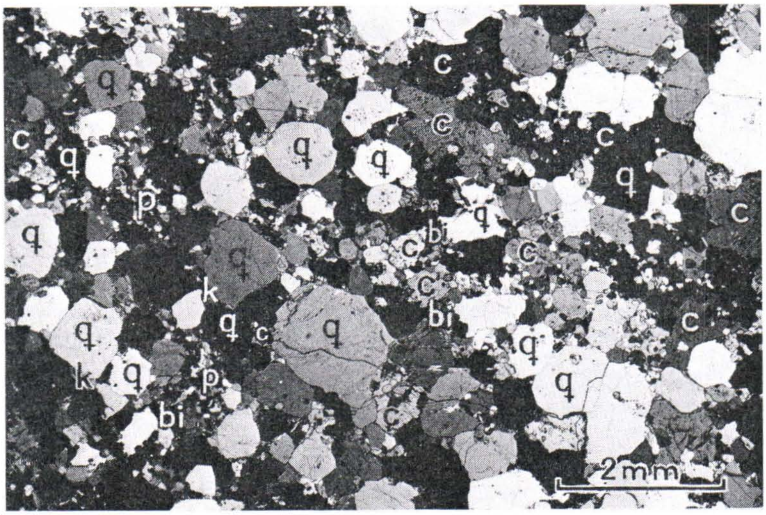

FIG. 65. Granodiorite(?), thermally metamorphosed under the conditions of pyroxene-hornfels facies: c = cordierite, q = quartz, bi = biotite, k = potash feldspar, p = plagioclase. Exposure No. 65 in Appendix 1. Kärjenlampi, Lappeenranta. Crossed nicols.

texture of the slightly darker bands in which the grain size is also smaller than in the lighter bands. The rock is somewhat richer in cordierite, too. Instead of polysynthetically twinned oligoclase-andesine anorthite-rich plagioclase (CaO 18.5, Na_2O 0.6 % according to partial electron probe micro analysis, exposure No. 778) occurs as small grains in the intergranular matrix. Some of the outcrops contain exclusively this »cordierite rock». The foliation is very difficult to determine in them. Fig. 65 illustrates the texture of the chemically analyzed »cordierite rock» (granodiorite hornfels) from outcrop No. 65. The mineral composition of this rock is: quartz, cordierite, plagioclase, orthoclase and biotite. Plagioclase occurs in the fine-grained granoblastic intergranular matrix. Its relief under the microscope shows it to be very rich in the anorthite component. From the granodiorite hornfels of No. 201 (anal. No. 3 in Table 4), An_{78} was optically measured. Worth noting are also the interfaces without any detectable reaction seam between the cordierite and the orthoclase. This is an indication of the conditions of the pyroxene-hornfels facies. As a whole, the amount of potash feldspar in the rock, however, is quite small.

A chemical analysis of the granodiorite containing scattered potash feldspar porphyroblasts is given in Table 4, analysis No. 1. Compared

TABLE 4

Chemical composition of granodiorite and associated rocks from the Ruoholampi roof pendant.[1]

	1.	2.	3.
SiO_2	69.19	70.86	69.88
TiO_2	.42	.36	.37
Al_2O_3	15.51	15.84	17.08
Fe_2O_3	.42	.50	.44
FeO	2.61	2.84	2.59
MnO	.05	.05	.08
MgO	1.46	2.87	2.53
CaO	1.64	2.32	2.77
Na_2O	2.03	.18	.45
K_2O	4.36	3.12	2.58
P_2O_5	.12	.12	.14
CO_2	.00	.00	.00
H_2O+	1.15	.75	1.65
H_2O-	.05	.05	.09
Cl	.07	.08	.09
F	.07	.13	.11
S	.00	.00	.00
Li_2O	.008	.004	.017
Cs_2O	.000	.000	—
Rb_2O	.017	.019	.011
SrO	.033	.007	.009
ZrO_2	.023	.024	.022
BaO	.11	.11	.11
	99.34	100.23	101.02
—O=Cl,F	.05	.07	.07
	99.29	100.16	100.95

1) Silicate analyses by Risto Saikkonen with XRF-analyses of Rb, Sr, Zr and Ba by Maija Hagel.

1. Granodiorite with scattered potash feldspar porphyroblasts. Exposure No. 791. South of Ruoholampi, Lappeenranta.
2. Granodiorite(?) hornfels. Exposure No. 65. Kärjenlampi, Lappeenranta.
3. Granodiorite(?) hornfels. Exposure No. 201. Kärjenlampi, Lappeenranta.

with the average composition of granodiorites in the Svecofennidic belt (see Simonen 1960, p. 23, Table VI), the analyzed sample is considerably poorer in CaO and the K/Na ratio is higher. Both of these figures approach those recorded for granitic rocks. The high K/Na ratio is evidently due to the metasomatically(?) grown potash feldspar porphyroblasts. The comparatively high MgO figure is reflected in the presence of cordierite in the rock.

Analyses Nos. 2 and 3 in Table 4 were made of the homogeneous cordierite-rich rocks from the hornfels zone. The results of the chemical analyses do not correspond to any figures for normal sedimentogenous rocks of the Svecofennidic belt. The K/Na ratio is very high, the Na_2O content being exceptionally small.

The chemical composition together with the petrographical data support the interpretation that a part of the hornfelses were originally granodiorite rocks. Close to the contact against the rapakivi, the oligoclase-andesinic plagioclase of granodiorite would have become unstable under the conditions prevailing during the culmination of the thermal metamorphism. The mineral seems to have been replaced by a plagioclase richer in Ca than the original one. Now this anorthite-rich plagioclase occurs in the intergranular matrix. The liberated sodium would have been ejected from the rock, which would explain the low Na_2O figure. If so, the hornfels zone as a whole could be interpreted in the same way as, for instance, the basic »behinds» (see Read 1957, p. 353) proper. In the case under discussion, no desilicification has been observed, however; the Mg, Ca, and Al contents seem to have increased, and the amount of alkaline decreased in comparison with the average composition of the granodioritic-granitic rocks of the Svecofennidic belt (see Simonen 1960).

EVOLUTION OF THE ROOF PENDANTS

The major events controlling the evolution of the roof pendants, the Ruoholampi roof pendant in especial, can tentatively be set forth as follows, reading from the oldest to the youngest:

Svecokarelidic orogenic rocks c. 1900 m.y.	Supracrustal Svecokarelidic rocks Emplacement of granodiorite concurrent with the culmination of the regional metamorphism Potash feldspar blastesis

— — — — — — — — — — — — Cratonization — — — — — — — — — — — —

and

— — — — — Denudation of about 10 km of the crust — — — — —

(continues)

(continued)

Subjotnian c. 1700 m.y.	Deep fractures; extrusion of the mantle-born basic magma: diabases, etc., producing minor hornfelses in the orogenic complex. Rise of rapakivi magma into the higher levels of the crust with associated volcanic eruptions, mainly of ignimbrite character: — Felsite porphyries and the Hiidenniemi porphyry; thermal metamorphism of the envelope rocks of the Hiidenniemi porphyry; hybridization of diabase. — Sinking of the roof pendants into the rapakivi magma; subsidence structures of possibly volcano-tectonical origin were formed and intrusive faulting presumably occurred; thermal metamorphism of the roof pendant rocks, the volcanic equivalents of rapakivi included, by the rapakivi granite; development of new foliation into the roof pendant rocks parallel with the floor of the pendants.

The possibility should be kept in mind that the arenaceous rocks, thermally metamorphosed quartzite in Törölä and the »siltstone», southeast of Kärjenlampi, are Subjotnian rocks.

It is probable that a cataclastic deformation preceded the thermal metamorphism in the envelope rocks of the Hiidenniemi porphyry. The thermal metamorphism took place partly under the conditions of the pyroxene-hornfels facies as indicated by, for instance, the common coexistence of potash feldspar and andalusite and/or cordierite. The almost ubiquitous occurrence of large flakes of late muscovite and biotite is the result of a later process, presumably connected with metasomatism. The occurrence of fibrolite in the contact aureole is possibly also connected with a later stage in the evolution of the aureole.

In some of the argillaceous hornfelses, diablastic intergrowth of andalusite with late muscovite is observed, indicating, that the two minerals grew concurrently. The andalusite growth took place episodically as revealed by the distinct zonality of andalusite porphyroblasts.

The granodiorite likewise underwent a thermal metamorphism by rapakivi. The cordierite rock formation, in which the cordierite is in equilibrium with the potash feldspar, corresponds to a basic »behind» impoverished in alkalies and produced from granodiorite by thermal metamorphism. A less plausible alternative would be that the cordierite rocks represent screens of older rock in granodiorite, screens which by pure coinsidence would be located in an appropriate place to stand for a contact-metamorphosed granodiorite. At any rate, the rock metamorphosed under the conditions of pyroxene-hornfels facies.

The diabases of the roof pendant areas are regarded as Subjotnian subvolcanic and volcanic rocks which were subjected to strong thermal metamorphism during the rapakivi emplacement and to hybridization during the stage when the rapakivitic effusive rocks were generated.

Characteristic of all the chemically analyzed rocks of the Ruoholampi roof pendant is the high K/Na ratio. It is known that the rapakivi granites have an unusually high K/Na ratio for a granite. Some of the porphyries (Table 2) have an even higher K/Na ratio than the rapakivi granites proper. This high K/Na ratio is also characteristic of the non-rapakivitic diabases (Table 1), argillaceous hornfelses (Table 3) and granodiorite hornfelses (Table 4). Common to the hornfelses is the occurrence of their plagioclase almost exclusively in the intergranular matrix and its richness in the anorthite component, which means equilibration at very high temperatures. Under these conditions, sodium was probably ejected from the rock.

On the preceding pages, many analogies between the roof pendant rocks and the Subjotnian Dala volcanics formation in western Sweden have been noted. The Ruoholampi roof pendant rocks, especially the diabase and the porphyries, have also been correlated to the Subjotnian porphyrite and quartz porphyry lava(?) flows comagmatic with the rapakivi, on the island of Hogland in the Gulf on Finland, at the southern margin of the Wiborg rapakivi granite massif. There the early lava flows, porphyrites, extruded on top of the rocks of the orogenic (Svecokarelidic) complex. Ramsay (1890) interpreted the Hogland volcanic formation as a tectonical subsidence structure. In the present paper, the Ruoholampi roof pendant has been defined as a volcano-tectonical subsidence structure correlated to the rapakivi emplacement and large-scale ash flow eruptions.

The data at hand suggest that the roof of the Wiborg rapakivi granite massif consisted partly of rocks of the Svecokarelidic orogenic complex and partly of Subjotnian basic (diabases and plagioclase porphyrite lava flows) and acid (ignimbrite eruptions, comagmatic with rapakivi) volcanic rocks. It is possible that also Subjotnian arenaceous sediments (e.g., The Törölä quartizite) constituted part of the roof of the Wiborg rapakivi massif.

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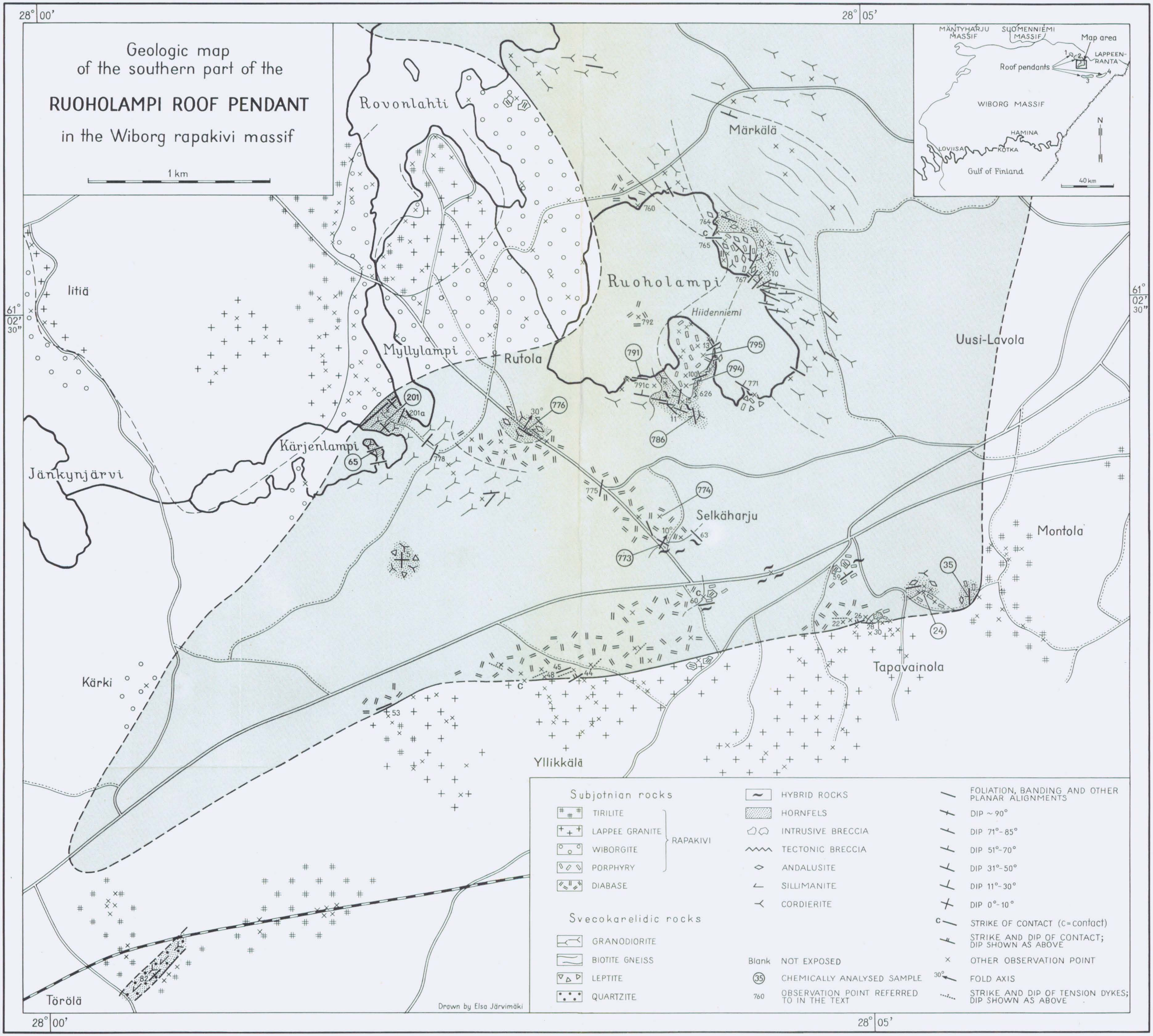

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