

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 725

AVHANDLINGAR OCH UPPSATSER

ARSBOK 70 NR 7

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KARL-AXEL KORNFÄLT

PETROLOGY OF THE  
RAGUNDA RAPAKIVI MASSIF,  
CENTRAL SWEDEN



STOCKHOLM 1976

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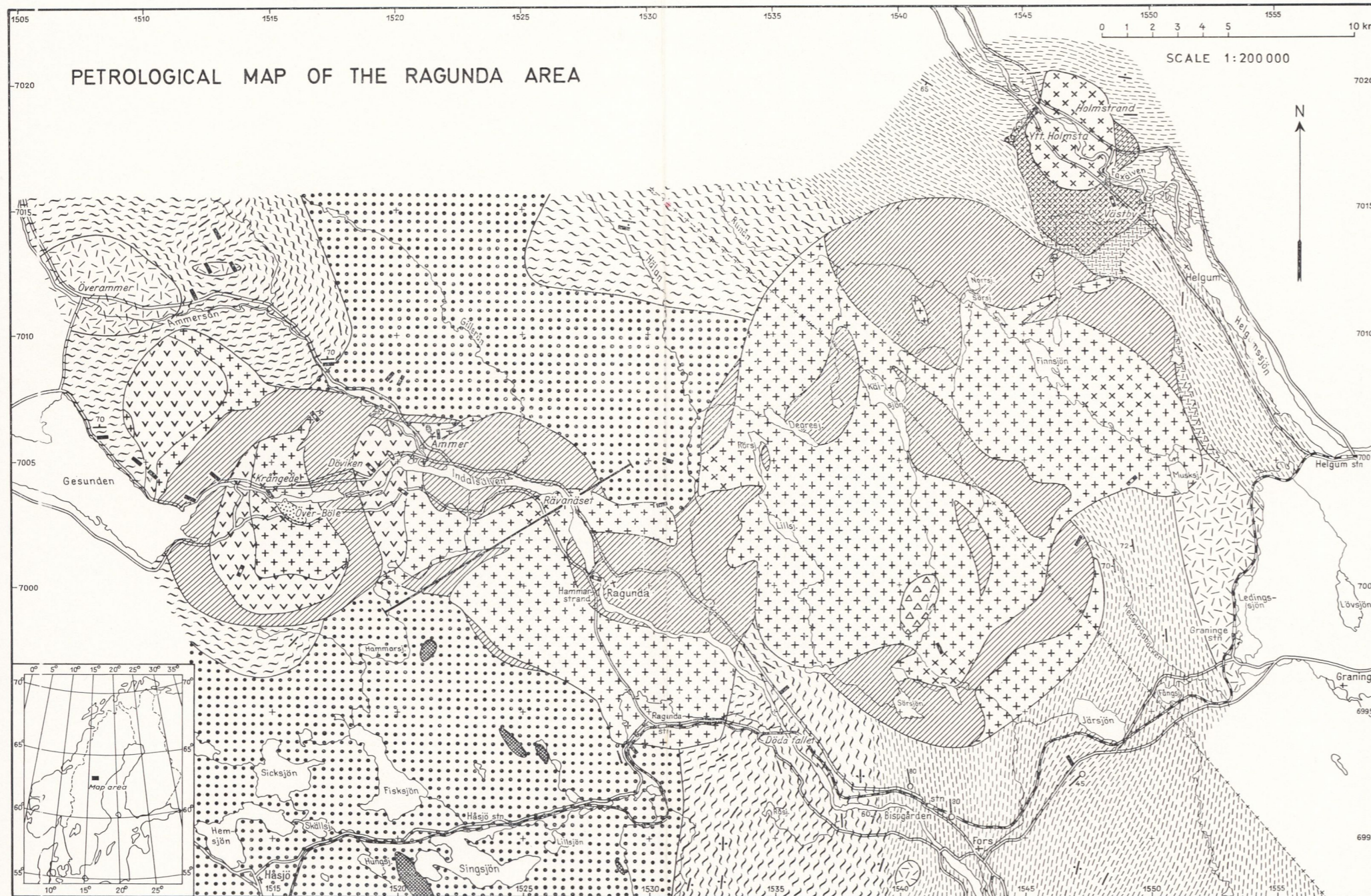
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ABSTRACT

The anorogenic Ragunda rapakivi massif comprises fayalite-bearing syenites and quartz syenites, hornblende granites, granite porphyry, medium- to coarse-grained biotite granites (Ragunda granite), fine-grained biotite granites and cutting acid or basic dikes. These rocks are younger than the anorthosite — gabbro — quartz gabbro, which also is included in the massif.

The anorthosite — gabbro — quartz gabbro complex was first emplaced into the older metasediments and granites. At a later date, c. 1 320 Ma ago, the intrusion of the syenite — quartz syenite — granite complex followed.

The syenite — quartz syenite — granite complex was intruded in two major magmatic pulses. The first, of quartz syenitic composition, fractionated after the emplacement to a slightly peralkaline residue which is reflected in the presence of the minerals arfvedsonite — riebeckite. The second intrusive phase, of granitic composition, crystallized at a lower temperature from a magma rich in volatiles.



**LEGEND**

- Dolerite
- 1 Basic dike. 2 Acid dike
- Biotite granite, fine-grained
- Biotite granite, medium- to coarse-grained (Ragunda granite)
- Granite porphyry
- Hornblende granite
- Syenite
- Holmsta granite
- Anorthositic gabbro
- Gabbro penetrated by Holmsta granite
- Gabbro penetrated by Ragunda granite
- Serorogenic to postorogenic granite, grey, with large phenocrysts (Revsund granite)
- Serorogenic granite (Härnö granite) and pegmatite, grey. (May have small phenocrysts)
- Metagreywacke penetrated by Holmsta granite
- Dikes of serorogenic granite and pegmatite in metagreywacke
- Migmatite derived from metagreywacke
- Metagreywacke, structurally well preserved
- Foliation with indicated dip
- Foliation with high dip (>85°)
- Foliation, vertical
- Foliation with unknown or variable dip
- Lineation
- Profile

Fig. 1. Petrological map of the Ragunda area. (Godkänd ur sekretessynpunkt för spridning. Statens lantmäteriverk 1977-01-17.)

## INTRODUCTION

A large complex of rapakivi-like rocks occurs in the area between Gesunden (a lake-like widening of the river Indalsälven) and the river Faxälven, on both sides of the boundary between the counties Jämtland and Västernorrland. The complex is known by the name of Ragunda, the most important parish in this region. The rocks of the massif are well exposed in the steep banks of the river valleys (Fig. 2), which are sometimes rather inaccessible. In between the rivers, however, the degree of exposure is lower. The amount of available information thus varies widely depending on accessibility and degree of exposure.

The rocks of the Ragunda massif consist of gabbro (which virtually always is penetrated by granite), syenite, hornblende granite, and biotite granite. There are also dikes of acid or basic composition cutting the massif and the surrounding rocks. Small amounts of alkali amphibole are often found in the syenite and the hornblende granite, but only a few rock samples are peralkaline.

The Ragunda massif is petrologically and tectonically comparable to the sub-Jotnian Nordingrå massif 100 km further east in Västernorrland County, as well as to the large rapakivi massifs in Finland and the Soviet Union (Savolathi 1956, p. 8).

According to a radiometric Rb-Sr dating (Welin, Lundqvist, and Kornfält, in prep.) the age of the Ragunda syenite and granite is  $1320 \pm 30$  Ma. The Ragunda massif is consequently much younger than the rapakivi granites of the Viborg massif in Finland, which have been attributed an age of approximately 1700 Ma (Kouvo 1964).

Rapakivi textures proper, i.e. potash feldspar mantled with plagioclase, occur only sporadically in the Ragunda granites. Also in other rapakivi occurrences, such as the Viborg massif, mantled potash feldspar is absent from many granite varieties. The term rapakivi granite has also been given a wider scope (Sahama 1945; Tuttle and Bowen 1958; Marmo 1962) and is now used by a majority of Fennoscandian and Russian geologists as a term to cover postorogenic or anorogenic granites of various types, which, regardless of potash feldspar mantling, have certain characteristic geochemical and mineralogical features in common.

Apart from texture these typical features include high K/Na proportions, low contents of Mg, very high Fe/Mg ratios in the mafic minerals, and fairly high contents of fluorine. Commonly, rapakivi potash feldspars display mixtures of monoclinic and triclinic structural states. They thus render more or less broad and diffuse, often mixed, 131 and  $131\bar{1}$  peaks in their X-ray diffractometer patterns (Kornfält 1969, p. 10; Vorma 1971, p. 42; Gorbatshev 1972, p. 225). Finally, it may be noted that rapakivi granites almost always associate with gabbros.



Fig. 2. Vättaberget and Kullstaberget, near Hammarstrand. View from the north. The picture illustrates the steep scarps along the river valleys. Here Indalsälven is to the left (east). To the right (west) the hills have gentle dip slopes, grading into a rather smooth plateau which extends to the next river valley. Photo K. A. Kornfält.

### EARLIER WORK

As early as 1847 Erdmann published a report on the gabbro breccia of the Ragunda area. He noted that dikes of granite cut the gabbro (called hypersthensfels by Erdmann) which consequently is the older rock. Erdmann thought that the granite dikes were associated with neighbouring large granite massifs. The granite was described as a medium-grained, occasionally fine-grained mixture of mainly red orthoclase and light grey quartz, some greyish white oligoclase, and a few mica flakes of blackish green colour. Erdmann also noted that the granite in the large neighbouring massifs is more coarse-grained, carries more mica and has an orthoclase of a redder colour.

Lundbohm (1893) gives a preliminary report of his observations on the rapakivi granites of Västernorrland County. In the Ragunda massif Lundbohm especially noticed its remarkable gabbro breccia and pointed out that the Ragunda "greenstone" seemed to occur in the central parts of the granite area and not at its edge, which was the case in the (Nordingrå) rapakivi massif of the coastal area. Because of the spatial relationship between the granite and the sandstone

Lundbohm believed the age of the Nordingrå massif to be post-Archaean.

A. G. Högbom (1893) published a rather detailed report on the rocks of the Ragunda massif. He noted the presence of augite-syenite and basic dikes, also calling attention to the similarity between the Ragunda massif, the Rödö massif, and the Coastal massif (later to be called the Nordingrå massif) on one hand and the Finnish rapakivi massifs on the other. Also Högbom pointed out that the Ragunda massif differs from the mentioned massifs by not having its basic rocks bound to the margins of the massif but occurring fortuitously. Högbom regarded the "greenstone" and the acid rocks as penecontemporaneous.

1894 saw the appearance of Högbom's description of the geology of Jämtland County accompanied by a map to the scale of 1 to 500 000. In this work, the Jämtland part of the Ragunda massif was described.

Lundbohm's description of the rocks of Västernorrland County, also this one with a map to the scale of 1 to 500 000, appeared in 1899. This map comprises the Västernorrland part of the Ragunda massif, which was named the Helgum massif by Lundbohm, who described it very cursorily.

The geology of the Ragunda region was discussed in greater detail by Högbom in a monograph (1899), where he undertook to show that the Ragunda massif was a laccolithic intrusion. Högbom further developed this hypothesis in a paper of 1909.

In 1962 the Geological Survey of Sweden commenced the mapping of the solid rocks of Jämtland County. The project is directed by P. H. Lundegårdh. In 1964 a remapping of the solid rocks began also in Västernorrland County where it is directed by Th. Lundqvist. Within the scope of these mapping programmes the present writer was in charge of the mapping of the Ragunda massif and its surrounding areas. The variation of triclinicity in potash feldspars from the Ragunda massif and the adjoining Revsund granites was also investigated and has been published previously (Kornfält 1969). In that paper it was demonstrated that the triclinic potash feldspar of the surrounding Revsund granite was converted into a strictly monoclinic variety in a rather wide contact zone around the Ragunda massif. This was ascribed to the heating caused by the intrusion of the Ragunda rapakivi rocks.

### METHODS OF INVESTIGATION

At the start of the field work only old maps to the scale of 1 to 100 000 were available as a topographical basis. In Västernorrland County aerial photos (1 to 30 000 scale) have also been used for plotting the geological data. Just after the end of the field work the new Topographic Map of Sweden (scale 1 to 50 000) started appearing and at present covers all of the Ragunda region.

In order to make the geological map included in this paper as adequate as possible, the Topographic Map has been used as a basis and all observations have been transferred there. It has thus been possible to use the Swedish National Coordinate System of the Topographic Map to describe the positions of geological localities. The chemical analyses given in this paper were made on rock samples of between 1 and 2 kg. The samples were obtained from fresh rock, mostly such found in abandoned quarries and road cuttings. Coordinate positions for all analysed samples are given in Table 1.

The chemical analyses of rocks, the microprobe analyses of minerals and the X-ray diffraction analyses of potash feldspars were made in the laboratories of the Geological Survey in Stockholm.

Normative minerals, Niggli values and ternary ratios were calculated using the BENORM computer program of the Survey.

Modal analyses have been made using Swift's automatic point counter. Some of the thin sections were stained in order to facilitate the identification of the feldspars. Microscopic determinations of plagioclase compositions, axial angles, etc. were made employing a Leitz 5-axis universal stage.

The refractive indices were determined in sodium light by the immersion method. The refractive indices of the immersion liquids were determined by a refractometer of Leitz-Jelley type.

The classification of the rocks is in accordance with the system worked out by Streckeisen (1967) and IUGS (1973).

In the petrographic descriptions the grain-size is given as follows:

coarse-grained	>5 mm
medium-grained	5—1 mm
fine-grained	1—0.05 mm
dense (aphanitic)	<0.05 mm

TABLE 1. Locations and descriptions of analysed samples.

Sample No.	SGU Lab. No.	Map quadrangle	Location <sup>1</sup>		Rock type
K 163a	010—253	Krångede SO	70003	15279	Fine-grained gabbro.
K 163b	010—254	do	do		Fine-grained quartz monzonite.
K 163c	010—255	do	do		Medium- to fine-grained quartz monzonite.
K 163d	010—256	do	do		Medium-grained, greyish red, porphyritic biotite granite penetrating the gabbro.
K 163e		do	do		Medium- to fine-grained, reddish grey biotite granite penetrating the gabbro.
K 163f		do	70005	15278	Fine-grained gabbro.
K 163g		do	do		Fine-grained quartz gabbro.
K 163h		do	70005	15279	Medium-grained, greyish red, porphyritic biotite granite. 2 m broad dike in gabbro.

<sup>1</sup> "Swedish National Coordinate System"

Sample No.	SGU Lab. No.	Map quadrangle	Location		Rock type
K 164a	010—257	do	70006	15256	Medium- to coarse-grained, flesh-red biotite granite from a blasting in the slalom slope.
K 164b	010—289	do	do		Medium- to coarse-grained, brownish red, granophyric biotite granite from a blasting in the slalom slope.
K 197	010—258	do	70035	15255	Medium- to coarse-grained, greenish grey hornblende granite.
K 209	010—259	Krångede SV	70039	15209	Medium-grained, pale-red biotite granite. Road cutting.
K 210	010—260	do	70038	15203	Aphanitic, bluish grey acid dike in quartz syenite. Road cutting.
K 229	010—261	do	70031	15187	Medium- to coarse-grained, greyish green alkali-feldspar quartz syenite. Road cutting.
K 239	010—262	do	70030	15175	Fine-grained quartz monzogabbro. Road cutting.
K 246		do	70031	15184	Fine-grained gabbro.
K 250	010—263	do	70026	15161	Fine-grained, pale-red granite. Road cutting.
K 251	010—264	do	70028	15154	Medium- to coarse-grained, reddish brown hornblende granite. Road cutting.
K 252		do	70028	15148	Medium- to coarse-grained, greenish grey alkali-feldspar hornblende granite. Road cutting.
K 259	010—7125	do	70011	15135	Medium- to coarse-grained, greyish green syenite.
K 309	010—7126	do	70038	15132	Medium- to coarse-grained, greyish brown quartz syenite.
K 320a	010—6664	Håsjö NO	69956	15277	Fine-grained, pale-red granite from the contact between Ragunda granite and Revsund granite.
K 320b	010—6665	do	do		Fine-grained, greyish red granite about 5 m from the contact between Ragunda granite and Revsund granite.
K 320c	010—6666	do	do		Medium- to coarse-grained, red, miarolitic biotite granite about 100 m from the contact between Ragunda granite and Revsund granite.
K 322		Håsjö NO	69938	15288	Fine-grained, brownish red, porphyritic biotite granite from the contact between Ragunda granite and Revsund granite.
K 336	010—6667	do	69940	15303	Medium-grained, light-red biotite granite. Old quarry.
K 391	010—265	do	69959	15299	Medium- to coarse-grained, pale-red biotite granite. Old quarry.
K 417a	010—266	Krångede SV	70036	15101	Medium-grained, greenish grey quartz syenite. Road cutting.
K 417b		do	70036	15102	Medium- to coarse-grained, greenish grey syenite. Road cutting.
K 429a		do	70035	15103	Medium- to fine-grained, brownish red, porphyritic biotite granite. Road cutting.
K 429b		do	do		Medium-grained, pale-red biotite granite. Road cutting.

Sample No.	SGU Lab. No.	Map quadrangle	Location		Rock type
K 430a	010—267	do	70032	15114	Fine-grained, dark grey, porphyritic basic dike in gabbro. Road cutting.
K 430b	010—268	do	do		Fine-grained quartz monzogabbro. Road cutting.
K 430c	010—269	do	do		Fine-grained gabbro. Road cutting.
K 431		do	70041	15128	Fine-grained quartz monzogabbro. Road cutting.
K 432	010—270	do	70043	15134	Medium- to fine-grained, greyish green alkali-feldspar quartz syenite. Road cutting.
K 454	010—7127	do	70055	15202	Medium- to fine-grained, dark greenish grey syenite.
K 463	010—271	do	70048	15190	Medium- to coarse-grained, greenish grey syenite.
K 470		do	70055	15163	Fine-grained, light greyish brown, porphyritic granite penetrating the gabbro.
K 473	010—7131	do	70068	15168	Greyish brown, microcrystalline quartz porphyry dike in biotite granite.
K 486		do	70068	15241	Fine-grained quartz monzogabbro.
K 492	010—272	do	70087	15236	Coarsely porphyritic, grey Revsund granite. Road cutting.
K 500	010—273	do	70059	15216	Medium-grained, light-red biotite granite. Old quarry.
K 524		Krångede SO	70051	15328	Medium-grained, faint greenish grey alkali-feldspar hornblende granite.
K 580	010—274	do	70026	15278	Medium-grained, pale-red, granophyric biotite granite. Old quarry.
K 582		do	70035	15322	Fine-grained quartz gabbro.
K 606		Krångede NO	69972	15401	Fine-grained, grey, porphyritic granite penetrating the gabbro.
K 615	010—7133	do	69976	15415	Fine-grained, dark grey, weakly porphyritic basic dike in biotite granite.
K 616	010—275	Krångede NO	69970	15419	Medium- to coarse-grained, reddish brown alkali-feldspar hornblende granite. Road cutting.
K 620	010—276	do	69993	15406	Fine-grained, brownish grey granite porphyry.
K 630	010—277	do	69984	15403	Fine-grained, red biotite granite. Dike cutting granite porphyry.
K 631a	010—278	do	69991	15415	Medium-grained, red, granophyric biotite granite with miarolitic cavities. Road cutting.
K 631b	010—279	do	do		Fine-grained, red, miarolitic granite. Road cutting.
K 634	010—280	Krångede SO	70003	15433	Fine-grained quartz gabbro. Road cutting.
K 698		Håsjö NO	69913	15389	Medium- to fine-grained, light grey Härnö granite.
K 760a		Krångede SV	70060	15080	Fine-grained, dark grey metagreywacke (paleosome). Road cutting.
K 760b	010—7134	do	do		Aphanitic, dark grey, porphyritic basic dike in migmatite. Road cutting.
K 762	010—281	do	70114	15074	Medium- to fine-grained, light grey Härnö granite.
K 828	010—282	do	70037	15148	Medium- to fine-grained, red, miarolitic biotite granite.

Sample No.	SGU Lab. No.	Map quadrangle	Location		Rock type
K 838		Graninge NV	69896	15542	Fine-grained, grey metagreywacke. Road cutting.
K 839a	010—283	Krångede SO	70004	15279	Aphanitic, grey quartz porphyry dike in gabbro. From the margin.
K 839b	010—284	do	do		Fine-grained, red quartz porphyry dike in gabbro.
K 939	010—6674	Håsjö NO	69976	15357	Medium-grained, greenish red biotite granite. Road cutting.
K 944	010—6675	Krångede SO	70040	15403	Medium- to coarse-grained, greyish red biotite granite. Road cutting.
Nr 30	010—290	do	70088	15386	Medium- to coarse-grained, flesh-red biotite granite. Road cutting.
Nr 46	010—7132	do	70041	15493	Microcrystalline, greyish brown quartz porphyry dike in biotite granite.
Nr 48	010—244	do	70128	15388	Fine-grained quartz gabbro.
Nr 53a	010—245	do	70070	15450	Medium- to coarse-grained, greyish brown, weakly porphyritic biotite granite. Road cutting.
Nr 53b	010—246	do	do		Medium- to coarse-grained, brownish red, weakly porphyritic biotite granite. Road cutting.
Nr 60		do	70127	15457	Medium- to fine-grained, dark grey anorthositic gabbro.
Nr 63a	010—6663	do	70146	15464	Coarsely porphyritic, reddish grey Holmsta granite with rounded phenocrysts. Road cutting.
Nr 63b	010—8797	Krångede SO	70146	15464	Fine-grained quartz gabbro. Road cutting.
Nr 64	010—247	do	70140	15464	Fine-grained quartz gabbro. Road cutting.
Nr 66	010—248	do	70131	15463	Medium-grained, pale-red, porphyritic biotite granite penetrating the gabbro.
Nr 90		do	70184	15431	Fine-grained, grey metagreywacke. Road cutting.
Nr 91a	010—249	do	70179	15456	Medium-grained, greenish grey quartz monzonite. Old quarry.
Nr 91b	010—250	do	do		Medium-grained, brownish red quartz monzonite. Old quarry.
Nr 93	010—7670	do	70178	15445	Coarsely porphyritic, grey Holmsta granite with rounded phenocrysts.
Nr 96	010—8798	do	70155	15484	Fine-grained quartz gabbro.
Nr 115	010—251	do	70071	15485	Medium-grained, greyish brown alkali-feldspar hornblende granite. Old quarry.
Nr 123	010—7130	Sollefteå SV	70127	15505	Fine- to medium-grained, greyish red granite porphyry dike in metagreywacke.
Nr 127	010—252	Krångede SO	70173	15494	Medium- to coarse-grained, light greenish grey anorthositic gabbro.
Nr 128		do	70202	15459	Fine-grained, grey metagreywacke from the contact with hornblende granite.
Nr 132	010—7128	do	70193	15479	Medium-grained, faintly reddish grey hornblende granite.
Nr 137	010—7129	do	70188	15485	Medium-grained, pale-red hornblende granite. Old quarry.

### THE ROCKS AROUND THE RAGUNDA MASSIF

The eastern part of the Ragunda massif is surrounded by structurally well-preserved metagreywackes and by migmatites of greywacke provenance. These rocks belong to the Svecofennian facies of the Svecokarelian evolution and have ages of c. 1 800—2 000 Ma (cf. Lundqvist 1973).

Associated with the migmatization is a serorogenic granite — called Härnö granite — which is accompanied by dikes and small massifs of pegmatite. The age of the Härnö granite is probably c. 1 800 Ma (Magnusson 1960, Welin and Blomqvist 1964).

After the intrusion of the Härnö granite, but before the emplacement of the anorogenic rocks of the Ragunda massif, the Revsund granite was intruded (Lundqvist 1968, p. 158; 1973, p. 5). This granite has an age of c. 1 785 Ma (Welin et al. 1971) and occurs particularly in the western part of the investigated area.

A very brief review of the petrography of the surrounding rocks is given here. These rocks will later on be treated in more detail in the planned Geological Survey descriptions of the solid rocks of Jämtland and Västernorrland Counties.

### METAGREYWACKE AND MIGMATITE

The easternmost part of the Ragunda massif is surrounded by grey, fine-grained, quartz-feldspar rich, low-grade metamorphic sediments, which, as a rule, have fairly high contents of mica. The following point-count analyses describe the mineral composition of some typical metagreywackes:

	K 760a	K 838	Nr 90	Nr 128
Quartz	27	47	44	16
Plagioclase (+ sec. sericite)	49	11	39	35
K-feldspar	—	11	—	23
Biotite	22	29	15	22
Chlorite	—	—	—	4
Muscovite	—	1	—	+
Apatite	2	1	1	+
Opagues	+	+	1	+
Zircon	+	+	+	+
% An in the plagioclase	35	30	35	10—16

— = not detected

+ = present in small quantities (<0.5%)



Fig. 3. Veined gneiss of sedimentary origin. South-east of Selsviken (70060 15080). Photo K. A. Kornfält.

Andalusite is often found in mica-rich layers. In the eastern parts of the area pegmatite dikes are rare. However, their frequency increases towards the west and, simultaneously, there is an increase of the grain-size of the metagreywacke as the rock passes into veined gneiss (Fig. 3).

In the veined gneisses there occur areas of stronger migmatization, where the paleosome is reduced to fragments in a metatect of granitic — granodioritic and pegmatitic composition (Fig. 4). The latter migmatite-type is predominant in the westernmost parts of the investigated area. The granitic (and/or pegmatitic) metatect may accumulate in places, forming small massifs of homogeneous, medium- to fine-grained, grey granite. In the westernmost parts of the investigated area small, well circumscribed massifs of pegmatite are also found.

#### HÄRNÖ GRANITE

As mentioned before, dikes and small massifs of homogeneous or locally foliated, fine- to medium-grained, greyish white Härnö granite occur in the migmatized areas. This granite is in most cases accompanied by numerous dikes of grey pegmatite.



Fig. 4. Strongly migmatized sedimentary gneiss. Marsand (70058 15088). Photo K. A. Kornfält.

North-west of Graninge there are a few outcrops of porphyritic Härnö granite. This variety carries rectangular megacrysts up to 1 cm in size and is richer in potash feldspar than the analysed samples quoted below.

The main minerals of the Härnö granite are plagioclase (oligoclase) and quartz. The granite also contains microcline perthite, reddish brown biotite, and muscovite. Accessories are apatite, chlorite, zircon, garnet, and opaque minerals. The plagioclase has partly altered to sericite. Myrmekitic intergrowths of plagioclase and quartz are found occasionally. Chlorite has formed by alteration of biotite.

The following two point-count analyses give the mineral compositions in a small massif (K 762) and a dike (> 2 m wide) in metagreywacke (K 698). A chemical analysis of sample K 762 is given in Table 2.

	K 698	K 762
Quartz	38	31
Plagioclase (+ sec. sericite)	27	43
Microcline	22	17
Biotite	11	7
Muscovite	2	1
Apatite, chlorite, zircon, opaques	1	1
% An in the plagioclase	15—18	20—25

TABLE 2. Chemical analysis and CIPW norm of Härnö granite, sample no. K 762.  
(For sample location, see Table 1.)

Major elements (weight %)		Chemical analysis		Minor elements (ppm)		Normative minerals (weight %)	
SiO <sub>2</sub>	72.4	Zr	100	Quartz	30.2		
TiO <sub>2</sub>	0.34	Sr	130	Corundum	1.9		
Al <sub>2</sub> O <sub>3</sub>	14.7	BaO	670	Orthoclase	23.3		
Fe <sub>2</sub> O <sub>3</sub>	0.5	Rb	170	Albite	30.0		
FeO	1.9			Anorthite	6.8		
MnO	0.04			Enstatite	2.2		
MgO	0.9			Ferrosilite	2.6		
CaO	1.6			Magnetite	0.7		
Na <sub>2</sub> O	3.6			Ilmenite	0.6		
K <sub>2</sub> O	4.0			Apatite	0.2		
H <sub>2</sub> O > 105°	1.1			Fluorite	0.2		
H <sub>2</sub> O < 105°	0.2					Total	98.7
P <sub>2</sub> O <sub>5</sub>	0.09						
F	0.09						
Total	101.5						

The metagreywacke, which surrounds the easternmost parts of the Ragunda massif, is rather well-preserved and shows no indications of serogenic migmatization. In this migmatite-free area, there is nevertheless a massif of serogenic porphyritic granite. It may derive from granitic material accumulated by the migmatization of neighbouring areas. Because of its mobility this granitic material was later able to intrude the higher-level, well-preserved metagreywacke (cf. Lundqvist 1968, p. 66).

### REVSUND GRANITE

The Revsund granite of the Ragunda region is usually grey and coarse-grained. It carries up to 5 cm large megacrysts of microcline set in a matrix of quartz, plagioclase (oligoclase), microcline, and biotite. Sometimes the granite also contains garnet and hornblende.

The Revsund granite is as a rule quite massive, but in the south-westernmost part of the mapped area (where there are also numerous small inclusions of supracrustals) there occur varieties with parallel-orientated microcline (Fig. 5). Part of these can possibly be considered as recrystallized older rocks. Varieties with dark, biotite-rich streaks are also found here (Fig. 6).

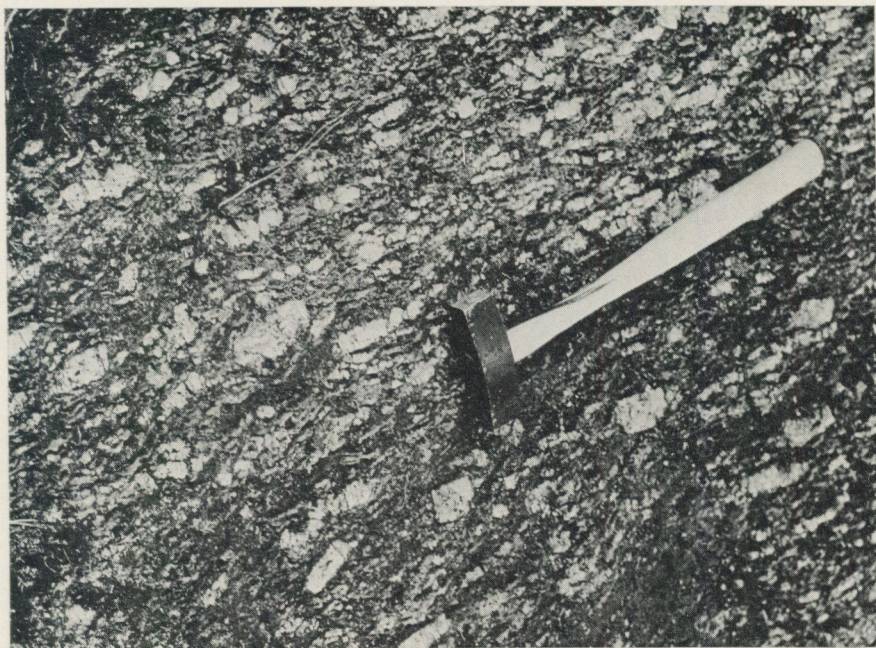


Fig. 5. Granodioritic rock with parallel-orientated microcline megacrysts in the Revsund granite terrain south of the Ragunda massif. The texture is possibly inherited from rocks older than the Revsund granite. Dårdimyrberget (69955 15132). Photo K. A. Kornfält.

The microcline megacrysts of the Revsund granite are strongly perthitic and carry inclusions of plagioclase, quartz, and biotite. The quartz of the matrix always shows undulatory extinction. Generally, the plagioclase is zoned. The biotite has sometimes altered to chlorite or prehnite. Chemical analyses of the Revsund granites are given in Table 3.

The microcline of the Revsund granite situated closest to the Ragunda rapakivi rocks has been converted into orthoclase in a rather wide zone (Kornfält 1969). In a zone varying between one and five metres in thickness and situated closest to the contacts of the Ragunda rocks, the orthoclase of the Revsund granite exhibits red colour.



## THE HOLMSTA GRANITE

A reddish grey, megacryst-bearing granite occurs near Holmsta, in the north-easternmost part of the Ragunda massif. The megacrysts consist of potash feldspar and are more or less rounded. They most frequently measure between 1 and 3 cm in diameter, are grey or light red in colour and are often surrounded by mantles of white plagioclase. The matrix is grey and medium-grained. Sometimes there is a weak structure which is due to the parallel alignment of potash feldspar megacrysts.

This granite variety is mentioned in the description to the geological map of Västernorrland County, where Lundbohm (1899, p. 25) compares it to granites occurring in the northernmost parts of Västernorrland, i.e. the kind of rock which today is called Revsund granite (p. 16). The Holmsta granite, indeed, reminds a little of certain varieties of Revsund granite, but macroscopically it most of all looks like the Råtan granite farther south (Lundqvist 1968, pp. 69—76).

The Holmsta granite generally occurs as dikes and small massifs in the Ra-



Fig. 7. Holmsta granite brecciating the Ragunda gabbro. Uthammarsberget (70154 15483). Photo K. A. Kornfält.

TABLE 4. Chemical analyses and CIPW norms of Holmsta granite. (For sample locations, see Table 1.)

Major elements (weight %)	Chemical analyses				Normative minerals (weight %)			
	Minor elements (ppm)							
	Nr 63a	Nr 93	Nr 63a	Nr 93				
SiO <sub>2</sub>	67.5	73.0	Zr	270	230	q	24.3	34.0
TiO <sub>2</sub>	0.55	0.46	Sr	150	100	c	1.5	1.9
Al <sub>2</sub> O <sub>3</sub>	15.4	13.3	BaO	510	350	or	25.6	25.9
Fe <sub>2</sub> O <sub>3</sub>	1.1	0.9	Rb	150	220	ab	29.0	26.2
FeO	2.6	2.3				an	10.2	4.2
MnO	0.05	0.04				en	2.5	1.5
MgO	1.0	0.60				fs	3.0	2.7
CaO	2.3	1.2				mt	1.6	1.3
Na <sub>2</sub> O	3.4	3.1				il	1.1	0.9
K <sub>2</sub> O	4.3	4.4				ap	0.3	0.1
H <sub>2</sub> O > 105° C	0.6	0.6				fr	0.1	0.3
H <sub>2</sub> O < 105° C	0.05	0.2				pr	0.1	0.4
P <sub>2</sub> O <sub>5</sub>	0.11	0.09				cc	0.1	0.2
CO <sub>2</sub>	0.04	0.01				Total	99.4	99.6
F	0.07	0.17						
S	0.03	0.02						
Total	99.1	100.4						

gunda gabbro and in the metagreywacke (Fig. 7). Only one massif, c. 1 km W.S.W. of Ytt. Holmsta, is large enough to be shown on the present small-scale map (Fig. 1).

The variety of Holmsta granite, which penetrates the gabbro in the shape of dikes, is generally reddish grey and as a rule has rounded, often mantled megacrysts, whereas the massif-building Holmsta granite is usually grey and rarely has mantled large feldspars. The Holmsta granite consists of potash feldspar (30—40%), quartz (25—35%), plagioclase (20—25%), and biotite (5—10%). Hornblende is sometimes found in the dike-forming variety. Other minerals are chlorite, epidote, apatite, muscovite, fluorite, sphene, zircon, calcite, and opaqués.

Chemical analyses of the Holmsta granite are given in Table 4.

The potash feldspars of two samples were investigated as to the variation of their triclinicity. In one of the samples, derived from a Holmsta granite penetrating the gabbro (Nr 63a), the triclinicity was determined as  $\Delta = 0.71$ . However, the X-ray diffractograms show rather diffuse peaks. In the other sample (Nr 93), which stems from the only large massif of fairly homogeneous Holmsta granite, the X-ray diffractogram shows very diffuse peaks without any maximum (cf. Kornfält 1969, p. 11, 3 b). These results indicate a mixture of monoclinic and triclinic structural states with a predominance of triclinic feldspar in Nr 63a.

The potash feldspar of the Holmsta granite is slightly pigmented in reddish brown tints. In sample Nr 63a there is a cross-hatch-twinned microcline containing clear untwinned patches (cf. Lundqvist 1973, p. 18). Also clear potash feldspars with weakly discernible cross-hatched patches can be found (cf. Kornfält 1969, Fig. 7). In sample Nr 93 the potash feldspar is generally perthitic. The perthite grains are of patch perthite and vein perthite types (Andersen 1928). Occasional patches with cross-hatch-twinning occur in some of the potash feldspars. The biotite is reddish brown and sometimes shows alteration to chlorite. There are numerous inclusions of zircon and apatite. Plagioclase (c.  $An_{20-30}$ ), which is occasionally zoned, occurs in the matrix as well as in the shape of phenocrysts.

Together with the described rather homogeneous Holmsta granite occur hybrid rocks, which have been interpreted as metasomatically altered gabbro. These hybrid rocks have compositions varying between granite and gabbro. Most of them are monzonitic and occasionally contain more or less sharp-edged fragments of fresh gabbro.

Approximately 1 km S.W. of Ytt. Holmsta (70173 15452), just at the border between the quartz gabbro and the hornblende-bearing rapakivi granite, the

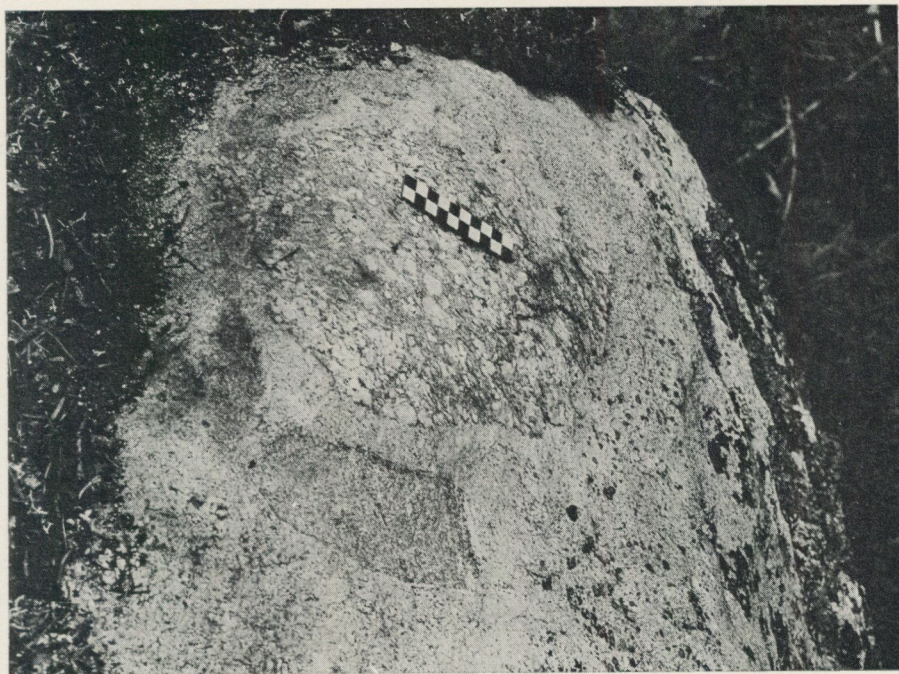


Fig. 8. Xenoliths of Holmsta granite (at the top) and gabbro (at the bottom) in hornblende granite. S. W. of Ytt. Holmsta (70173 15452). Photo K. A. Kornfält.

latter contains xenoliths of Holmsta granite and of gabbro, which have in part suffered from metasomatal alteration (Fig. 8). From this observation it is obvious that the Holmsta granite is older than the hornblende-bearing rapakivi granite.

The Holmsta granite does not belong to the rapakivi granite suite, which is clear from the chemical differences between the two granites (cf. Fig. 44). However, the chemical composition of the Holmsta granite is comparable to those of the analysed Härnö and Revsund granites of the mapped area. From Fig. 45 it is evident that also the Rätan granite of the Los-Hamra region is chemically comparable to the Holmsta granite.

The potash feldspars of the Holmsta granite with their cross-hatch-twinned patches are quite different from the potash feldspars of the Ragunda rapakivi rocks, which hardly ever have that kind of twinning.

As already mentioned, the Holmsta granite exhibits both macroscopical and chemical similarities to the early post-orogenic (Lundqvist 1968, p. 158 ff.) Rätan granite, which, however, is not found anywhere close to the Ragunda massif. There are, however, both Härnö and Revsund granites (cf. Map, Fig. 1) in the immediate surroundings of the Ragunda massif. Not far from the Holmsta granite there is thus a small area of porphyritic Härnö granite (p. 14) bordering on the Ragunda massif. This Härnö granite perhaps had a somewhat greater extent prior to the intrusion of the Ragunda rocks.

Because of its different appearance the Holmsta granite cannot be grouped together with the established serorogenic rock types of the area. The most similar known rock in appearance is the Rätan granite, which, however, does not occur in this region. The Holmsta granite is older than the rapakivi granite but younger than the gabbro and thus younger than the serorogenic granites (cf. however, the field observation mentioned on p. 84). As the Holmsta granite chemically is comparable to the adjacent serorogenic granites it is thought to be a recrystallized and mobilized serorogenic granite formed in connection with the intrusions of the rapakivi rocks (cf. p. 99).

As mentioned above, the gabbro has more than the metagreywacke been subject to metasomatic alterations associated with the intrusion of the Holmsta granite. This can possibly be explained by the circumstance that the gabbro has been more mechanically competent and thus ruptured more easily than the metagreywacke, thereby providing greater possibilities for granite penetration and attendant metasomatal alteration. The Holmsta granite invading the metagreywacke seems to have intruded mainly along its schistosity planes. Consequently, the metagreywacke is not as strongly fractured by the granite as the gabbro. Apart from that, the metagreywacke is less competent because of its relatively high contents of mica. In the metagreywacke area the Holmsta granite forms larger homogeneous areas alternating with larger areas of apparently relatively unaltered metagreywacke.

## THE ROCKS OF THE RAGUNDA MASSIF

The Ragunda massif is composed of the following rocks:

- Anorthositic gabbro (oldest)
- Gabbro—quartz gabbro
- Syenite—quartz syenite
- Hornblende granite
- Granite porphyry
- Medium- to coarse-grained biotite granite (Ragunda granite)
- Fine-grained biotite granite
- Acid and basic dikes (youngest)

A classification of the rocks of the Ragunda massif according to modal mineral content (IUGS 1973) is given in Fig. 9. In accordance with this system perthite falls into mineral group A (= alkali feldspars). It is then presumed that the sodium phase of the perthite corresponds to albite  $An_{00-05}$ . This is probably the case in the Ragunda rapakivi rocks, at least as far as film, string and vein perthite (Andersen 1928) are concerned. In the patch perthite (op. cit.) the An content of the patches usually exceeds 5%. Consequently, patches of plagioclase in the potash feldspars (in part constituting perthite) have in the present paper been grouped into P (= plagioclase  $An_{05-100}$ ; cf. IUGS 1973).

The borderlines between the rocks of the Ragunda massif as drawn on the map (Fig. 1) must be looked upon as more or less summaric generalizations, because the rocks in fact grade into each other in most cases. The quartz content of the granites and syenites is somewhat variable. Furthermore, the hornblende content varies. Therefore, it is possible that within the biotite granites there are minor areas which petrographically ought to be designated as syenite or hornblende granite. Likewise, the syenite may contain minor areas with the quartz content of a granite. The gabbro is mostly brecciated by granite and, in certain cases, it has been difficult to decide whether the granite or the gabbro is the predominating rock.

The syenite—quartz syenite is younger than the gabbro—anorthosite complex, as xenoliths of the latter are found in the syenite (e.g. at the Krångede power station). Dikes of syenite occur in the gabbro but are extremely rare, even in areas where gabbro borders on syenite.

Well-defined dikes of medium-grained Ragunda biotite granite are never found in the syenite. The syenite is, however, intersected by fine-grained dikes of a type associated with the granites, and therefore the granite is supposed to be younger than the syenite.

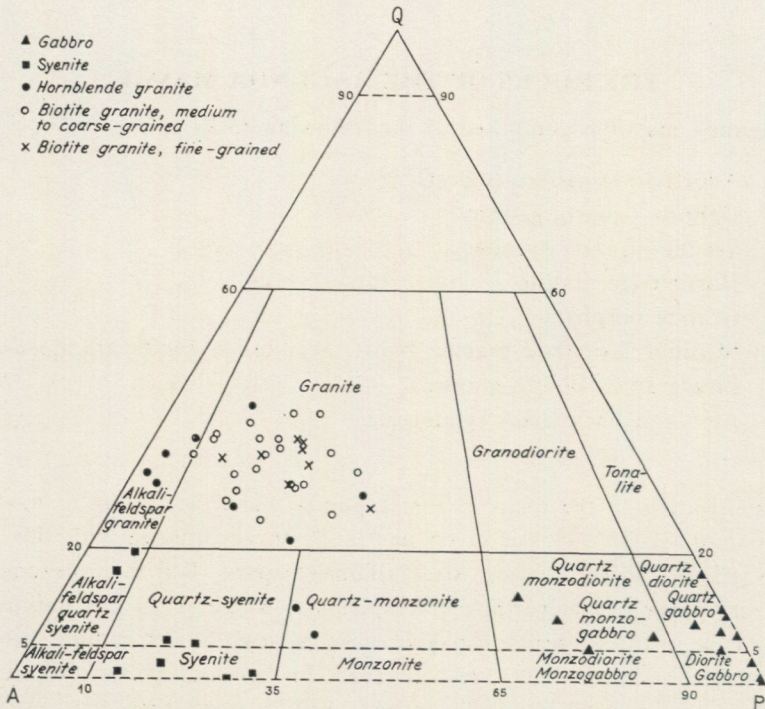


Fig. 9. Modal classification of the rocks from the Ragunda rapakivi massif according to IUGS (1973). The rock designations used in the key to the signs are assigned to those of the map in Fig. 1.

The granite porphyry is found as xenoliths within the Ragunda biotite granite (Fig. 27), and for this reason it must be older than the granite.

The hornblende granite at Holmstrand in the north-eastern part of the mapped area forms an isolated massif without any field relations to the syenite or biotite granite of the main massif further to the west.

The small massifs of hornblende granite within the Ragunda biotite granite have very diffuse contacts with the latter. It is thus impossible to determine the age of the hornblende granite in relation to the biotite granite and syenite by means of field observations.

The contact relations between the fine-grained granite and the biotite granite are a little confusing. There are xenoliths of the fine-grained biotite granite in the medium-grained Ragunda granite indicating the existence of an earlier and more rapidly crystallized variety of the biotite granite. On the other hand, there are varieties of the fine-grained granite — often miarolitic — which seem to be younger than the Ragunda granite (cf. p. 65).

The observed contact relations between the Ragunda massif and the older rocks are treated on page 83.

ANORTHOSITIC GABBRO

In the north-eastern part of the Ragunda massif, near Gagnet (70173 15494), there is a small isolated outcrop consisting of a gabbro variety which macroscopically differs from the common quartz gabbro by larger grain-size, and microscopically, among other things, by higher plagioclase content. In the present paper this gabbro variety has been designated as anorthositic gabbro (cf. Buddington 1939, p. 19). Anorthositic gabbro also occurs at some other places c. 6 km S.W. of Gagnet (70127 15457). The latter outcrops have been described by Lundbohm in the description to the geological map of Västernorrland County (1899, p. 26) as a coarse-grained variety of "greenstone". At the locality mentioned the anorthositic gabbro occurs in smaller areas (c. 10 sq. metres) within the normal gabbro, without any sharp contacts between the two rocks.

The anorthositic gabbro is light grey or bluish grey, with a grain-size varying between medium-grained and coarse-grained.

TABLE 5. Chemical analysis, CIPW norm, and atomic ratios of anorthositic gabbro, sample no. Nr 127.  
(For sample location, see Table 1.)

Chemical analysis		Minor elements		Normative minerals	
Major elements (weight %)		(ppm)		(weight %)	
SiO <sub>2</sub>	52.8	V	140	Orthoclase	4.1
TiO <sub>2</sub>	0.68	Cr	290	Albite	29.3
Al <sub>2</sub> O <sub>3</sub>	20.3	Co	50	Anorthite	37.2
Fe <sub>2</sub> O <sub>3</sub>	1.0	Ni	200	Diopside	4.5
FeO	5.3	Zr	< 100	Hypersthene	19.2
MnO	0.09	Sr	780	Forsterite	0.7
MgO	6.1	BaO	250	Fayalite	0.4
CaO	8.8			Magnetite	1.4
Na <sub>2</sub> O	3.5			Ilmenite	1.3
K <sub>2</sub> O	0.7			Apatite	0.1
H <sub>2</sub> O > 105°	1.5			Total	98.2
H <sub>2</sub> O < 105°	0.2				
P <sub>2</sub> O <sub>5</sub>	0.05				
F	0.02				
Total	101.0				
-O for F	0.01				
Corr. sum	101.0				

Atomic ratios

Fe/Mg	0.57
Mg/Mg+Fe	0.64
K/K+Na	0.12
Ca/Ca+Na	0.58

TABLE 6. Some geochemical data for anorthositic gabbro compared with gabbro. (The data are taken from Tables 5, 7, 8 and 23.)

	Anorthositic gabbro Nr 127	Gabbro (average of 8 analyses)
Fe/Mg	0.57	1.05
(Or+ab)/an	0.90	1.84
Fe/Mg in olivine	0.49	0.80 (sample K 582)
% An in plagioclase	51—66	21—61
V (ppm)	140	236
Cr (ppm)	290	67
Ni (ppm)	200	46
BaO (ppm)	250	596

Main mineral in the anorthositic gabbro is plagioclase ( $An_{51-66}$ ), forming c. 60—75 % of the rock. The plagioclase grains, a minor part of which are weakly zoned, may reach a length up to 1 cm. Weakly curved albite twins are occasionally met with.

Clinopyroxene ( $2V_{\gamma} = 44^{\circ}$ ,  $c \wedge \gamma = 40^{\circ}$ ) and amphibole (uralite) are the essential mafic minerals, usually developed as 2—4 mm large crystals. Olivine ( $Fe_{67}Fa_{33}$ , Table 23, p. 104), biotite, opaque minerals, and apatite occur in subordinate amounts. The pyroxene is frequently altered to amphibole and chlorite. The olivine has partially altered to serpentine and talc. A chemical analysis of anorthositic gabbro is given in Table 5.

The biotite granite of the Ahvenisto massif (in Finland) is to a great extent surrounded by an arc of gabbro—*anorthosites* (Savolahti 1956). These rocks are built up of several different intrusions, each with a differentiation series of rocks ranging from *anorthosites* via gabbro—*anorthosites* to albite diabases. The differentiation is supposed to have taken place subsequent to the intrusion stage (op. cit., p. 180).

Anorthosite also occurs in the Nordingrå massif (Sobral 1913), another large rapakivi massif in Sweden. Von Eckermann (1938) supposed, on account of structural reasons, that the anorthosite in Nordingrå was formed by gravitative accumulation of early rising plagioclase crystals in a gabbroid magma.

In the Ragunda massif it has been impossible from field observations to decide if the anorthositic gabbro is older or younger than the surrounding gabbro. It is, however, possible to determine the crystallization sequence of the mentioned rocks by use of fractionation indices such as Fe/Mg and (or+ab)/an.

It is thus clear from Table 6 that the ratios Fe/Mg and (or+ab)/an increase in direction from anorthositic gabbro to gabbro (cf. also Fig. 46). This is consistent with the observed chemical trend in successive crystalline fractions of stratified plutons, e.g. the Skaergaard intrusion (Carmichael et al. 1974, p. 485).

The increase of the ratios Fe/Mg in olivine and Na/Ca in plagioclase from anorthositic gabbro to gabbro (Table 6) are consistent with the data of laboratory experiments during a fractionation process (op. cit.).

Also the variation in trace-element concentrations (Table 6) follows the solidification (fractionation) trend reported from e.g. the Skaergaard intrusion (Wager and Brown 1967, p. 190 ff.).

There are thus strong chemical evidences indicating that the anorthositic gabbro of the Ragunda massif was formed earlier than the "common" gabbro during the differentiation processes, which took place in the primary basic magma.

### GABBRO—QUARTZ GABBRO

The gabbro of the Ragunda massif is fine-grained. It is grey in colour and contains occasionally white, in part sericitized, megacrysts of plagioclase which are 2—4 mm in size (maximum 1 cm). Coarser, fine medium-grained, black and white speckled, diorite-like gabbro varieties are also met with.

The gabbro is always more or less brecciated and penetrated by granite, and where these intrusions are abundant, monzonitic rocks have been formed (see p. 34 ff.). The penetrating granite is mostly Ragunda granite or aplite. The gabbro in the north-eastern part of the massif is, however, brecciated by Holmsta granite (Fig. 7). This granite has not been able to transform the brecciated gabbro into more acid rocks in the same way as the Ragunda granite.

The Ragunda gabbro was described by A. Erdmann (1847), who called it "hypersthenfels". Lundbohm described it as "greenstone" (Lundbohm 1899). Högbom (1893, 1894, 1899) used the designation diabase for this rock, but notes that "the rocks only as an exception and less perfectly have a true diabase texture"<sup>1</sup> (Högbom 1893, p. 215). In the revised second edition of the description of the geological map of Jämtland County (1920), Högbom instead used the designation "diabase-like gabbro". In the description to accompany the map of the Pre-Quaternary rocks of Sweden (Magnusson et al. 1960) this rock is called a gabbroic quartz-diabase (op. cit., p. 63).

It is true that the fine-grained Ragunda gabbro macroscopically often gives the impression of a diabase-like, ophitic texture. In the microscope, however, it appears that the rock does not have a typical ophitic texture according to the definition of Krokström (1932). The plagioclase occurs partly as rather

<sup>1</sup> translated by the author

TABLE 7. Modal analyses (volume percent) of Ragunda gabbros, quartz gabbros, and quartz monzogabbros.  
(For sample locations and rock types, see Table 1.)

	K 163f	K 163g	K 239*	K 246	K 430b*	K 430c*	K 431	K 486	K 582	K 634*	Nr 48*	Nr 63b	Nr 64*	Nr 96
K-feldspar (perthitic)	—	—	12	—	7	—	14	16	2	—	3	+	1	—
Quartz	2	4	3	—	4	+	6	8	3	5	5	9	4	6
Plagioclase + secondary sericite and epidote	53	50	43	48	48	42	42	37	53	43	49	44	45	51
Olivine	—	—	—	—	—	—	—	—	+	—	—	—	—	—
Pyroxene	21	20	16	20	10	22	9	8	18	+	17	13	9	21
Amphibole	9	8	11	3	8	1	16	20	9	31	1	11	15	2
Biotite	11	14	10	21	19	29	7	5	6	6	15	16	19	17
Epidote	—	—	—	—	+	—	+	—	—	+	—	—	+	+
Iddingsite	—	—	—	—	—	—	—	—	+	—	—	—	—	—
Chlorite	2	—	+	1	+	+	+	2	1	5	5	+	3	+
Zircon	—	—	—	—	—	—	—	+	—	—	—	+	+	+
Apatite	+	2	2	1	+	1	—	1	1	2	1	3	1	2
Calcite	—	—	+	—	+	—	—	—	—	—	—	—	—	—
Opaque minerals	1	2	3	6	3	4	5	2	5	7	4	3	2	1
% An in the plagioclase	22—68	25—60	21—58	22—74	26—66	20—64	18—60	20—55	25—62	18—49	20—65	20—64	20—53	20—57

\* = chemically analysed sample

— = not detected

+ = present in small quantities (<0.5 %)

TABLE 8. Chemical analyses, CIPW norms, and atomic ratios of gabbros, quartz gabbros, and quartz monzogabbros.  
(For sample locations and rock types, see Table 1.)

Sample no	K 239	K 430b	K 430c	K 634	Nr 48	Nr 63b	Nr 64	Nr 96
Chemical analyses (weight %)								
SiO <sub>2</sub>	55.4	52.3	51.6	55.0	53.3	54.2	54.2	53.2
TiO <sub>2</sub>	1.10	1.55	1.39	1.28	1.40	1.7	1.85	1.6
Al <sub>2</sub> O <sub>3</sub>	16.3	16.3	16.5	15.3	16.7	15.4	15.6	16.4
Fe <sub>2</sub> O <sub>3</sub>	2.4	2.9	3.1	2.5	3.1	1.8	3.0	1.4
FeO	6.2	8.0	7.7	6.9	6.6	7.7	7.9	7.7
MnO	0.13	0.14	0.14	0.15	0.14	0.14	0.13	0.13
MgO	5.3	5.1	5.7	5.2	5.3	4.7	4.5	5.6
CaO	7.5	7.8	7.9	8.0	7.1	7.8	7.0	7.8
Na <sub>2</sub> O	3.6	3.7	3.6	3.3	3.3	3.8	3.8	3.7
K <sub>2</sub> O	2.0	1.8	1.5	1.8	1.5	1.7	2.1	1.6
H <sub>2</sub> O > 105° C	1.3	1.5	1.8	1.6	2.1	1.1	1.5	0.8
H <sub>2</sub> O < 105° C	0.2	0.2	0.2	0.2	0.3	0.1	0.2	0.1
P <sub>2</sub> O <sub>5</sub>	0.18	0.23	0.20	0.20	0.20	0.21	0.32	0.24
F	n.d.	0.07	n.d.	n.d.	n.d.	0.06	n.d.	0.06
Total	101.6	101.6	101.4	101.4	101.0	100.4	102.1	100.3
-O for F	—	0.03	—	—	—	0.03	—	0.03
Corr. sum	101.6	101.6	101.4	101.4	101.0	100.4	102.1	100.3
Minor elements (ppm)								
V	200	280	300	410	190	120	280	110
Cr	100	40	60	40	50	70	20	155
Co	30	50	50	50	40	30	40	30
Ni	40	30	50	10	70	40	40	90
Sr	490	660	700	580	600	480	490	700
BaO	560	840	770	620	530	400	550	500
Normative minerals (weight %)								
Quartz	2.7	—	—	4.1	4.0	1.8	1.9	—
Orthoclase	11.6	10.5	9.3	10.5	8.8	10.0	12.1	9.4
Albite	30.0	30.8	30.0	27.5	27.6	32.0	31.5	31.2
Anorthite	22.0	22.2	23.8	21.3	26.0	19.8	18.9	23.3
Diopside	11.0	11.6	11.2	13.6	6.2	13.7	10.8	10.9
Hypersthene	15.3	12.5	11.6	14.8	17.5	14.8	14.7	16.9
Forsterite	—	1.6	2.6	—	—	—	—	0.8
Fayalite	—	1.4	2.0	—	—	—	—	0.7
Magnetite	3.4	4.1	4.4	3.6	4.4	2.6	4.3	2.0
Ilmenite	2.1	2.9	2.6	2.4	2.6	3.2	3.4	3.0
Apatite	0.4	0.5	0.5	0.5	0.5	0.5	0.7	0.6
Fluorite	—	0.1	—	—	—	0.1	—	0.1
Total	98.5	98.2	98.0	98.2	97.6	98.5	98.3	98.9
Atomic ratios								
Fe/Mg	0.88	1.17	1.03	0.99	0.99	1.11	1.32	0.90
Mg/Mg+Fe	0.53	0.46	0.49	0.50	0.50	0.47	0.43	0.53
K/K+Na	0.27	0.24	0.23	0.26	0.23	0.23	0.27	0.22
Ca/Ca+Na	0.53	0.54	0.55	0.57	0.54	0.53	0.50	0.54

short laths, partly as more rounded grains. The pyroxene crystals are small, sometimes subhedral and do not enclose the plagioclase. The most appropriate term for this texture would be sub-doleritic to doleritic (Krokström, *op. cit.*).

Table 7 gives the mineral compositions of a number of gabbros. Olivine occurs only in one thin section. The chemical analyses show normative olivine in two samples (Table 8). According to the IUGS (1973) system of classification most of the modal analyses fall into the gabbro—diorite or quartz gabbro—quartz diorite fields (Fig. 9). The potash feldspar-bearing gabbros (K 239, K 430b, K 431, and K 486) are exceptions and fall into the quartz monzogabbro—quartz monzodiorite field.

Now the question presents itself if the Ragunda gabbro actually should be designated as a gabbro and not as a diorite. An anorthite content above 50 percent is common for gabbros, and the figure of 50 percent is proposed by Streckeisen (1967, p. 171) as a limit between gabbro and diorite. As far as the plagioclase of the Ragunda gabbro is concerned the anorthite content usually exceeds 50 percent. The composition of the mafic minerals with both ortho- and clinopyroxene are also typical of gabbros. Olivine, which is a typical mineral in many gabbros, occurs only sporadically in the Ragunda gabbros. The basic rock of the Ragunda massif should on the basis of the mentioned criteria, chiefly the anorthite content of the plagioclases, be termed gabbro and quartz gabbro, respectively (Streckeisen 1967; IUGS 1973).

In general the plagioclase forms crystals measuring 1—2 mm in length (maximum 3 mm). A few are rounded but most of them are lath-shaped parallel to (010). The plagioclase is always more or less zoned: the core is composed of labradorite and the marginal zone of oligoclase. In a few gabbro varieties there are greater (2—4 mm) phenocrysts of plagioclase. The plagioclase has always more or less altered to sericite and a grey (in the microscope) mineral, probably epidote. This holds in particular for the cores of the crystals.

Potash feldspar occurs in some of the analysed thin sections. In general it is weakly reddish coloured. The amount of potash feldspar increases occasionally and the rock grades into monzogabbro.

Quartz occurs in practically all analysed samples as an interstitial filling between the other minerals, forming small irregular grains, in most cases with undulatory extinction.

In the modal analyses the pyroxene is not given as clino- or orthopyroxene owing to the fact that reliable identifications are impossible without using the universal stage for every separate pyroxene grain. However, optical determinations of some thin sections using universal stage procedures show that clinopyroxene is more frequent than orthopyroxene. There is probably, however, orthopyroxene in all analysed thin sections, an assumption supported by the presence of hypersthene in the CIPW norm.

The clinopyroxene is probably a ferroaugite (Table 24, p. 105). It is pale greyish green in colour and has the following optical characteristics:

$$\begin{aligned}n\gamma &= 1.695 \\n\alpha &= 1.669 \\n\gamma - n\alpha &= 0.026 \\2V\alpha &= 48^\circ - 50^\circ \\c/\wedge\gamma &= 38^\circ - 39^\circ\end{aligned}$$

The orthopyroxene is a ferrohypsthene (Table 24). It is pale reddish brown without visible pleochroism and has the following optical characteristics:

$$\begin{aligned}n\gamma &= 1.716 \\n\alpha &= 1.705 \\n\gamma - n\alpha &= 0.011 \\2V\alpha &= 48^\circ - 49^\circ\end{aligned}$$

The pyroxenes have more or less altered to amphibole (Fig. 10). Occasionally the last mentioned mineral occurs as a mantle around a core of pyroxene. The chemical composition of the amphibole indicates a ferrohastingsite (Table 25, p. 106). The mineral has optical characteristics as follows:

$$\begin{aligned}n\gamma &= 1.670 \\n\alpha &= 1.653 \\n\gamma - n\alpha &= 0.017 \\2V\alpha &= 68^\circ - 71^\circ \\c/\wedge\gamma &= 17^\circ - 18^\circ\end{aligned}$$

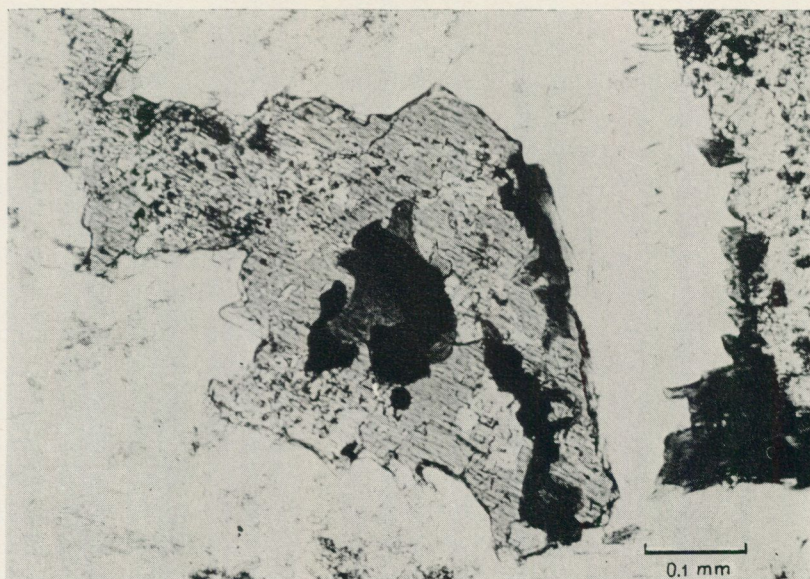


Fig. 10. Pyroxene grain altered to amphibole (grey). The white spots in the grain are unaltered pyroxene. The amphibole has partially altered to biotite (dark grey) in which opaque minerals (black) occur. 1 nic. Sample K 430b (see Table 1). Photo K. A. Kornfält.

The amphibole has frequently altered to biotite ( $n_{\gamma} = n_{\beta} = 1.649$ ;  $2V_{\alpha} = 0^{\circ}$ ) along the margins and along the cleavages. The chemical composition of the biotite is given in Table 27 (p. 108). The biotite has quite often partially altered to green biotite and chlorite.

Olivine ( $FO_{56} Fa_{44}$ ;  $2V_{\gamma} = 97^{\circ}-102^{\circ}$ ), mostly altered to serpentine, has been found only in a single thin section. A partial electron microprobe analysis of this olivine is given in Table 23 (p. 104).

The opaque minerals ilmenite, magnetite, and pyrite are always present, and in some thin sections they occur in abundance. Most of the opaque minerals are found in the biotite. They are often formed like a skeleton (Fig. 11).

The compositions of the coexisting pyroxenes of the analysed sample K 430b (Table 24, p. 105) are plotted in Fig. 12. The position of the pyroxenes in the diagram indicates a rather early crystallization compared with the pyroxene crystallization trends from e.g. the Skaergaard and Bushveld intrusions (Wager and Brown 1967, p. 39 and 391).

As pointed out by Carmichael et al. (1974, p. 32) a plutonic rock may be unrepresentative of the magma which cooled to produce it. This is so because during the relatively slow cooling a plutonic rock will tend to modify in compo-

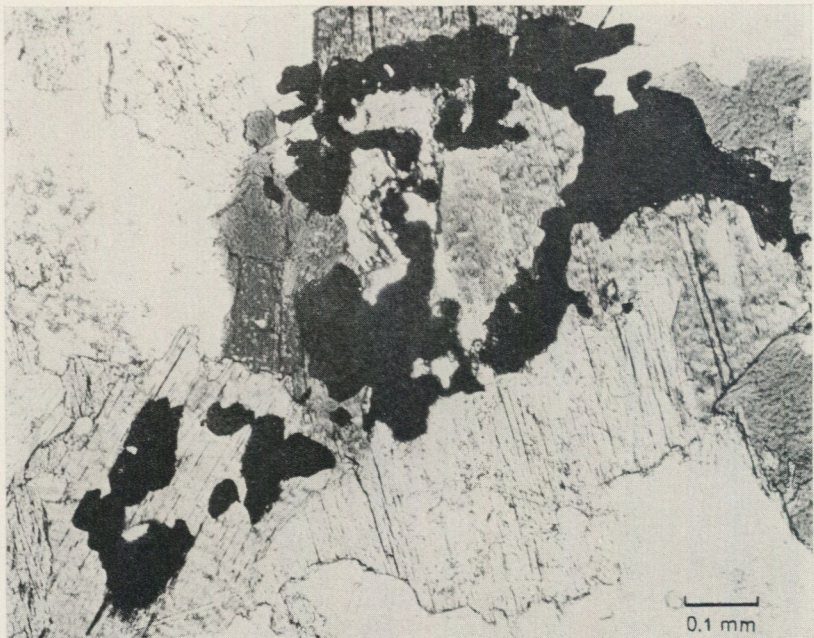


Fig. 11. Amphibole (light grey) in part altered to biotite (dark grey). Skeleton opaque minerals (black) occur within the biotite crystals. (The light grey crystal in the lower part to the left is biotite with opaque minerals.) 1 mic. Sample Nr 64 (see Table 1). Photo K. A. Kornfält.

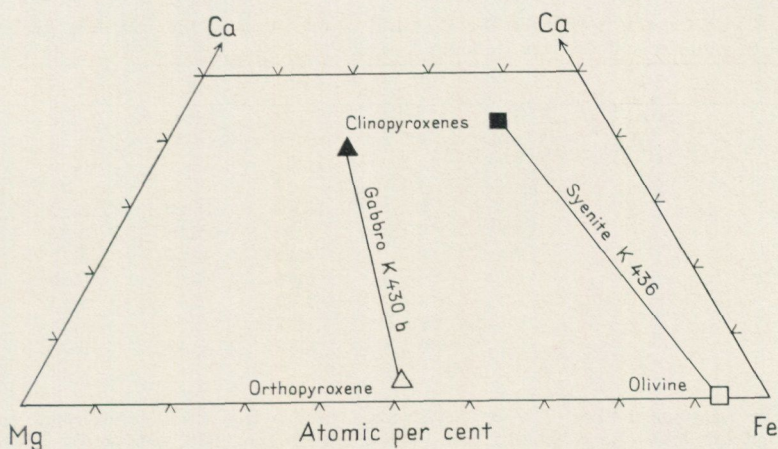


Fig. 12. Composition of analysed coexisting pyroxenes and olivine in gabbro (triangles) and syenite (squares) from the Ragunda massif. (The data are taken from Tables 23 and 24.)

sition by interaction with the surrounding rock-water envelope. The classification of the different magma types (e.g. by means of a  $\text{Na}_2\text{O} + \text{K}_2\text{O}/\text{SiO}_2$  diagram according to Kuno 1966) is therefore based on the better suited volcanic rocks. If such a diagram (in reality prepared for volcanic rocks) is used to classify the magma-type which gave rise to the gabbros of the Ragunda massif, the result will erroneously point to a magma of alkali olivine-basalt or high- $\text{Al}_2\text{O}_3$  basalt affinity, as this classification is based on elements (alkalis and silicon) which very likely in part have been added during or after the cooling of the rock.

There are, however, other criteria which can be used to classify the original magma type. The Ragunda gabbro has for example substantial normative hypersthene (Table 8) which indicates a tholeiitic affinity. Also the normative quartz is typical of tholeiitic basalts poor in, or lacking modal olivine (cf. Carmichael et al. 1974, p. 33).

A comparison between the chemical composition of the Ragunda gabbro and average tholeiitic basalts (Table 9) shows that the Ragunda gabbro is higher in  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and alkalis but lower in  $\text{FeO}$ ,  $\text{MgO}$ , and  $\text{CaO}$ . The Ragunda gabbros show fairly good agreement with Nockolds' (1954) average of plutonic quartz gabbro. A comparison between the chemistry of the Ragunda gabbro and the chemistry of other gabbros of rapakivi affinity (Mårdsjö, Nordingrå, and Ahvenisto; Table 9) reveals a rather close similarity to the gabbro of the Mårdsjö massif (situated approximately 20 km to the north-west of the Ragunda massif). In comparison with the Nordingrå gabbro and the Ahvenisto quartz diabase the Ragunda gabbro has more  $\text{SiO}_2$ ,  $\text{MgO}$ , and alkalis but considerably less  $\text{FeO}$ .

TABLE 9. A comparison between the chemical composition of the Ragunda gabbro with some other gabbros and average tholeiitic basalt.

	1	2	3	4	5	6
SiO <sub>2</sub>	53.7	52.2	51.93	50.36	54.39	51.32
TiO <sub>2</sub>	1.48	2.05	3.36	2.09	1.29	2.05
Al <sub>2</sub> O <sub>3</sub>	16.1	15.8	15.27	17.34	16.72	14.17
Fe <sub>2</sub> O <sub>3</sub>	2.5	3.1	1.31	2.12	2.49	2.91
FeO	7.3	8.4	12.00	10.68	7.15	9.09
MnO	0.14	0.16	0.40	0.09	0.20	0.18
MgO	5.2	4.7	4.45	4.17	4.15	6.40
CaO	7.6	7.9	6.86	8.01	6.68	10.52
Na <sub>2</sub> O	3.6	3.1	2.37	2.78	3.15	2.25
K <sub>2</sub> O	1.8	1.6	1.39	1.37	1.58	0.83
P <sub>2</sub> O <sub>5</sub>	0.22	0.32	0.39	0.66	0.35	0.23

1. Average Ragunda gabbro. 2. Average Mårdsjö gabbro (Kornfält, unpublished data). 3. Average gabbro from the Nordingrå massif (von Eckermann 1938, average of 2 analyses). 4. Average quartz diabase from the Ahvenisto massif (Savolahti 1956, average of 2 analyses). 5. Average plutonic quartz gabbro (Nockolds 1954). 6. Average tholeiitic basalt (Nockolds 1954).

A comparison of the mineral composition between the Nordingrå gabbro (von Eckermann 1938, p. 250 ff.) and the Ragunda gabbro shows that both are quartz- and potash feldspar-bearing and have orthopyroxene as well as clinopyroxene. The pyroxene of the Nordingrå gabbro consists in part of a lamellar intergrowth of ortho- and clinopyroxene, suggesting the initial presence of pigeonite (Gunilla Lundqvist, unpublished lic. thesis). This suite has not been observed in the Ragunda gabbro. Olivine is generally present in the Nordingrå gabbro, a fact which distinguishes it from the Ragunda gabbro which only as an exception is olivine-bearing.

### GABBRO BRECCIAS

As mentioned in the introduction, the gabbro of the Ragunda massif is always more or less brecciated by Ragunda granite, aplite, aplite granite or pegmatite. In the north-easternmost part of the massif, however, the gabbro is penetrated by Holmsta granite (cf. p. 19). The metasomatic processes in the gabbro, which were caused by the intrusion of the Holmsta granite have, however, not at all been so intense as those related to the intrusion of the Ragunda granite, and the transformation of the gabbro at Holmsta has never been able to obliterate the original minerals completely.

A very beautiful gabbro breccia is found just at the foot of the reservoir of the hydro-power station at Hammarstrand (70005 15278), in the uncovered rocks which before the building of the power station had caused the famous Hammar-

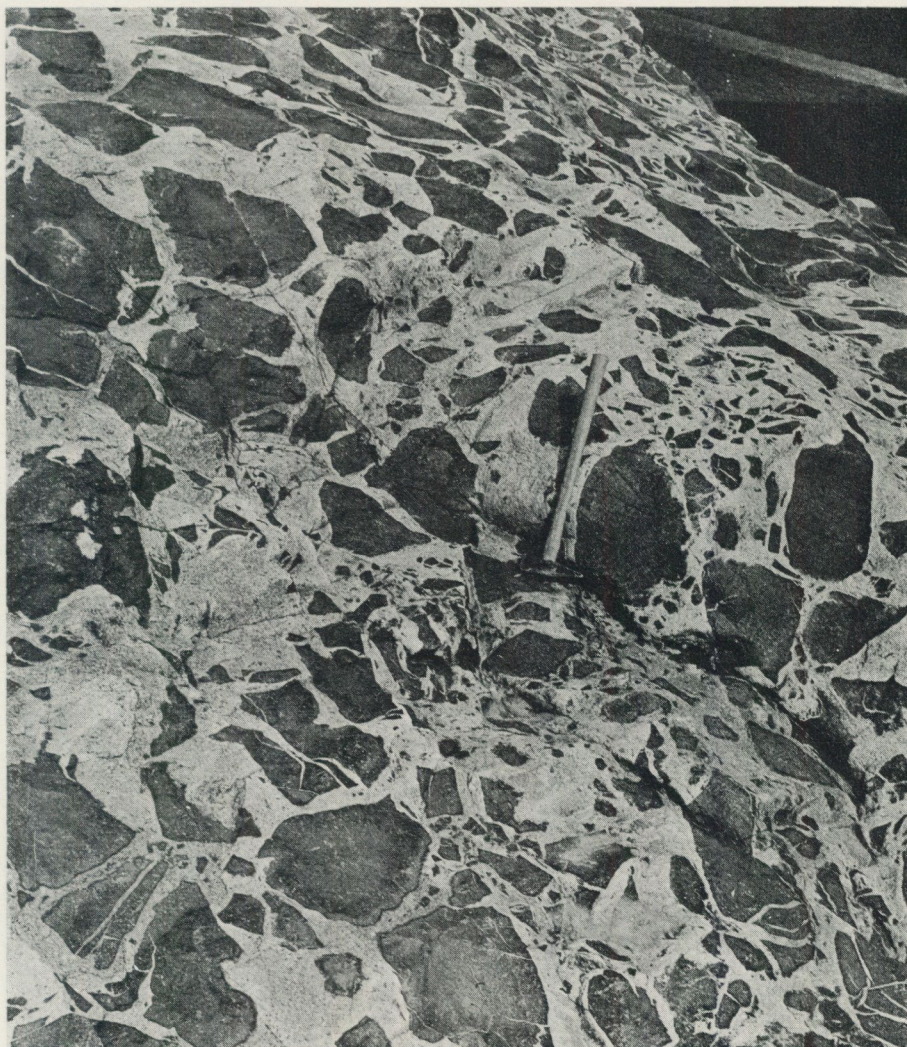


Fig. 13. View of the gabbro breccia at the former Hammarforsen Falls, Hammarstrand.  
Photo K. A. Kornfält.

forsen Falls (cf. Högbom 1899, pp. 22—26). Figure 13 shows a very strongly brecciated gabbro. Within the area there are also larger, more unaltered gabbro xenoliths.

At the same locality one can study how the gabbro, under the influence of the granite intrusion, has been transformed into different hybrid rocks where all gradations between granite and gabbro occur. A remarkable phenomenon of

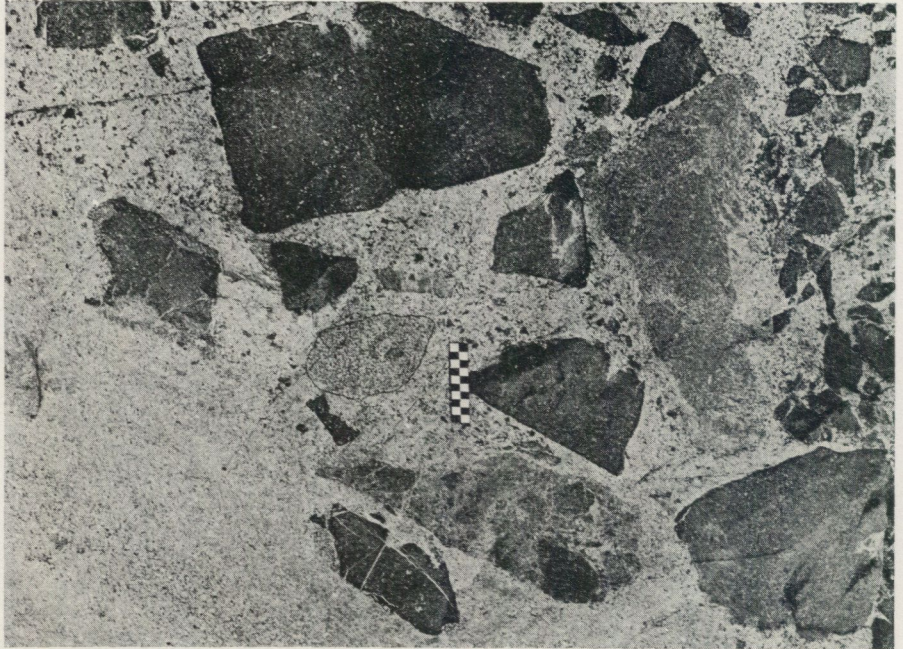


Fig. 14. Detail of the gabbro breccia at the former Hammarforsen Falls, Hammarstrand, showing transitional stages between gabbro and granite. Photo K. A. Kornfält.

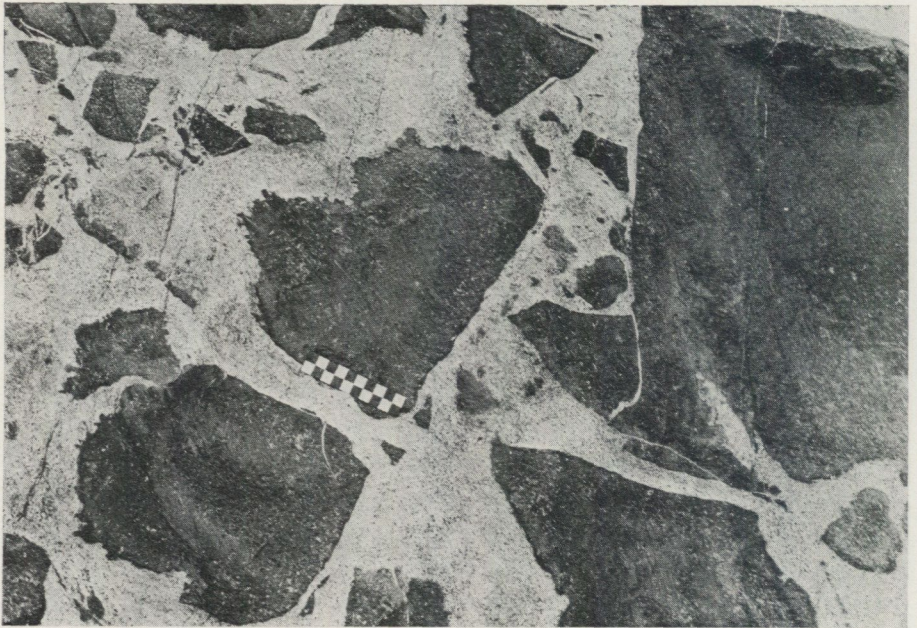


Fig. 15. Detail of the gabbro breccia at the former Hammarforsen Falls, Hammarstrand. One edge of the gabbro xenolith (with the scale) has a diffuse boundary to the granite, while the others have sharp boundaries. Photo K. A. Kornfält.



Fig. 16. Detail of the gabbro breccia at the former Hammarforsen Falls, Hammarstrand. The gabbro forms more or less elongated parallel oriented xenoliths. Photo K. A. Kornfält.

the Hammarforsen breccia is that almost completely unaltered quartz gabbro is found side by side with almost wholly granitized varieties, together with transitional stages between them (Fig. 14).

On one side of the gabbro xenoliths the boundary between granite and gabbro may be razor sharp while on the other sides the boundary may be quite diffuse (Fig. 15). This was already observed by Högbom (1899).

The gabbro xenoliths are in some places more or less elongated and parallel (Fig. 16).

The matrix between the gabbro xenoliths is, as a rule, very inhomogeneous, but the mineral composition is mostly that of a monzonite. The colour is reddish grey to red. It is fine medium-grained or medium-grained and accordingly more fine-grained than the Ragunda granite proper, which is coarsely medium-grained.

Where the gabbro xenoliths are scarce or lacking, which is the case in a few minor patches within the gabbro areas, a red granite occurs, the composition of which is comparable with the Ragunda granite proper. The former is, however, a little more fine-grained and more porphyritic than the latter. The coarsely medium-grained, typical Ragunda granite is only exceptionally found within the gabbro areas.

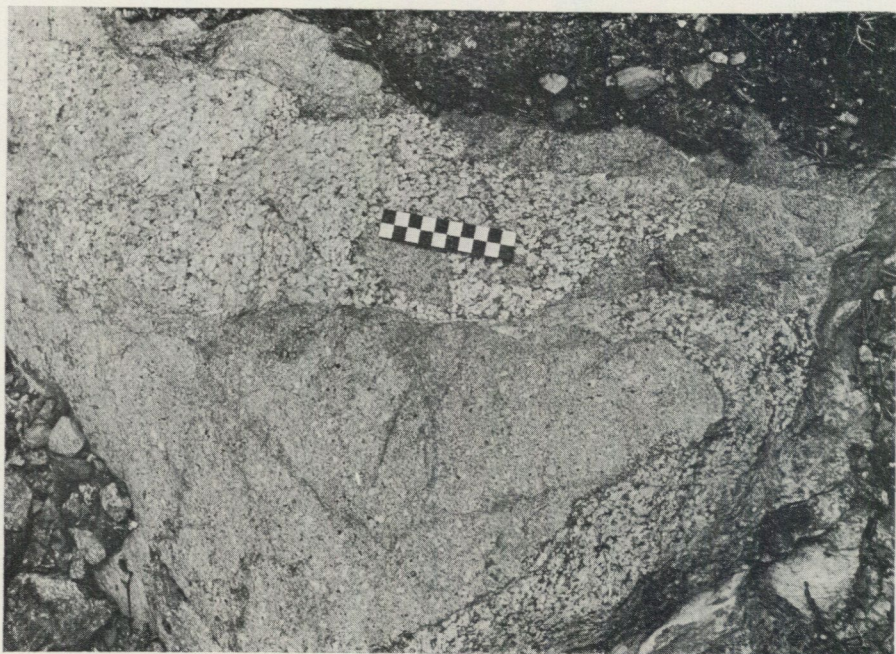


Fig. 17. Ragunda gabbro brecciated by porphyritic Ragunda granite. Note the plagioclase mantled potash megacrysts. W. of Bakåmyran (70124 15464). Photo K. A. Kornfält.

In aplite dikes penetrating the gabbro breccias, e.g. at the Hammarforsen Falls, a few pegmatite lenticles with quartz at the center are found. Within the areas of the Ragunda granite, however, pegmatites are extremely rare.

As mentioned above, the gabbro is always more or less brecciated by granite or aplite. The previously mentioned hybrid rocks are not always present. They are often completely missing and instead a quite homogeneous porphyritic granite occurs, occasionally with plagioclase-mantled potash feldspar megacrysts. In this granite almost unaffected xenoliths of gabbro are enclosed (Fig. 17).

In the larger gabbro areas (e.g. c. 3 km W. of Krångede) the brecciation of the gabbro is in its central parts reduced to a network of narrow, mainly horizontal aplite or pegmatite dikes (Fig. 18). In the margins of the gabbro, when bordering on the granite, there are larger brecciating granitic intrusions.

Where the gabbro borders on quartz syenite (e.g. at Krångede) the syenite has brecciated the gabbro in the border zone. Intrusions of syenite are, however, never found far inside the gabbro massifs.

When the rapakivi magma intruded the gabbro, part of the latter was subjected to an assimilation process.

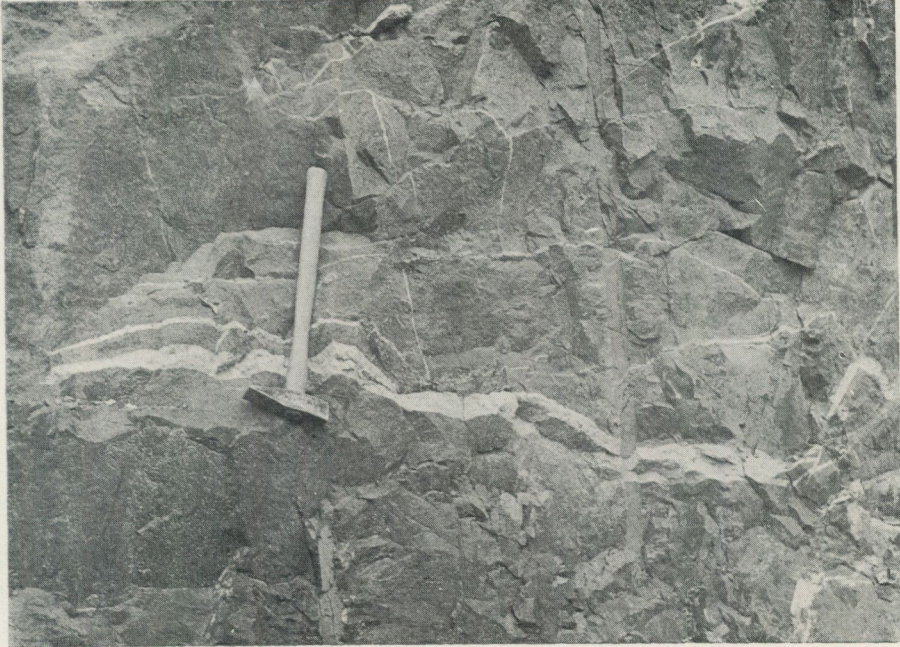


Fig. 18. Narrow dikes of aplite and pegmatite penetrating the gabbro. Stadsberget (70032 15114). Photo K. A. Kornfält.

According to Bowen's reaction principle any magma is effectively supersaturated with respect to minerals with a higher temperature range of crystallization. Inclusions of such mineral aggregates the melting range of which is above that of the magma will not be melted by the magma. The transformation of the gabbro xenoliths in the magma of the Ragunda granite is not the result of a melting process but may be regarded as an attempt of the granite magma to react upon and transform the gabbro minerals in the gabbro xenoliths into other minerals in equilibrium with the magma.

At the Hammarforsen Falls occur, as mentioned above, transitional rocks between gabbro and granite. With the intention of showing the changes in chemical composition of the rocks connected with the assimilation, three chemical analyses were made from a small area, where the gabbro gradually grades into granite (Table 10: K 163b, K 163c, K 163d). Analysis K 163a in Table 10, which is included for comparison, is from a near-by, larger gabbro xenolith with sharp edges and surrounded by monzonite.

The mineral content of the above analysed hybrid rocks is given in the following table:

	K 163a	K 163b	K 163c	K 163d
K-feldspar	+	20	41	47
Quartz	+	9	18	38
Plagioclase	48	34	31	11
Pyroxene	28	—	—	—
Amphibole	1	27	7	1
Biotite	19	2	3	+
Allanite	—	—	—	+
Chlorite	2	2	—	+
Zircon	—	—	+	+
Sphene	—	+	—	—
Apatite	+	1	+	+
Opaques	1	3	+	2
% An in the plagioclase	22—70	19	13—26	15—20

— = not detected

+ = present in small quantities (<0.5 %)

As is evident from Table 10, the amounts of  $K_2O$  and  $SiO_2$  increase in connection with the assimilation. The K/Na ratio also increases. The amounts of Al, Ca, and Mg decrease. Ti,  $Fe^{3+}$ ,  $Fe^{2+}$ , and Mn are higher in sample K 163b than in K 163a but decrease in the direction of the granite.

The potash supply connected with the assimilation has, among other things, resulted in an alteration of the pyroxene and amphibole of the gabbro into biotite. This alteration of the Fe-rich pyroxenes and amphiboles liberates Fe which after oxidation forms magnetite (or ilmenite). The opaque minerals occur mainly within the biotite grains. The biotite on the other hand occurs often as patches within the pyroxene grains.

When the granite magma intruded, perhaps in a slow, stoping-like process, the already crystallized gabbro must have adopted approximately the same temperature as the granite magma since chilled margins are generally missing. At the granite intrusion the gabbro was broken and more or less assimilated by the granite.

These metasomatic, assimilating processes have obviously been of various intensity in different parts of the granite magma. The variations are great also within very small areas. At the Hammarforsen Falls it is thus possible to observe that half of the gabbro xenoliths have remained fairly unaltered whereas half of them have been completely transformed into monzonite (Fig. 19). Gabbro xenoliths showing initial reaction with the granite magma have been broken at a later moment of the intrusion and may also be included in a breccia of the type described above.

The granite magma must have intruded without influence of stress since gneissose structures have never been observed. Fluidal structures indicating viscosity differences in the magma occur occasionally (Fig. 16).

TABLE 10. Chemical analyses and CIPW norms of rocks from the transitional zone between gabbro and granite in the gabbro-breccia at Hammarforsen (70003 15279).

Sample no	K 163a	K 163b	K 163c	K 163d
Chemical analyses (weight %)				
SiO <sub>2</sub>	53.8	56.3	70.0	74.1
TiO <sub>2</sub>	1.09	1.97	0.56	0.30
Al <sub>2</sub> O <sub>3</sub>	15.6	14.3	14.1	12.9
Fe <sub>2</sub> O <sub>3</sub>	2.2	3.7	1.7	1.0
FeO	6.8	8.4	1.8	1.2
MnO	0.14	0.17	0.04	0.03
MgO	6.3	3.1	0.9	0.27
CaO	9.4	5.6	1.8	0.9
Na <sub>2</sub> O	3.3	3.8	3.4	2.8
K <sub>2</sub> O	1.2	2.5	5.2	6.0
H <sub>2</sub> O > 105° C	0.8	1.0	0.8	0.6
H <sub>2</sub> O < 105° C	0.2	0.2	0.2	0.1
P <sub>2</sub> O <sub>5</sub>	0.18	0.34	0.09	0.01
F	n.d.	0.10	0.15	0.02
Total	101.0	101.5	100.7	100.2
—O for F	0.04	0.04	0.06	0.01
Corr. sum	101.0	101.4	100.7	100.2
Minor elements (ppm)				
V	320	340	50	10
Cr	170	< 10	10	< 10
Co	50	30	< 10	< 10
Ni	30	< 10	< 10	< 10
Zr	< 100	< 100	< 100	200
Sr	550	460	180	140
BaO	490	890	620	390
Rb	40	70	300	210
Normative minerals (weight %)				
Quartz	1.4	7.0	25.1	32.0
Corundum	—	—	0.2	0.2
Orthoclase	7.0	14.5	30.5	35.4
Albite	27.6	31.7	28.5	23.6
Anorthite	24.0	14.4	7.4	4.4
Wollastonite	8.8	4.4	—	—
Enstatite	15.5	7.6	2.2	0.7
Ferrosilite	9.0	9.3	1.0	0.9
Magnetite	3.2	5.3	2.4	1.4
Ilmenite	2.0	3.7	1.1	0.6
Apatite	0.4	0.8	0.2	—
Fluorite	—	0.1	0.3	0.0
Total	98.9	98.8	98.9	99.2

The first great granite intrusion was followed by minor dike-shaped intrusions which broke up the already crystallized primary breccia (Fig. 20). These late granite intrusions have not been able to granitize the enclosed gabbro and monzonite xenoliths in such a high degree as the earlier, primary intrusion. The interior parts of the larger gabbro massifs (e.g. Stadsberget, c. 2 km W. of Krångede) have been more resistant against the brecciating effects of the granite magma than the smaller massifs.

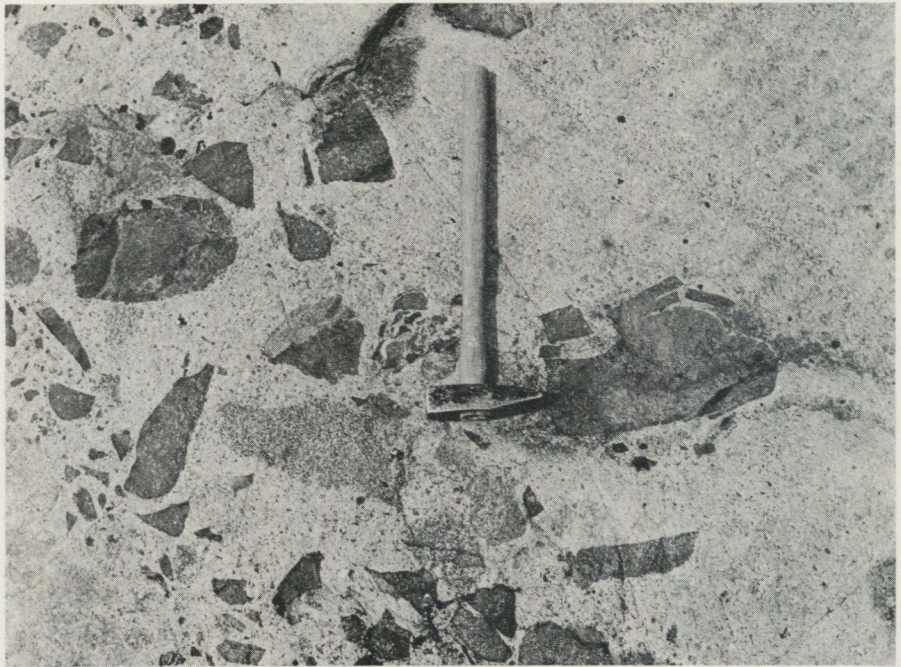


Fig. 19. Detail of the gabbro breccia at the former Hammarforsen Falls, Hammarstrand. The gabbro xenoliths may have one half quite intact, whereas the other has been completely transformed into monzonite. See e.g. the xenolith just to the left of the hammer. Photo K. A. Kornfält.

The interpretation of the field observations may be summed up in the following way:

1. There is a range of rocks showing gabbro compositions with monzonitic fractions. These rocks contain xenoliths of gabbro and transitional rock types between gabbro and monzonite.
2. The metasomatic activity of the granite magma has varied locally (possibly owing to the content of volatiles) and has worked simultaneously with fracturing of xenoliths which have already been variably metasomatically influenced. Different parts of the same xenolith have thus been altered to different degrees.
3. The granite magma has intruded repeatedly. A primary larger intrusion has been followed by one or several minor dike-shaped intrusions, which have brecciated the already existing, primary breccia.

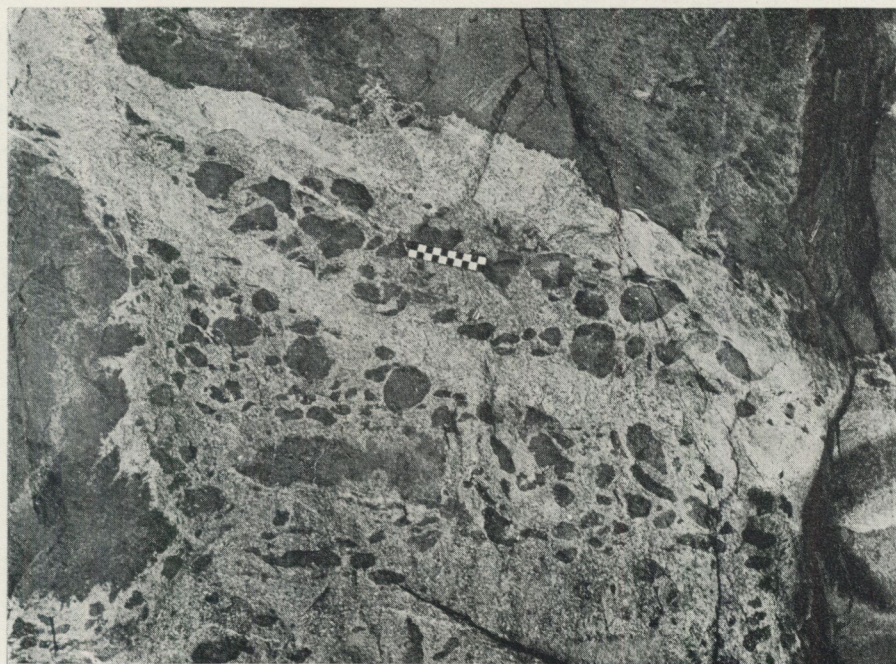


Fig. 20. Detail of the gabbro breccia at the former Hammarforsen Falls, Hammarstrand. A late granite dike has brecciated the primary breccia. Photo K. A. Kornfält.

#### SYENITE — QUARTZ SYENITE

In the western parts of the Ragunda massif there occurs a medium- to coarsely medium-grained, greenish grey, quartz-poor rock, the composition of which is that of a quartz syenite or syenite (Table 11). This coarser type grades in places into medium-grained to fine-grained varieties.

The syenitic rocks have generally a light brown weathering surface which distinguishes them from the granites, the weathering surface of which is as a rule more reddish brown.

The contact between the quartz syenite and the Ragunda granite is very diffuse. These two rocks grade into each other within a zone which in places is quite wide and contains areas of quartz-poor granite.

Within the regions mapped as syenite there occur minor areas richer in quartz. Here the syenite grades into quartz syenite. Quartz is present in all analysed

TABLE 11. Modal analyses (volume percent) of syenites and quartz syenites. (For sample locations, see Table 1.)

	K 229*	K 259*	K 309*	K 417a*	K 417b	K 432*	K 454*	K 463*
K-feldspar (perthitic)	70	65	65	64	60	68	71	50
Quartz	15	2	5	5	1	18	1	+
Plagioclase + secondary sericite and epidote	5	15	15	19	28	6	11	20
Olivine	1	1	1	2	3	1	2	7
Pyroxene	5	6	3	5	1	3	8	10
Amphibole	2	4	10	4	2	3	3	3
Alkali amphibole	+	+	+	+	+	+	—	—
Biotite	+	3	2	+	2	1	1	2
Iddingsite	—	1	—	+	—	+	1	1
Allanite	—	—	—	+	—	—	—	—
Chlorite	—	—	—	+	—	—	—	—
Fluorite	+	—	—	—	—	+	—	—
Zircon	+	—	—	—	+	+	—	—
Apatite	+	+	+	+	+	+	+	1
Opaques	1	2	1	1	2	+	3	4
% An in the plagioclase								
discrete grains	19	24	—	26	16	—	—	—
perthite	13	9	9	12	11	6	12	16

\* = chemically analysed sample

— = not detected

+ = present in small quantities (&lt;0.5 %)

thin sections, but the amounts may occasionally be less than 1 percent.

The grain-size of the syenites is in most cases too large to permit reliable point count analyses. All performed point count analyses have still been compiled (Table 11) in order to give a survey of the minerals occurring in the syenite. The amounts can be looked upon as rough estimates.

If the modal analyses given above are used for the classification of the rock (according to the system worked out by IUGS 1973; Fig. 9), the result is that the samples K 229 and K 432, which both have very low contents of plagioclase, ought to be termed alkali-feldspar quartz syenites, while the others fall into the fields of quartz syenites and syenites.

The chemical compositions of the syenitic rocks are given in Table 12.

The potash feldspar of the syenitic rocks is mainly orthoclase (Kornfält 1969, p. 11). It is generally pigmented in greyish brown with great variations of the colour intensity both in different rock samples and in grains within the same sample. These variations in colour are probably due to selective hydrothermal action after the cooling of the magma (cf. p. 50). The potash feldspars are as a rule 3—8 mm in size, with very irregular contours. In sample K 432 the potash feldspar is rectangular. The potash feldspar of the syenite is perthitic, forming film, vein, and patch perthite (cf. Andersen 1928). The patches of the patch perthite consist of oligoclase. These patches may in places grow into larger

TABLE 12. Chemical analyses, CIPW norms, and atomic ratios of syenites and quartz syenites.

(For sample locations and rock types, see Table 1.)

Sample no	K 229	K 259	K 309	K 417a	K 432	K 454	K 463
Chemical analyses (weight %)							
SiO <sub>2</sub>	61.9	62.9	64.4	64.4	63.9	61.9	59.0
TiO <sub>2</sub>	0.84	0.74	0.67	0.58	0.64	1.0	1.63
Al <sub>2</sub> O <sub>3</sub>	16.8	15.4	15.9	16.3	15.3	16.3	15.9
Fe <sub>2</sub> O <sub>3</sub>	1.7	1.5	1.8	1.1	1.8	1.4	2.4
FeO	5.3	5.8	4.1	5.1	4.6	5.7	6.7
MnO	0.15	0.18	0.15	0.15	0.15	0.18	0.20
MgO	0.65	0.55	0.40	0.21	0.31	0.72	1.4
CaO	2.5	2.3	2.0	2.2	2.0	2.7	3.3
Na <sub>2</sub> O	5.0	4.7	3.1	4.5	4.8	4.4	4.5
K <sub>2</sub> O	6.0	5.3	5.4	5.9	5.8	5.6	5.6
H <sub>2</sub> O > 105° C	0.5	0.5	0.6	0.8	1.0	0.3	1.3
H <sub>2</sub> O < 105° C	0.2	0.2	0.3	0.2	0.3	0.2	0.2
P <sub>2</sub> O <sub>5</sub>	0.26	0.15	0.14	0.10	0.08	0.29	0.65
CO <sub>2</sub>	n.d.	0.06	< 0.01	n.d.	n.d.	0.05	n.d.
F	0.03	0.05	0.05	0.06	0.07	0.04	0.06
S	n.d.	0.04	0.01	n.d.	n.d.	0.04	n.d.
Total	101.8	100.4	99.0	101.6	100.8	100.8	102.8
—O for F, S	0.01	0.04	0.03	0.03	0.03	0.04	0.03
Corr. sum	101.8	100.3	99.0	101.6	100.7	100.8	102.8
Minor elements (ppm)							
Zr	< 100	170	140	< 100	< 100	60	< 100
Sr	60	40	50	60	30	90	130
BaO	700	270	670	580	350	800	1460
Rb	50	< 30	90	110	90	50	30
Normative minerals (weight %)							
Quartz	2.0	7.3	19.1	8.0	7.8	6.0	1.5
Corundum	—	—	1.7	—	—	—	—
Orthoclase	34.8	31.2	32.2	34.3	34.0	32.8	32.1
Albite	41.5	39.6	26.5	37.5	40.3	36.9	37.0
Anorthite	5.6	5.3	8.9	6.7	3.0	8.1	6.5
Wollastonite	2.1	1.9	—	1.3	2.5	1.3	2.3
Enstatite	1.6	1.4	1.0	0.5	0.8	1.8	3.4
Ferrosilite	7.1	8.4	5.2	7.7	6.1	7.8	7.8
Magnetite	2.4	2.2	2.6	1.6	2.6	2.0	3.4
Ilmenite	1.6	1.4	1.3	1.1	1.2	1.9	3.0
Apatite	0.6	0.4	0.3	0.2	0.2	0.7	1.5
Fluorite	—	0.1	0.1	0.1	0.1	—	—
Pyrite	—	0.1	—	—	—	0.1	—
Calcite	—	0.1	—	—	—	0.1	—
Total	99.3	99.4	98.9	99.0	98.6	99.5	98.5
Atomic ratios							
Mg/Mg+Fe	0.14	0.12	0.11	0.06	0.08	0.16	0.22
K/K+Na	0.44	0.43	0.53	0.46	0.44	0.46	0.45
Ca/Ca+Na	0.22	0.21	0.26	0.21	0.19	0.25	0.29

plagioclase crystals with the same optical orientation as the minor patches within the potash feldspar crystal. Practically all the plagioclase of the syenites occurs in this way. Discrete crystals of plagioclase are rarely found. In case of the presence of such plagioclases they are strongly zoned and may be looked upon as early formed crystals.

The quartz of the syenites occurs partly between the potash feldspar individuals as rather euhedral crystals and partly as anhedral inclusions within the potash feldspar. The quartz shows often a weak undulatory extinction. Part of the quartz occurs in tiny patches of myrmekite between or in the margins of the potash feldspar crystals. Myrmekite has not been observed in all samples and is quite subordinate when present.

The chemical composition of the olivine of syenite sample K 463 given in Table 23 (p. 104) shows that the olivine is a fayalite ( $\text{Fo}_{6.5} \text{Fa}_{93.5}$ ). Olivine is present in all of the analysed syenite samples. It occurs as a rule together with the rest of the mafic minerals forming intergrowths with them. Free silica and olivine which is found in the Ragunda syenites can occur together in equilibrium if the olivine — as in the present case — is a highly ferriferous variety (Bowen and Schairer 1935, p. 214). The assemblage quartz and olivine may also be possible because of lack of equilibrium in the system. The presence of zoned plagioclases and reaction rims of pyroxene or amphibole around olivine (Fig. 21)

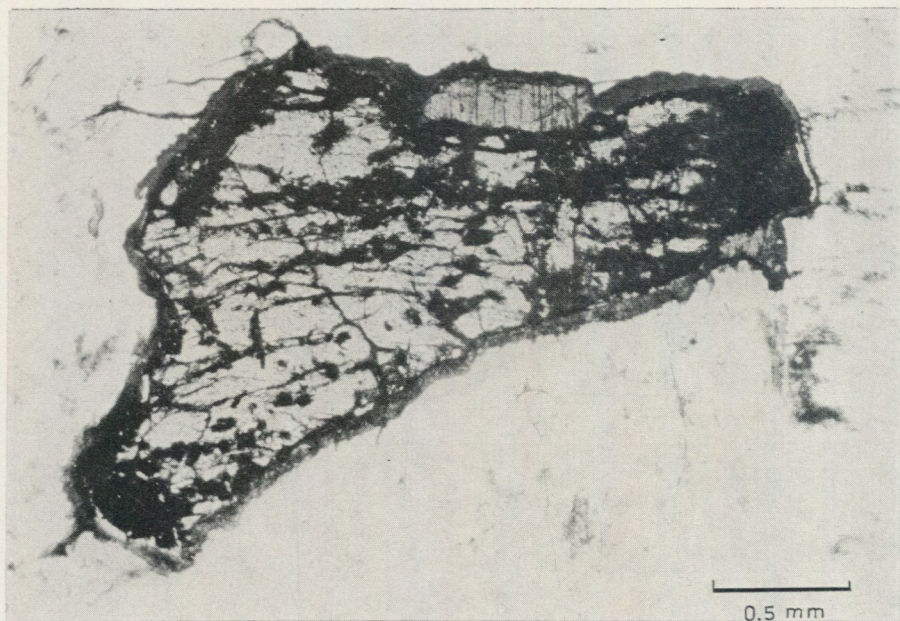


Fig. 21. Olivine with kelyphitic rim of amphibole. The black patches in the grain are iddingsite and iron oxides. Alkali-feldspar quartz syenite. 1 nic. Sample K 229 (see Table 1). Photo K. A. Kornfält.

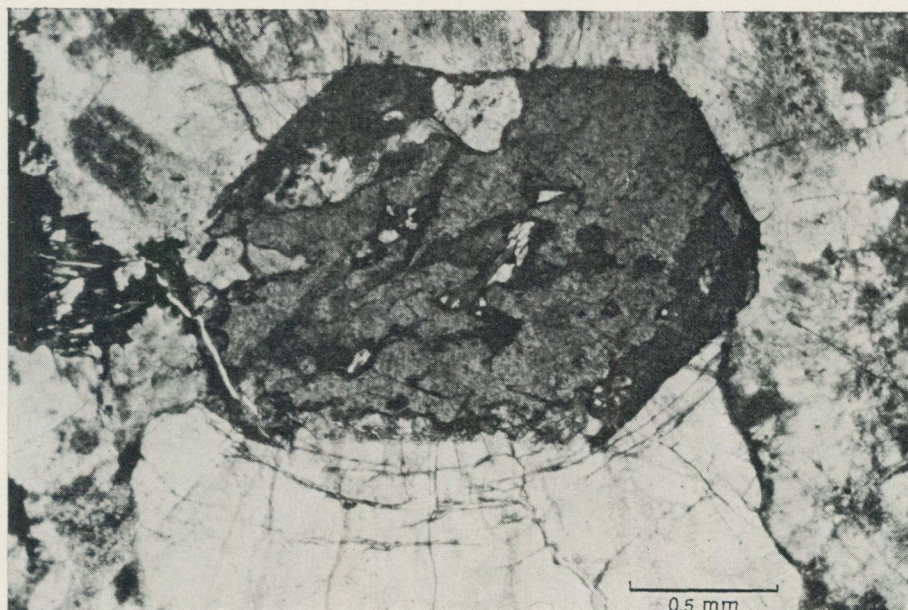


Fig. 22. Euhedral crystal of allanite in quartz syenite. Note the anastomosing cracks in the surrounding minerals. 1 nic. Sample K 417a (see Table 1). Photo K. A. Kornfält.

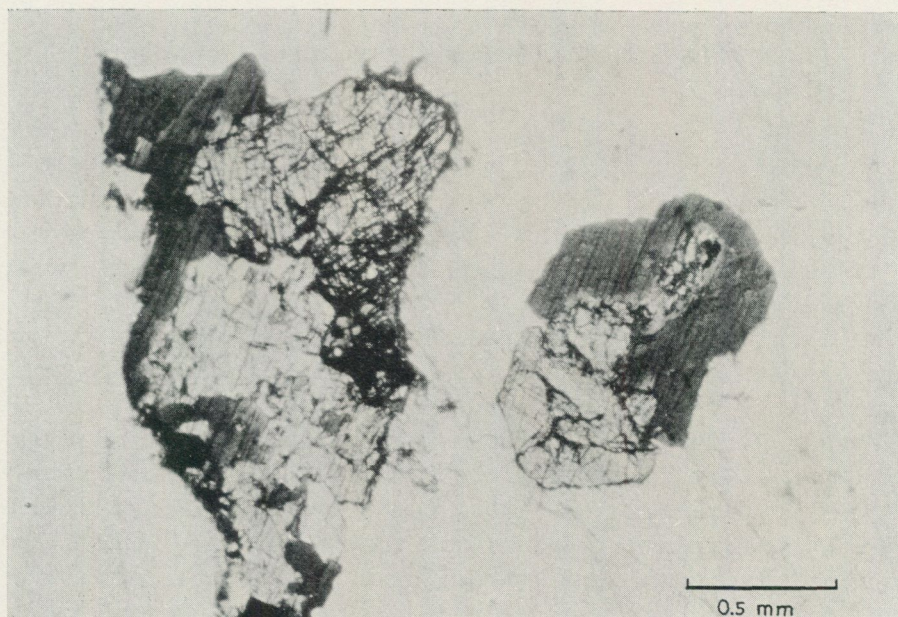


Fig. 23. Pyroxene grains of syenite partially altered to hornblende. (The light grey grain at the top of the left pyroxene grain is olivine.) 1 nic. Sample K 417b (see Table 1). Photo K. A. Kornfält.

in the Ragunda syenite reflects a metastable condition of its mineral assemblages. The olivine has partially altered to yellowish red or yellowish brown iddingsite, or more rarely to green serpentine.

In syenite sample K 417a there also occurs allanite. This mineral is yellowish brown and occurs in discrete crystals forming anastomosing cracks in the surrounding minerals (Fig. 22). The chemical composition of the allanite is given in Table 28 (p. 108).

The pyroxene crystals of the syenites, which as a rule measure 1—2 mm in diameter, are pale greenish grey in colour. They are occasionally euhedral in shape. Part of the pyroxene (generally the margins) has altered to amphibole (Fig. 23). Sometimes only a central core of pyroxene remains. The pyroxene is monoclinic, with a chemical composition which corresponds to a ferroaugite (Table 24, p. 105). The optical characteristics of the clinopyroxene are as follows:

$$\begin{aligned}n\gamma &= 1.714 \\n\alpha &= 1.689 \\n\gamma - n\alpha &= 0.025 \\2V\gamma &= 47^\circ \\c \wedge \gamma &= 42^\circ\end{aligned}$$

The amphibole of the Ragunda syenites has probably, at least in part, formed by alteration of pyroxene. Its chemical composition is given in Table 25 (p. 106) and corresponds to a ferrohastingsite. The optical characteristics are as follows:

$$\begin{aligned}n\gamma &= 1.703 \text{ (blackish green)} \\n\alpha &= 1.679 \text{ (light green—yellowish green with a brown tinge)} \\n\gamma - n\alpha &= 0.024 \\2V\alpha &= 51^\circ \\c \wedge \gamma &= 18^\circ\end{aligned}$$

In the ferrohastingsite there are sometimes small patches with anomalous, greenish blue interference colours. These patches are probably composed of alkali amphibole (cf. p. 54), which is practically always present in the syenites though in very small amounts.

The biotite of the syenites has probably formed secondarily from pyroxene and amphibole. The biotite which occurs in small rims around the opaque minerals has very likely formed from these.

The opaque minerals occurring in the syenites are mainly ilmenite and pyrrhotite together with small amounts of chalcopyrite and pyrite. Also titanomagnetite occurs occasionally. The opaque minerals are, as a rule, surrounded by amphibole and sometimes by biotite. These amphibole rimmed opaque minerals are rather often situated within pyroxene grains.

As mentioned above, the colour of the syenites is most frequently grey or greyish green. Greyish brown and reddish brown varieties also occur. The green colour of certain rapakivi rocks has been interpreted as a pigmentation of,



Fig. 24. Bands forming weed texture within a potash feldspar crystal. The weed texture bands have a yellowish green colour and are probably made up of amphibole. Alkali-feldspar quartz syenite. 1 nic. Sample K 229 (see Table 1). Photo K. A. Kornfält.

above all, the potash feldspar (Sederholm 1893; Berghell 1898; Hackman 1934). Savolahti (1956, p. 67; 1962, p. 42 f.) is of the opinion that the green colour of the rapakivi rocks is due to "weed texture", i.e. fine bands of green hornblende surrounding other crystals and filling the cleavage cracks in these (Fig. 24).

It is clear from the microscopic investigation of the Ragunda rocks that the brownish red rock varieties have just as much weed texture as the green ones. Consequently, it is not only the weed texture which creates the green colour of the Ragunda rocks, but also the pigmentation of the potash feldspar. It appears that the potash feldspars of the greyish green syenite variety are not as strongly greyish brown in colour (see p. 44) as are those of the brownish red syenite variety. One would therefore suppose that one condition for the appearance of the green colour caused by the weed texture is that the brown pigmentation of the potash feldspars either is weak or absent. The identification of the fine bands forming the weed texture has not yet been successful because of its small dimensions. It may well be, however, that the weed texture bands emanate from rest solutions of the syenite magma (cf. p. 100).

The brown colour of the potash feldspar crystals is probably due to a pigmentation caused by hematite (cf. Rosenqvist 1951, p. 65 ff.; Lundqvist 1968,

p. 147 f.). It is evident from the analyses of separated potash feldspars (Table 22) that the  $\text{Fe}_2\text{O}_3$  content is highest, 0.34 %, in sample K 259, which is a greyish green syenite, whereas in the red biotite granites it may be as low as 0.15 %. Consequently, it is probably not the presence of the mere  $\text{Fe}^{3+}$ -ion that causes the red colour. Presumably the  $\text{Fe}^{3+}$ -ion must be hydrated and hydrolysed, and these processes may have occurred by means of hydrothermal action (volatiles) after the intrusion of the magma.

### HORNBLLENDE GRANITE

Within the mainly pale brownish red biotite granite of the Ragunda massif occur minor areas with greyish green or light brown to greenish brown rocks. The weathered surface of the latter are (like the syenite) always light brown. These different coloured granites always contain amphibole (mainly hornblende), which in most cases exceeds biotite (Table 13). The amphibole-bearing granites have been grouped together and are treated as one unit even if variations exist in appearance, composition, and age relations.

Two main types of hornblende granite are distinguished in respect of occurrence. One displays small massifs in the Ragunda granite, without any sharp contacts with the latter. Such small massifs occur at Rävänäset (K 197) c. 4 km N.W. of Hammarstrand, at N. Leddalsberget (K 524) c. 7.5 km N.E. of Ragunda church, at Kvisselberget (K 616) c. 6 km N. of Bispgården railway station, at Finnåberget (Nr 115) c. 3 km S.W. of Helgum church, and at Krångede. The latter occurrence, which is somewhat larger than the other mentioned, is situated along the border between biotite granite and syenite.

The other type of hornblende granite forms a larger isolated massif at Holmstrand, c. 4 km N.W. of Helgum church.

The above mentioned hornblende granite varieties differ somewhat from each other also with reference to mineral content and chemical composition. The first type, i.e. the hornblende granite of the small massifs, contain as a rule olivine or secondary minerals after olivine. Several of these hornblende granites have also monoclinic potash feldspar or mixed structures with both monoclinic and triclinic potash feldspar (Kornfält 1969). In this way they resemble the syenitic rocks. Other similarities to the syenites also exist. Thus, the potash feldspar is of the same type as that in the syenites with vein and patch perthite. Furthermore, virtually all plagioclase in this type of hornblende granite occurs as in the syenite, in the shape of patch perthite. The texture is granophyric in many samples. (One occurrence of hornblende granite — K 616 in Table 1 — differs both macro- and microscopically from the others in this group. The colour is light reddish brown with black patches of amphibole. The texture is highly grano-

phyric. The quartz shows unusually strong undulatory extinction and the potash feldspar is very strongly brown coloured. The amphibole crystals in patches have altered to alkali amphibole which also exists as occasional, discrete grains.)

The brownish red hornblende granite in the isolated massif at Holmstrand is, however, more like the biotite granites. The plagioclase (oligoclase) occurs mainly as discrete crystals. Granophyric texture is rare. Olivine or secondary minerals after olivine do not occur in this type of hornblende granite. Chemically the hornblende granite of the Holmstrand massif differs from the other hornblende granites by a lower  $\text{SiO}_2$  content (Table 14: Nr 91a, Nr 91b, Nr 132, and Nr 137). The quartz content may occasionally decrease so much that the hornblende granite grades into monzonite (Table 13: Nr 91a and Nr 91b).

The amphibole of the hornblende granites is probably a ferrohastingsite (Table 25, p. 106). It has the following optical characteristics:

$$\begin{aligned} n\gamma &= 1.711 \\ n\alpha &= 1.690 \\ n\gamma - n\alpha &= 0.021 \\ 2V\alpha &= 60^\circ \\ c \wedge \gamma &= 20^\circ \end{aligned}$$



Fig. 25. Needles of alkali amphibole penetrating a quartz crystal. The large black grain down to the right is also alkali amphibole. Alkali-feldspar hornblende granite. 1 nic. Sample Nr 115 (see Table 1). Photo K. A. Kornfält.

TABLE 13. Modal analyses (volume percent) of hornblende granites (including alkali-feldspar granites and quartz monzonites).  
(For sample locations and rock types, see Table 1.)

	K 197*	K 251*	K 252	K 524	K 616*	Nr 91a*	Nr 91b*	Nr 115*	Nr 132*	Nr 137*
K-feldspar (perthitic)	55	45	63	55	59	50	52	64	35	49
Quartz	25	40	29	35	33	6	10	30	25	20
Plagioclase + secondary sericite and epidote	15	10	4	5	3	32	29	2	28	24
Olivine	—	—	—	+	—	—	—	—	—	—
Pyroxene	—	—	—	—	—	+	—	—	—	—
Amphibole	2	—	2	3	3	10	7	2	3	4
Alkali amphibole	+	2	+	+	+	+	—	+	—	—
Biotite	2	2	1	1	1	1	1	1	6	3
Chlorite	+	—	—	—	—	—	—	+	—	—
Allanite	—	—	—	—	—	—	+	—	+	—
Iddingsite	1	+	+	+	—	—	—	+	—	—
Fluorite	1	+	+	+	+	+	+	+	+	—
Zircon	—	+	+	+	—	+	+	+	+	+
Sphene + leucoxene	—	—	—	—	+	—	+	—	—	—
Apatite	—	—	—	+	—	+	+	—	+	—
Calcite	—	—	—	—	—	—	+	—	—	+
Opaque minerals	—	+	+	1	+	1	+	+	+	+
% An in the plagioclase discrete grains		30			35	30	27		25	27
perthite	12	8	3	3	7	6	12	3	11	11

\* = chemically analysed sample

— = not detected

+ = present in small quantities (<0.5 %)

TABLE 14. Chemical analyses, CIPW norms, and atomic ratios of hornblende granites (including alkali-feldspar granites and quartz monzonites). (For sample locations and rock types, see Table 1.)

Sample no	K 197	K 251	K 616	Nr 91a	Nr 91b	Nr 115	Nr 132	Nr 137
Chemical analyses (weight %)								
SiO <sub>2</sub>	73.8	74.2	74.5	67.4	66.5	74.7	70.4	71.8
TiO <sub>2</sub>	0.25	0.21	0.29	0.38	0.36	0.21	0.33	0.24
Al <sub>2</sub> O <sub>3</sub>	13.0	13.1	12.2	15.5	16.2	12.1	14.6	14.4
Fe <sub>2</sub> O <sub>3</sub>	0.7	0.9	0.8	1.0	1.0	1.1	0.5	0.5
FeO	1.6	1.3	2.1	2.9	2.9	1.2	2.5	1.9
MnO	0.03	0.03	0.06	0.06	0.06	0.03	0.06	0.04
MgO	0.10	0.10	0.09	0.15	0.14	0.07	0.22	0.17
CaO	0.8	0.6	0.6	1.6	1.5	0.5	1.3	1.2
Na <sub>2</sub> O	3.7	3.7	4.1	4.5	4.5	3.9	3.8	3.6
K <sub>2</sub> O	5.5	5.6	5.1	6.0	6.1	4.8	5.1	5.1
H <sub>2</sub> O > 105° C	0.8	0.8	0.7	1.9	1.1	1.0	0.6	0.4
H <sub>2</sub> O < 105° C	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
P <sub>2</sub> O <sub>5</sub>	<0.01	<0.01	<0.01	0.02	0.01	<0.01	0.07	0.03
CO <sub>2</sub>	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.05	0.12
F	0.21	0.18	0.12	0.08	0.11	0.31	0.11	0.13
S	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01	0.01
Total	100.7	100.9	100.8	100.8	100.7	100.1	99.9	99.8
—O for F, S	0.09	0.08	0.05	0.03	0.05	0.13	0.05	0.06
Corr. sum	100.6	100.8	100.8	100.8	100.6	100.0	99.8	99.8
Minor elements (ppm)								
Zr	400	200	<100	500	500	400	1150	460
Sr	20	30	10	80	70	10	65	60
BaO	170	270	50	530	480	150	550	500
Rb	200	200	110	150	180	200	190	400
Normative minerals (weight %)								
Quartz	28.9	29.5	29.0	13.6	12.1	32.9	24.5	28.1
Corundum	0.1	0.3	—	—	—	0.4	1.0	1.4
Orthoclase	32.3	32.8	29.9	35.2	35.8	28.3	30.2	30.2
Albite	31.1	31.0	34.0	37.8	37.8	33.0	32.2	30.5
Anorthite	2.4	1.7	—	4.3	5.9	0.2	5.0	4.2
Acmite	—	—	0.3	—	—	—	—	—
Wollastonite	—	—	0.9	1.2	0.3	—	—	—
Enstatite	0.2	0.2	0.2	0.4	0.3	0.2	0.5	0.4
Ferrosilite	2.0	1.3	2.9	4.0	4.0	1.0	3.7	2.8
Magnetite	1.0	1.3	1.0	1.4	1.4	1.6	0.7	0.7
Ilmenite	0.5	0.4	0.5	0.7	0.7	0.4	0.6	0.5
Apatite	—	—	—	—	—	—	0.2	0.1
Fluorite	0.4	0.4	0.2	0.2	0.2	0.6	0.2	0.3
Calcite	—	—	—	—	—	—	0.1	0.3
Total	98.9	98.9	99.0	98.8	98.5	98.7	99.0	99.5
Atomic ratios								
Mg/Mg+Fe	0.07	0.07	0.05	0.06	0.06	0.05	0.11	0.11
K/K+Na	0.49	0.50	0.45	0.47	0.47	0.45	0.47	0.48
Ca/Ca+Na	0.11	0.08	0.07	0.16	0.16	0.07	0.16	0.16

In several analysed thin sections of hornblende granite (K 197, K 252, K 524, K 616, and Nr 115) the ferrohastingsite contains patches of anomalous, greenish blue interference colours. Discrete small crystals in the same anomalous interference colours also occur occasionally. Microprobe analyses of this mineral in samples K 252 and Nr 115 show that the patches are alkali amphibole (presumably riebeckite or arfvedsonite; see Table 26, p. 107).

The alkali amphibole occurs, as mentioned above, in most cases within the ferrohastingsite, where it appears as patches of anomalous colour. In the margins of the grains these patches pass into sheaf-shaped bundles of bluish green alkali amphibole fibres which penetrate the surrounding minerals (Fig. 25). It is the quartz crystals primarily which contain the fibrous alkali amphibole. The content of alkali amphibole is higher in the hornblende granites than in the syenite. But the presence of alkali amphibole is reflected by normative acmite only in one sample (K 616).

In the hornblende granite at Holmstrand alkali amphibole is found only in a greenish coloured part of the otherwise brownish red hornblende granite.

Alkali amphibole is mostly absent in other rapakivi massifs. In a bluish grey quartz porphyry boulder from the neighbourhood of Strömsund, northern Jämtland, G. Frödin (1918) has found arfvedsonite (cf. p. 71).

It is clear from the chemical composition that the biotite ( $n_{\gamma} = n_{\beta} = 1.684$ ) of the hornblende granite is lepidomelane (Table 27, p. 108), i.e. iron-rich biotite (Deer et al. 1962, vol. 3, p. 57; cf. Simonen and Vormä 1969).

As the olivine of the hornblende granite has nearly always altered into yellowish green or yellowish brown chlorite or iddingsite minerals, it has not been possible to determine its composition.

Allanite has been found only in thin sections from the samples Nr 91b and Nr 132 (Table 1).

As the hornblende granite of the isolated Holmstrand massif does not border anywhere on the biotite granite of the main massif, it is impossible to decide whether this hornblende granite is younger or older than the "normal" biotite granite of the Ragunda massif. The mentioned hornblende granite has a  $\text{SiO}_2$  content (66—72 %) lying between the  $\text{SiO}_2$  contents of the syenites and biotite granites (Fig. 46). The Holmstrand hornblende granite too, occupies an intermediate position (Fig. 46) in respect of the concentration of other elements (e.g. FeO and CaO). Some of the chemical variation diagrams (e.g.  $\text{Mg}/\text{Mg}+\text{Fe}$  versus  $\text{Ca}/\text{Ca}+\text{Na}$ , Fig. 48) indicate that the hornblende granite at Holmstrand, as well as the other hornblende granite varieties, follow the syenitic trend. The chemical characteristics mentioned above may suggest that the hornblende granite massif at Holmstrand represents a somewhat more differentiated stage of the quartz syenite magma. Another possibility is — notwithstanding the weak chemical evidences of a syenitic affinity — that the Holmstrand hornblende granite represents a more deep-seated section of a granite intrusion.

The other type of hornblende granite seems, as mentioned (p. 50), to be more like the syenite in mineralogical respect. Chemically, however, this type of hornblende granite shows on the whole great similarities to the biotite granite (Fig. 46), but the low  $Mg/Mg+Fe$  value reveals the syenitic affinity (Fig. 47). The mentioned hornblende granite is found within or bordering on the biotite granite without any sharp contacts. For this reason and owing to the chemical and mineralogical similarities with the syenite it is very likely that these hornblende granites are older than the Ragunda biotite granite and perhaps constitute the upper, more differentiated parts of a syenitic body. There may also have been some secondary supply of silica, when the biotite granite intruded. The hornblende granite of this type may also be interpreted as remnants of an earlier formed syenite which has been transformed more or less into granite under the influence of the granitic magma (cf. p. 89). The larger amounts of late sodium-rich derivatives (cf. above) in the hornblende granite, as well as the existence of granophyric texture, favours the assumption that the hornblende granites in the small massifs have formed from late siliceous residues concentrated in the upper part of a syenitic body. It is quite possible that syenite underlies the biotite granite in the eastern part of the main massif, where most of the small hornblende granite massifs are found. The fact that the rocks in the eastern part of the main massif are miarolitic to a higher degree than in the western part and that granite porphyry varieties are found here indicates that the eastern part represents a more shallow section of the massif. This assumption is, however, not valid for the little isolated massif at Holmstrand, where the hornblende granite may represent a deeper, more basic, section of a granite intrusion.

### GRANITE PORPHYRY

About 5 km N. of Bispgården railway station (location K 620), there occurs within the Ragunda granite a fine-grained, greyish brown to brownish grey rock with c. 1 cm long, pink, euhedral phenocrysts of potash feldspar. Phenocrysts of light green, euhedral plagioclase measuring c. 5 mm in length are also found. The quartz is subhedral and occurs as crystals measuring 3—5 mm (Fig. 26). The matrix is fine-grained, and therefore this porphyritic rock is a little too coarse-grained to be termed porphyry. It has thus been designated granite porphyry.

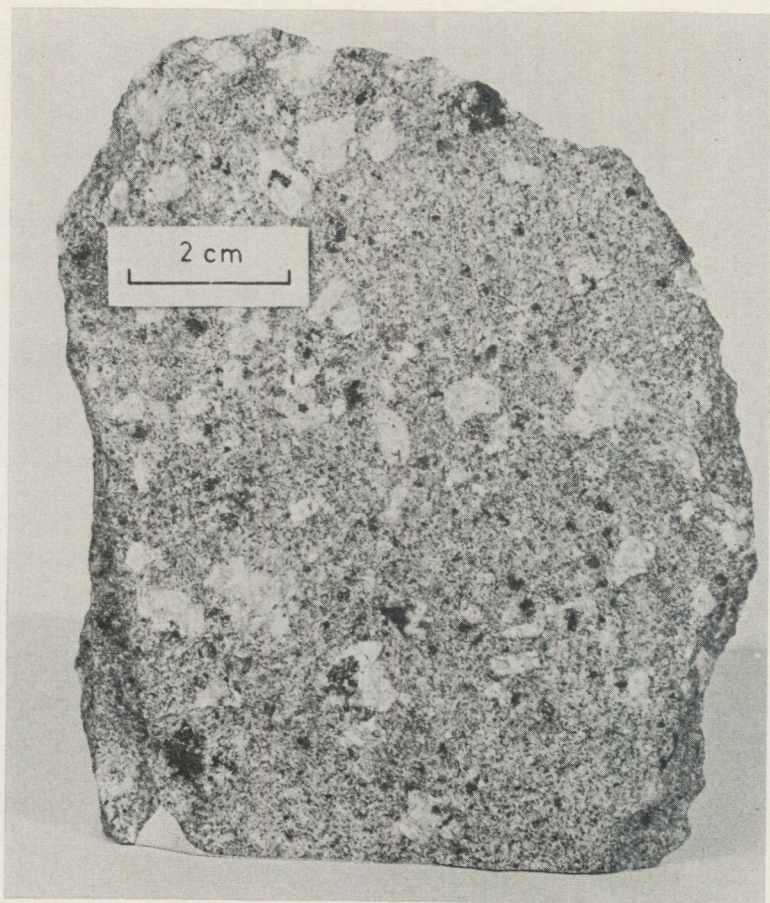


Fig. 26. Granite porphyry. Sample K 620 (see Table 1). Photo K. A. Kornfält.

The granite porphyry from location K 620 has the following modal composition (vol. %):

	<i>Matrix (c. 80 %)</i>	<i>Phenocrysts (c. 20 %)</i>
K-feldspar	42	56
Quartz	30	20
Plagioclase + sericite	21	24
Biotite	3	
Chlorite	3	
Opagues	1	
Zircon, apatite	<1	

TABLE 15. Chemical analysis, CIPW norm, and atomic ratios of granite porphyry, sample no K 620.  
(For sample location, see Table 1.)

Chemical analysis		Minor elements		Normative minerals	
Major elements (weight %)		(ppm)		(weight %)	
SiO <sub>2</sub>	73.4	Zr	100	Quartz	29.1
TiO <sub>2</sub>	0.30	Sr	90	Corundum	0.7
Al <sub>2</sub> O <sub>3</sub>	13.6	BaO	370	Orthoclase	31.0
Fe <sub>2</sub> O <sub>3</sub>	0.7	Rb	280	Albite	30.1
FeO	1.4			Anorthite	3.4
MnO	0.04			Enstatite	1.0
MgO	0.39			Ferrosilite	1.6
CaO	0.9			Magnetite	1.0
Na <sub>2</sub> O	3.6			Ilmenite	0.6
K <sub>2</sub> O	5.3			Fluorite	0.3
H <sub>2</sub> O > 105°	1.0			Total	98.8
H <sub>2</sub> O < 105°	0.2				
P <sub>2</sub> O <sub>5</sub>	0.02				
F	0.14				
Total	101.0				
—O for F	0.06				
Corr. sum	100.9				
Atomic ratios					
Mg/Mg+Fe	0.25				
K/K+Na	0.49				
Ca/Ca+Na	0.12				

The potash feldspar is red. It is perthitic, principally containing vein perthite but occasionally also patch perthite. The patch perthite is sometimes concentrated to the margins of the potash feldspar grains and may, when that is the case, form a mantle of plagioclase (often sericitized) around the potash feldspar.

The plagioclase (An<sub>31</sub>) has quite strongly altered to sericite. The biotite ( $\alpha$  = light brown,  $\gamma$  = dark green) of the granite porphyry contains dark patches of oxide minerals. Partial chloritization of the biotite is common.

The chemical composition of the granite porphyry is given in Table 15.

In the potash feldspar megacrysts of the granite porphyry in sample K 620 the triclinicity has an inferior value ( $\Delta = 0.0-0.1$ ), whereas in the matrix it is higher ( $\Delta = 0.0-0.71$ ; Kornfält 1969, Table 4).

The granite porphyry grades without any sharp contacts into (coarsely) medium-grained Ragunda granite, which can be studied at Västansjöberget (69983 15404). Not far from the said locality the granite porphyry is cut by a 2 m wide dike of fine-grained biotite granite (K 630).

Within the Ragunda granite, in the area nearest the granite porphyry, a few xenoliths of the latter are found (Fig. 27).

The field observations mentioned above indicate that the granite porphyry is older than the surrounding (coarsely) medium-grained Ragunda granite.

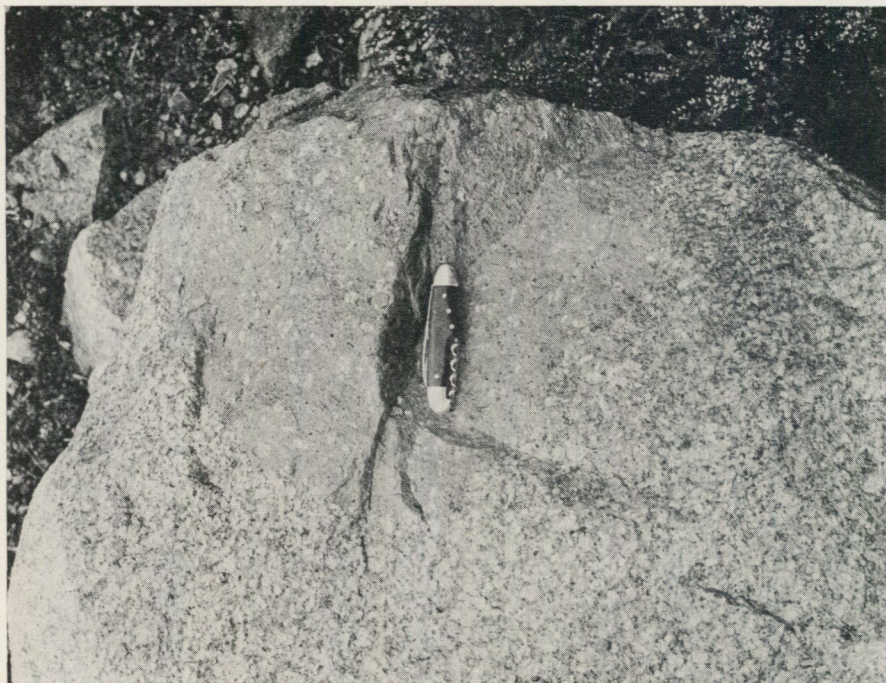


Fig. 27. Ragunda biotite granite with inclusion of granite porphyry. 3 km N. N. W. of Åssjön. Photo K. A. Kornfält.

#### MEDIUM- TO COARSE-GRAINED BIOTITE GRANITE (RAGUNDA GRANITE)

The most frequent granitic rock of the Ragunda massif is a red, medium- to coarse-grained biotite granite (Ragunda granite).

This granite is rather heterogeneous, with a fairly high variability in colour, grain-size, and texture from one locality to another. The predominant colour is different shades of pale red, but there are also reddish grey, brownish red, and flesh red biotite granites.

The grain-size varies from finely to coarsely medium-grained. Texturally, the biotite granite can be divided into two main groups: the one granophyric and the other granitic (Fig. 28). Granitic texture is most frequent. The Ragunda granite is as a rule more or less porphyritic with most frequently rectangular potash feldspar megacrysts (measuring maximally 1 cm in length) in a medium-grained matrix (Fig. 29). More even-grained varieties occur as well, but in general these also have rectangular potash feldspars. The potash feldspar is occasionally mantled with plagioclase (Fig. 28).

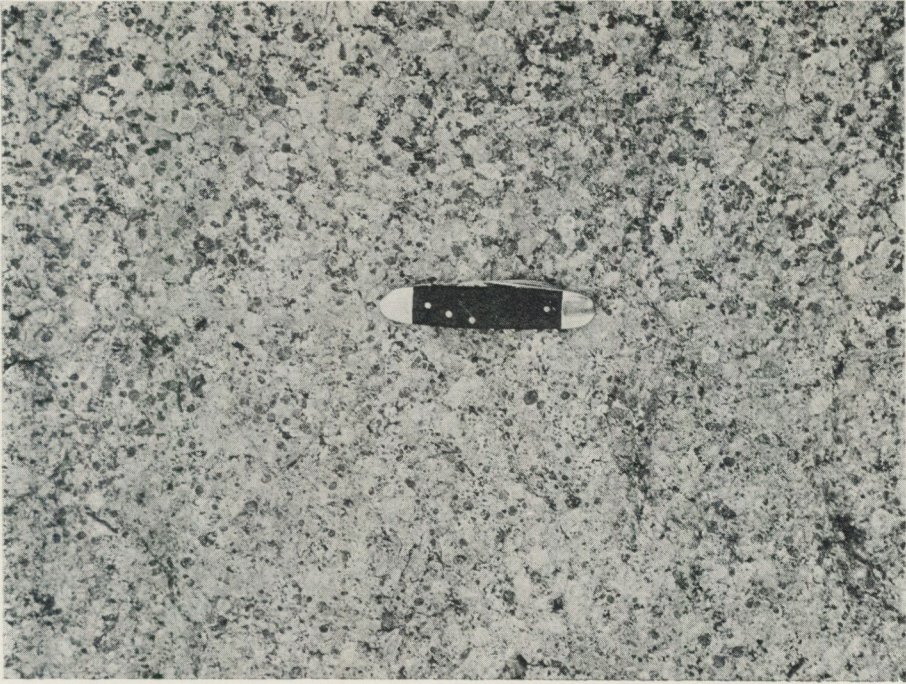


Fig. 28. Ragunda granite with granitic texture (above the knife) bordering on the same with granophyric texture (below the knife). Note the rapakivi mantling of some of the potash feldspar crystals. Kullstaberget (70008 15256). Photo K. A. Kornfält.

The petrographic variability of the Ragunda granite is probably due to minor changes during the differentiation of the granite magma and should thus not indicate any large age disparities between the different rock types. These grade into each other, making it impossible to discuss their relative ages on the basis of contact relations. In a few cases it has, nevertheless, been possible to determine the age sequence. Thus, the granophyric granite occurs as irregular veins in the non-granophyric granite at Kullstaberget (70009 15256; Fig. 28), which shows the granophyric granite to be younger. Furthermore, at Krångede (70035 15103), inclusions of porphyritic Ragunda granite occur in the even-grained type. This indicates that the porphyritic granite is the older one.

In the granophyric varieties quartz is present as micropegmatite, but in these, as well as in the non-granophyric ones, there are also well-rounded quartz crystals, measuring c. 2—5 cm in diameter (Fig. 28). In the area W. and S.W. of Hammarstrand these rounded quartz grains are especially well-developed.

The Ragunda granite, and particularly the granophyric variety has occasionally miarolitic cavities in which crystals of fluorite and quartz are found. Such a miarolitic variety occurs e.g. in a road-cutting at Överböle (70027 15169).

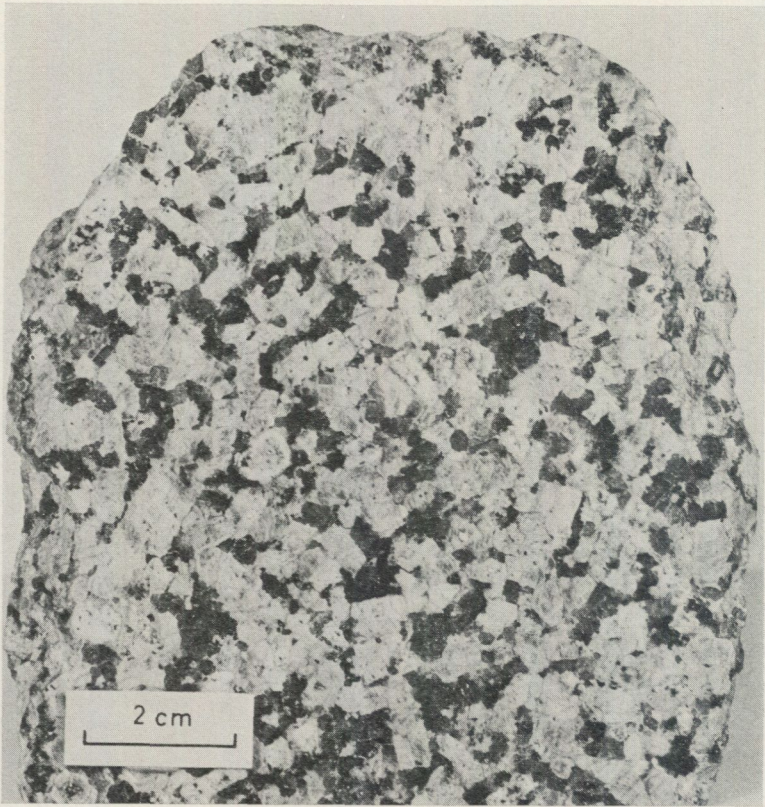


Fig. 29. Polished surface of Ragunda granite. Sample K 336 (see Table 1). Photo K. A. Kornfält.

The mineral content of 21 analysed thin sections of Ragunda granites varies within the following limits (vol. %):

K-feldspar	35—56 (average 47)
Quartz	23—40 (average 32)
Plagioclase + sericite	6—28 (average 16)
Biotite + chlorite	1—6 (average 3)

Small amounts of amphibole ( $< 1\%$ ) are present in 7 of the analysed samples. Zircon and fluorite are present as accessory minerals in all samples, whereas allanite, sphene, epidote, and apatite are present in not quite half of the analysed samples. The opaque minerals magnetite and ilmenite are found in all the samples.

According to Streckeisen's (1967) and IUGS' (1973) classifications of rocks, the Ragunda granite will mainly fall into the granite field (3; Fig. 9). Positions in sub-field 3a (i.e. the left half of the granite field of Fig. 9) are typical for the rapakivi granites (Streckeisen 1967, p. 224).

The chemical composition of the Ragunda granites is given in Table 16.

The potash feldspar of the biotite granite is strongly coloured in greyish brown to reddish brown. It is always perthitic, mainly with vein and patch perthite. Also string perthite (Andersen 1928) is quite often present. Carlsbad twinning is found in many of the analysed samples. Micropegmatitic intergrowths of quartz and potash feldspar are common, especially in the margins of the potash feldspar crystals. In the more pronouncedly porphyritic varieties greater (c. 1 cm) subhedral or sometimes euhedral potash feldspar crystals occur in a medium-grained (1–2 mm) granophyric matrix.

The potash feldspar of the biotite granite has generally triclinicity values which are high or moderately high. Mixed structural states between monoclinic and triclinic potash feldspar occur frequently (Kornfält 1969, Table 6).

The quartz forms partly large (2–5 mm), more or less euhedral grains, partly small (< 1 mm) anhedral grains intergrown with the potash feldspar forming granophyric texture. Anhedral quartz grains occur also between the potash feldspar crystals. The quartz crystals occasionally contain small inclusions of potash feldspar and more seldom plagioclase.

In some of the analysed samples practically all modal plagioclase occurs as exsolved patches in the potash feldspar crystals. These patches of exsolved oligoclase ( $An_{10-15}$ ) have sometimes grown so as to develop a band in the margin of the potash feldspar grains, thus forming a mantled texture (cf. Kornfält 1969, Fig. 5). The small patches of oligoclase in the potash feldspar crystals may also have concentrated to larger coherent patches in the centre of the grains, thus forming "anti-rapakivi" texture (Fig. 30). However, the main part of the modal plagioclase ( $An_{28-32}$ ) is, as a rule, found as discrete crystals. The plagioclase is mostly sericitized to various degrees and has consequently a lighter colour.

The biotite flakes measure in general 1–3 mm in length. They are often altered to chlorite. Green biotite is also present. The optical characteristics of the biotite are as follows:

$$\begin{aligned} n_{\gamma} &\approx n_{\beta} = 1.673 \\ \gamma &\approx \beta = \text{dark greenish brown} \\ \alpha &= \text{yellowish brown} \end{aligned}$$

Its chemical composition is given in Table 27 (p. 108). The biotite flakes have frequently inclusions of zircon and opaque minerals.

When amphibole is present in the Ragunda granite, it appears clustered together with biotite and opaque minerals. The amphibole ( $2V_{\alpha} = 58^{\circ} - 62^{\circ}$ ;  $c \wedge \gamma = 20^{\circ}$ ) is pleochroic with  $\gamma = \text{verdigris green}$ , and  $\alpha = \text{brownish yellow}$ .

TABLE 16. Chemical analyses, CIPW norms, and atomic ratios of medium- to coarse-grained biotite granites.  
(For sample locations, see Table 1.)

Sample no	K 164a	K 164b	K 209	K 320c	K 336	K 391	K 500
Chemical analyses (weight %)							
SiO <sub>2</sub>	76.1	75.9	75.0	76.5	73.2	73.3	73.8
TiO <sub>2</sub>	0.22	0.22	0.26	0.19	0.29	0.29	0.26
Al <sub>2</sub> O <sub>3</sub>	12.4	12.5	12.8	12.1	13.8	13.7	13.1
Fe <sub>2</sub> O <sub>3</sub>	0.3	0.4	0.7	1.1	0.6	0.5	0.6
FeO	1.2	1.3	1.3	0.2	1.5	1.5	1.4
MnO	0.03	0.03	0.03	0.01	0.04	0.04	0.03
MgO	0.22	0.22	0.24	0.08	0.35	0.29	0.20
CaO	0.6	0.5	0.7	0.2	1.0	0.9	0.7
Na <sub>2</sub> O	3.2	3.1	3.3	2.1	3.5	4.0	3.3
K <sub>2</sub> O	5.2	5.3	5.5	6.5	4.8	5.2	5.7
H <sub>2</sub> O >> 105° C	0.9	0.7	0.9	0.9	0.3	0.8	0.7
H <sub>2</sub> O << 105° C	0.1	0.2	0.2	0.22	0.03	0.1	0.1
P <sub>2</sub> O <sub>5</sub>	< 0.01	< 0.01	< 0.01	< 0.01	0.02	0.04	0.02
CO <sub>2</sub>	n.d.	n.d.	n.d.	0.08	0.10	n.d.	n.d.
F	0.18	0.18	0.21	0.01	0.19	0.18	0.18
S	n.d.	n.d.	n.d.	< 0.01	0.01	n.d.	n.d.
Total	100.7	100.6	101.1	100.2	99.8	100.8	100.1
-O for F, S	0.08	0.08	0.09	0.00	0.08	0.08	0.08
Corr. sum	100.6	100.5	101.1	100.2	99.7	100.8	100.0
Minor elements (ppm)							
Zr	< 100	100	400	520	350	100	100
Sr	40	20	50	15	60	60	40
BaO	190	170	270	200	380	330	230
Rb	190	250	240	240	150	230	220
Normative minerals (weight %)							
Quartz	35.5	35.7	32.5	39.0	31.3	27.3	30.8
Corundum	0.9	1.2	0.7	1.4	1.6	0.4	0.7
Orthoclase	30.5	31.1	32.1	38.3	28.4	30.5	33.6
Albite	26.9	26.1	27.6	17.7	30.5	33.6	27.9
Anorthite	1.7	1.2	2.0	0.4	2.9	2.9	2.1
Enstatite	0.5	0.5	0.6	0.2	0.9	0.7	0.5
Ferrosilite	1.6	1.7	1.4	—	1.9	1.9	1.7
Magnetite	0.4	0.6	1.0	0.1	0.9	0.7	0.9
Hematite	—	—	—	1.0	—	—	—
Ilmenite	0.4	0.4	0.5	0.4	0.6	0.5	0.5
Apatite	—	—	—	—	—	0.1	—
Fluorite	0.4	0.4	0.4	—	0.4	0.4	0.4
Calcite	—	—	—	0.2	0.1	—	—
Total	98.8	98.9	98.8	98.6	99.6	99.0	99.1
Atomic ratios							
Mg/Mg+Fe	0.21	0.19	0.18	0.10	0.23	0.21	0.16
K/K+Na	0.52	0.53	0.52	0.67	0.47	0.46	0.53
Ca/Ca+Na	0.09	0.08	0.10	0.05	0.13	0.11	0.10

TABLE 16. (continued)

Sample no	K 580	K 631a	K 828	K 939	K 944	Nr 30	Nr 53a	Nr 66
Chemical analyses (weight %)								
SiO <sub>2</sub>	75.6	74.9	76.8	76.5	73.8	74.6	73.4	73.2
TiO <sub>2</sub>	0.19	0.11	0.12	0.21	0.20	0.27	0.26	0.26
Al <sub>2</sub> O <sub>3</sub>	12.4	13.7	12.1	12.2	12.9	13.6	12.8	13.4
Fe <sub>2</sub> O <sub>3</sub>	0.4	0.5	0.5	0.5	<0.1	1.1	0.9	0.7
FeO	0.9	0.5	1.1	1.1	2.3	1.0	1.6	1.2
MnO	0.03	0.02	0.03	0.03	0.02	0.05	0.04	0.04
MgO	0.22	0.11	0.09	0.35	0.27	0.12	0.23	0.24
CaO	0.6	0.7	0.4	1.0	0.8	0.3	0.8	0.8
Na <sub>2</sub> O	3.4	3.9	3.5	2.8	3.0	3.3	3.7	3.3
K <sub>2</sub> O	5.3	5.2	5.0	4.6	4.8	5.6	5.1	5.6
H <sub>2</sub> O >> 105° C	0.8	0.9	0.8	0.4	0.9	0.9	0.8	1.2
H <sub>2</sub> O << 105° C	0.1	0.2	0.1	0.05	0.06	0.1	0.2	0.2
P <sub>2</sub> O <sub>5</sub>	<0.01	<0.01	<0.01	0.01	0.02	0.04	<0.01	<0.01
CO <sub>2</sub>	n.d.	n.d.	n.d.	0.02	0.03	n.d.	n.d.	n.d.
F	0.22	0.27	0.18	0.19	0.27	0.07	0.22	0.16
S	n.d.	n.d.	n.d.	<0.01	<0.01	n.d.	n.d.	n.d.
Total	100.2	101.0	100.7	100.0	99.4	101.1	100.1	100.3
-O for F, S	0.09	0.11	0.08	0.08	0.11	0.03	0.09	0.07
Corr. sum	100.1	100.9	100.6	99.9	99.3	101.0	100.0	100.2

Minor elements (ppm)								
Zr	100	<100	<100	170	200	500	<100	100
Sr	30	30	<10	50	45	20	40	40
BaO	90	170	120	180	220	180	170	240
Rb	360	410	210	280	260	160	220	220

Normative minerals (weight %)								
Quartz	34.1	31.0	35.9	40.0	35.3	32.8	30.1	30.3
Corundum	0.6	1.1	0.7	1.4	2.2	1.8	0.3	0.9
Orthoclase	31.3	30.4	29.3	27.2	28.5	32.7	30.1	33.0
Albite	28.7	32.7	29.4	23.7	25.5	27.6	31.3	27.8
Anorthite	1.4	1.6	0.7	3.4	1.7	0.8	2.4	2.8
Enstatite	0.5	0.3	0.2	0.9	0.7	0.3	0.6	0.6
Ferrosilite	1.1	0.4	1.5	1.3	4.0	0.6	1.8	1.3
Magnetite	0.6	0.7	0.7	0.7	—	1.6	1.3	1.0
Hematite	—	—	—	—	—	—	—	—
Ilmenite	0.4	0.2	0.2	0.4	0.4	0.5	0.5	0.5
Apatite	—	—	—	—	—	0.1	—	—
Fluorite	0.5	0.5	0.4	0.4	0.6	0.1	0.5	0.3
Calcite	—	—	—	—	0.1	—	—	—
Total	99.2	98.9	99.0	99.4	99.0	98.9	98.9	98.5

Atomic ratios								
Mg/Mg+Fe	0.24	0.17	0.09	0.29	0.17	0.09	0.14	0.19
K/K+Na	0.51	0.47	0.48	0.52	0.51	0.53	0.48	0.53
Ca/Ca+Na	0.09	0.09	0.06	0.16	0.13	0.05	0.11	0.12

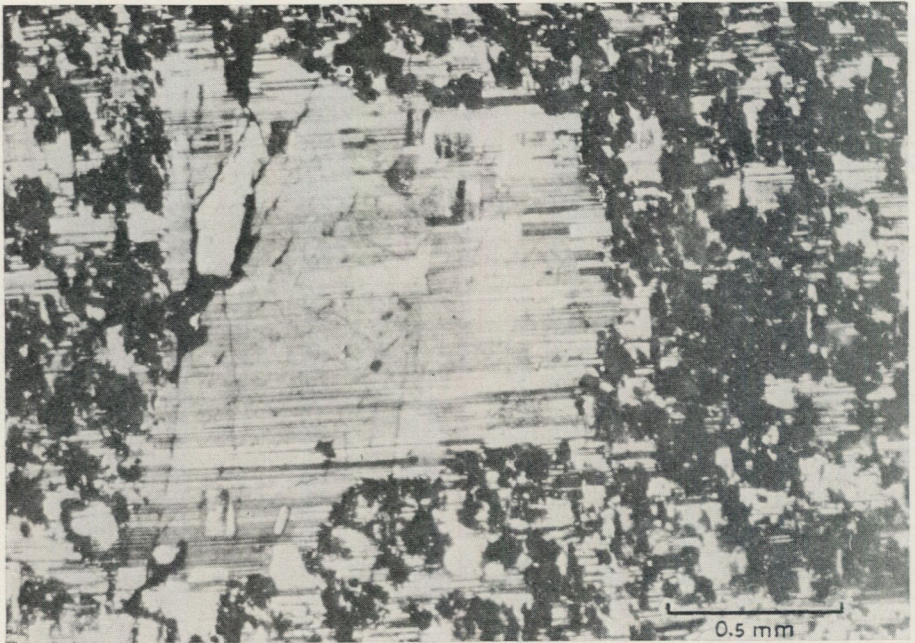


Fig. 30. Patch perthite. All white patches, the small ones as well as the large, have the same optical orientation. The anorthite content of the large white patch corresponds to an oligoclase. 2 nic. Sample K 391 (see Table 1). Photo K. A. Kornfält.

The optical characteristics indicate that the amphibole of the biotite granite is a common hornblende.

Allanite is present in 10 of 21 analysed thin sections of Ragunda granite (cf. p. 48). This mineral is reddish brown or yellowish brown and occurs partly together with the other mafic minerals, partly as discrete grains.

The Ragunda granite occasionally contains rounded, dark xenoliths of a more basic rock. These xenoliths probably represent remnants of Ragunda gabbro, which have been incompletely assimilated by the granite magma.

The medium-grained biotite granite, which penetrates the gabbro everywhere within the Ragunda massif differs a little from the massif-forming Ragunda granite. It is thus more common that the penetrating granite is porphyritic and has a rapakivi texture. The potash feldspar in one of the samples (Nr 66) from this granite variety has also cross-hatched twinning, which has not been observed in any other rock of the Ragunda massif.

## FINE-GRAINED BIOTITE GRANITE AND APLITE

In addition to the aplitic granite, which occurs together with the biotite granite in the gabbro breccias, a fine-grained, red, mostly porphyritic, granophyric granite has been found within the Ragunda massif. This granite is closely associated with the Ragunda granite. The age relation of the fine-grained biotite granite to the Ragunda granite has not yet been fully elucidated.

It is clear that the Ragunda granite in places has a fine-grained marginal zone bordering on the surrounding rocks (cf. p. 83). Nearest to the contact, within a zone varying from a few decimetres to c. five metres, the granite is fine-grained. At the outer edge of this zone (counting from the contact) phenocrysts of quartz and potash feldspar begin to appear. The amount of phenocrysts increases as does the grain-size, and the rock grades into (coarsely) medium-grained biotite granite.

This fine-grained marginal zone, which was obviously crystallized somewhat earlier and more rapidly than the main part of the Ragunda granite magma, can be studied e.g. at Råssäkerberget (69956 15277) and at Middagsberget (69938 15288), W. of Ragunda railway station.

The other variety of fine-grained biotite granite occurs sporadically in the shape of rather numerous small massifs all over the investigated area. In most cases its contacts with the adjacent Ragunda granite are not visible owing to the low degree of exposure. At locality K 631, where the contact, nevertheless, is visible, one gets the impression that the fine-grained biotite granite is younger than the medium-grained. The last mentioned rock grades here into a more fine-grained variety with medium-grained, pegmatitic blebs and miarolitic cavities. In other places, e.g. at Kåtamyran (70062 15436), there are xenoliths of the fine-grained biotite granite in the (coarsely) medium-grained Ragunda granite, which indicate that the former might be older. These fine-grained xenoliths occasionally have coarser, pegmatitic blebs.

Dikes of fine-grained biotite granite are found in the granite porphyry (K 630) and in the metagreywacke (Nr 123).

In the Ragunda granite narrow dikes (< 2 m) of aplite occur which cut the granite with sharp contacts. The aplite is greyish red to red and has hardly any mafic minerals. There are only a few aplite dikes observed.

The fine-grained biotite granite is generally pale red, with sparse euhedral phenocrysts (1—3 mm in length) of potash feldspar. Somewhat more frequently, euhedral phenocrysts (1—2 mm in length) of quartz are found. Plagioclase may occasionally occur as sericitized phenocrysts. The matrix is fine-grained with micropegmatitic intergrowths of quartz and potash feldspar. The phenocrysts occupy only 5—15 % of the volume of the rock.

TABLE 17. Modal analyses (volume percent) of fine-grained biotite granites. (For sample locations, see Table 1.)

	K 250*	K 320b*	K 322	K 470	K 606	K 630*	K 613b*	Nr123*
K-feldspar (perthitic)	48	42	42	54	45	43	43	36
Quartz	33	35	35	33	28	32	35	24
Plagioclase + secondary sericite and epidote	15	18	19	10	20	22	20	31
Biotite	3	4	3	2	6	1	2	3
Chlorite	+	—	1	—	—	2	1	+
Fluorite	+	1	+	+	+	+	+	1
Zircon	—	+	+	+	+	+	+	+
Apatite	—	—	—	—	—	+	—	+
Sphene + leucoxene	—	—	+	—	+	—	—	—
Opaques	+	+	+	+	1	+	+	4
% An in the plagioclase	30	34	29	32	32	38	33	31

\* = chemically analysed sample

— = not detected

+ = present in small quantities (&lt;0.5 %)

The modal composition of the fine-grained biotite granites is given in Table 17.

The potash feldspar is rather strongly coloured reddish brown. It is perthitic with vein and patch perthite. The potash feldspar occurs partly as larger euhedral phenocrysts, partly in the matrix intergrown with anhedral quartz forming micropegmatite. Sometimes the potash feldspar phenocrysts in the fine-grained granite are surrounded by a zone of micropegmatite (cf. Kornfält 1969, Fig. 6), a phenomenon which, however, is absent in a few rock varieties. This is the case in K 630 and Nr 123 which are dikes. Triclinic potash feldspar and mixed states between triclinic and monoclinic potash feldspar predominate within the fine-grained biotite granite. In the contact with the surrounding Revsund granite the potash feldspar is monoclinic (Kornfält 1969, Table 8).

The plagioclase of the fine-grained biotite granite has a composition which is around the boundary between oligoclase and andesine. It is always more or less sericitized. The phenocrysts of plagioclase are, as a rule, more highly sericitized than those of the matrix. The plagioclase is often poikilitic, with inclusions of opaque minerals and biotite.

The biotite ( $\alpha$  = yellowish brown,  $\gamma$  = blackish green) of the fine-grained biotite granite has partially altered into chlorite and has occasionally secondary lenses of prehnite.

The chemical composition of some fine-grained biotite granites is given in Table 18.

TABLE 18. Chemical analyses, CIPW norms, and atomic ratios of fine-grained biotite granites.

(For sample locations, see Table 1.)

Sample no	K 250	K 320a	K 320b	K 630	K 631b	Nr 123
Chemical analyses (weight %)						
SiO <sub>2</sub>	75.7	76.5	75.2	77.0	76.7	75.6
TiO <sub>2</sub>	0.14	0.04	0.21	0.14	0.12	0.03
Al <sub>2</sub> O <sub>3</sub>	12.7	12.5	11.9	12.0	12.3	13.6
Fe <sub>2</sub> O <sub>3</sub>	0.4	< 0.1	< 0.1	0.3	0.4	0.4
FeO	1.1	0.6	1.3	0.4	0.3	0.8
MnO	0.02	0.02	0.01	0.03	0.03	0.02
MgO	0.07	0.11	0.09	0.15	0.14	0.04
CaO	0.6	0.5	0.2	0.5	0.7	0.8
Na <sub>2</sub> O	3.8	3.2	2.2	3.2	3.3	2.7
K <sub>2</sub> O	4.9	4.8	6.3	5.4	5.4	4.3
H <sub>2</sub> O > 105° C	0.9	0.9	0.6	0.8	0.9	0.4
H <sub>2</sub> O < 105° C	0.10	0.08	0.14	0.20	0.20	0.20
P <sub>2</sub> O <sub>5</sub>	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.03
CO <sub>2</sub>	n.d.	0.04	0.01	n.d.	n.d.	0.02
F	0.38	0.06	0.27	0.14	0.26	0.37
S	n.d.	< 0.01	< 0.01	n.d.	n.d.	< 0.01
Total	100.8	99.4	98.4	100.3	100.8	99.3
-O for F, S	0.16	0.03	0.11	0.06	0.11	0.16
Corr. sum	100.7	99.3	98.3	100.2	100.7	99.2
Minor elements (ppm)						
Zr	100	110	460	< 100	< 100	100
Sr	< 10	35	15	30	20	40
BaO	80	240	60	150	60	80
Rb	280	210	360	300	400	440
Normative minerals (weight %)						
Quartz	33.7	38.3	Norm	35.6	35.6	42.7
Corundum	1.1	1.4	not	0.3	0.4	4.2
Orthoclase	28.7	28.5	com-	31.8	31.7	25.6
Albite	31.9	27.2	put-	27.0	27.7	23.0
Anorthite	0.2	1.8	able	1.5	1.6	1.0
Enstatite	0.2	0.3		0.4	0.3	0.1
Ferrosilite	1.5	1.1		0.3	0.1	1.1
Magnetite	—	—		0.4	0.6	0.6
Ilmenite	0.3	0.1		0.3	0.2	0.1
Fluorite	0.8	0.1		0.3	0.5	1.0
Calcite	—	0.1		—	—	—
Total	98.4	98.0		98.9	98.7	99.4
Atomic ratios						
Mg/Mg+Fe	0.07	0.24	0.11	0.29	0.27	0.05
K/K+Na	0.46	0.50	0.65	0.53	0.52	0.51
Ca/Ca+Na	0.08	0.08	0.05	0.08	0.10	0.14

## ACID AND BASIC DIKES

The Ragunda massif and surrounding rocks are cut by a number of dikes with acid or basic composition. The dikes are narrow, for the most part not wider than 3 metres. Consequently, it is difficult to find them during a cursory mapping and it is therefore probable that the number of dikes in reality is greater than is evident from the present map (Fig. 1).

The dikes mentioned are very fine-grained, often porphyritic, with aphanitic chilled margins. The acid dikes differ clearly from the earlier described dikes of aplite (which lack chilled margins) and fine-grained granite (which are more coarse-grained). The directions of the dikes vary considerably. Directions towards N.N.W.—S.S.E. seem, however, to be predominant among the basic dikes, and directions towards N.W.—S.E. among the acid ones. The basic dikes are much more frequent than the acid dikes.

Basic dikes occur e.g. at the tunnel through Stadsberget, Krångede (70032 15144; Fig. 31). The basic dikes are greyish black, fine-grained, often porphyritic with phenocrysts of plagioclase or potash feldspar. The texture is ophitic or subophitic in the widest dikes. Very narrow dikes ( $< 0.2$  m) are as well as the margins of the other dikes always very fine-grained and occasionally aphanitic.

In the northern part of Uthammarsberget, Västby (70155 15485), a composite dike occurs. First a grey, fine-grained plagioclase-porphyritic rock has intruded into the gabbro. This intrusion has an aphanitic contact with the country rock. Later on an intrusion of fine-grained, greyish red quartz porphyry brecciated the primary dike.

The phenocrysts of the basic dikes consist partly of plagioclase, partly of potash feldspar, probably orthoclase. The phenocrysts are c. 5 mm in length and euhedral. Also quartz and pyroxene occur as phenocrysts (c. 1—2 mm). In some of the basic dikes the pyroxene has practically completely altered to amphibole. Olivine is never present, but presumably some of the chlorite spots which occur in most of the analysed samples are pseudomorphs after olivine.

The acid dikes are bluish grey, greyish brown or red in colour. They are porphyritic with phenocrysts of quartz, potash feldspar and plagioclase in a microcrystalline or aphanitic matrix.

The quartz porphyry dike at Hammarforsen (c. 6 m across; K 839), which already was described by Högbom (1899, p. 26), is in its central part fine-grained and reddish brown in colour (K 839b). The modal composition, corresponding to that of a quartz syenite, is given below (vol. %):

K-feldspar	53	Chlorite	2
Quartz	17	Fluorite	1
Plagioclase (An <sub>31</sub> ) + sec. sericite	20	Epidote, calcite, apatite, and opaques	2
Biotite	5		

TABLE 19. Chemical analyses, CIPW norms, and atomic ratios of acid dikes.  
(For sample locations, see Table 1.)

Sample no	K 210	K 473	K 839a	K 839b	Nr 46
Chemical analyses (weight %)					
SiO <sub>2</sub>	74.6	77.6	74.0	73.2	77.2
TiO <sub>2</sub>	0.21	0.17	0.21	0.22	0.13
Al <sub>2</sub> O <sub>3</sub>	10.8	10.4	12.6	12.7	11.6
Fe <sub>2</sub> O <sub>3</sub>	1.9	0.9	0.8	0.7	0.6
FeO	2.3	2.0	2.0	2.1	1.7
MnO	0.05	0.04	0.05	0.05	0.04
MgO	0.04	0.08	0.09	0.10	0.13
CaO	0.20	1.1	1.2	1.3	0.4
Na <sub>2</sub> O	4.0	2.8	3.1	3.2	2.9
K <sub>2</sub> O	4.7	3.0	5.4	5.5	4.3
H <sub>2</sub> O > 105° C	0.6	0.8	0.9	1.0	0.7
H <sub>2</sub> O < 105° C	0.2	< 0.1	0.1	0.2	0.1
P <sub>2</sub> O <sub>5</sub>	< 0.01	0.02	0.02	< 0.01	0.02
CO <sub>2</sub>	n.d.	0.84	n.d.	n.d.	0.14
F	0.13	0.02	0.38	0.44	0.07
S	n.d.	< 0.01	n.d.	n.d.	0.05
Total	99.7	99.8	100.8	100.7	100.1
-O for S, F	0.05	0.01	0.16	0.19	0.04
Corr. sum	99.7	99.8	100.7	100.5	100.0
Minor elements (ppm)					
V	10	40	20	10	45
Cr	n.d.	20	n.d.	n.d.	20
Co	< 10	10	< 10	< 10	10
Ni	< 10	20	< 10	< 10	25
Zr	1000	1100	200	200	1500
Sr	10	80	20	40	20
BaO	60	60	80	160	50
Rb	260	230	280	300	340
Normative minerals (weight %)					
Quartz	32.8	48.6	32.3	30.4	42.3
Corundum	—	2.6	0.5	0.3	2.0
Orthoclase	27.8	17.8	31.6	32.3	25.4
Albite	29.5	23.7	26.0	26.9	24.5
Anorthite	—	—	3.0	3.2	0.5
Acmite	3.9	—	—	—	—
Enstatite	0.1	0.2	0.2	0.2	0.3
Ferrosilite	3.5	2.7	2.7	3.0	2.4
Magnetite	0.8	1.3	1.1	1.0	0.9
Ilmenite	0.4	0.3	0.4	0.4	0.2
Apatite	—	0.0	0.0	—	0.0
Fluorite	0.3	0.0	0.8	0.9	0.1
Pyrite	—	—	—	—	0.1
Calcite	—	1.9	—	—	0.3
Total	99.1	99.1	98.6	98.6	99.0
Atomic ratios					
Mg/Mg+Fe	0.02	0.05	0.05	0.06	0.09
K/K+Na	0.44	0.41	0.53	0.53	0.49
Ca/Ca+Na	0.03	0.18	0.18	0.18	0.07



Fig. 31. Basic dikes in gabbro. Stadsberget, W. of Krångede. Photo K. A. Kornfält.

Towards the contact the texture becomes aphanitic and the colour changes to greyish black (K 839a). However, the chemical composition remains on the whole unchanged (Table 19).

Högbom (1899) has given a rather detailed account of the hypabyssal rocks of the Ragunda massif. He grouped the basic rocks into melaphyres (i.e. dikes with olivine) and porphyrites. Högbom supposed that the porphyritic dikes were older than the Ragunda granite. This interpretation is based on an observation (made by Hj. Lundbohm) in a railroad cutting W. of Ragunda railway station. It was impossible to find this locality again during the present mapping.

A more thorough investigation of the basic dikes from the Ragunda massif would perhaps clarify if there are any age differences between the dike varieties. During the present mapping nothing has, however, come forth which would

indicate that the different dike varieties might represent any greater differences of age. There are both basic and acid dikes cutting the Ragunda granite and, consequently, both kinds of dikes must be younger. It is impossible to decide the relations between the dikes of the surrounding rocks and the Ragunda granite, but as these dikes mostly are of the same type as those cutting the Ragunda granite, one may suppose that they are younger than the granite as well.

In a few places within the Ragunda massif (e.g. K 210) a bluish grey quartz porphyry is found. The colour of the rock is probably caused by numerous small, bluish green needles occurring in the matrix. The chemical analysis (K 210, Table 19) shows that the rock contains more sodium than usual and therefore it is probable that the bluish green mineral is an alkali amphibole (cf. p. 54).

Frödin (1918) has described a similar quartz porphyry from a boulder near Strömsund, northern Jämtland. Frödin supposed that the bluish colour was caused by arfvedsonite.

From the rapakivi area of Rödön, Västernorrland County, Holmquist (1899) has described in great detail a number of dikes with varying composition, which in some cases are similar to the dikes cutting the Ragunda massif. Holmquist interpreted the dikes of Rödön as younger than the rapakivi granite. The acid dikes are younger than the basic. Holmquist supposed that the basic dikes were structural modifications of the Åsby dolerite (p. 74).

Apart from the granite porphyry dikes described by Savolathi (1956), the Finnish rapakivi massifs are not cut by any dikes of the above kinds.

With the exception of the quartz syenitic dike at locality K 839b and a few wider basic ones (Table 21), the dikes are, as a rule, too fine-grained to allow modal analyses. The normative minerals from the chemical analyses give a composition of the acid dikes which correspond to a granite, whereas the basic dikes give a composition lying between gabbro and monzonite.

As mentioned above, the basic dikes cut the Ragunda granite and are consequently younger than this. Therefore, the dikes could not have been formed in connection with the intrusion of the Ragunda gabbro. The basic dikes also differ chemically from the Ragunda gabbro, above all by their higher potassium contents (Tables 20 and 8).

As the acid dikes have chilled margins, they might possibly represent late differentiation products from the rapakivi magma intruded so late that the rapakivi syenite and granite were practically completely solidified.

There are some more dikes of the above described types within the area between the massifs of Ragunda and Nordingrå (Lundbohm 1899; Th. Lundqvist, personal communication).

TABLE 20. Chemical analyses, CIPW norms, and atomic ratios of basic dikes. (For sample locations, see Table 1.)

Sample no	K 430a	K 615	Nr 760b
Chemical analyses (weight %)			
SiO <sub>2</sub>	50.0	56.4	53.2
TiO <sub>2</sub>	1.25	1.57	1.46
Al <sub>2</sub> O <sub>3</sub>	16.6	15.9	16.8
Fe <sub>2</sub> O <sub>3</sub>	3.4	2.0	1.9
FeO	6.0	6.1	8.0
MnO	0.16	0.12	0.14
MgO	6.9	3.7	3.8
CaO	7.6	4.8	7.3
Na <sub>2</sub> O	2.6	3.6	2.6
K <sub>2</sub> O	3.0	3.1	2.6
H <sub>2</sub> O > 105° C	3.4	2.4	2.2
H <sub>2</sub> O < 105° C	0.4	0.5	0.4
P <sub>2</sub> O <sub>5</sub>	0.29	0.37	0.35
CO <sub>2</sub>	n.d.	0.32	0.06
F	0.07	0.12	0.07
S	n.d.	0.04	0.11
Total	101.7	101.0	101.0
-O for F, S	0.03	0.06	0.06
Corr. sum	101.6	101.0	100.9
Minor elements (ppm)			
V	290	190	240
Cr	n.d.	50	30
Co	40	55	55
Ni	110	70	55
Zr	< 100	370	290
Sr	460	520	480
BaO	1930	1040	1070
Rb	120	120	60
Normative minerals (weight %)			
Quartz	—	6.8	4.6
Orthoclase	17.4	18.1	15.2
Albite	21.6	30.1	21.8
Anorthite	24.3	17.9	26.2
Diopside	8.7	0.7	5.7
Hypersthene	8.8	15.8	17.2
Forsterite	5.2	—	—
Fayalite	2.1	—	—
Magnetite	4.8	2.9	2.7
Ilmenite	2.3	2.9	2.7
Apatite	0.7	0.9	0.8
Fluorite	0.1	0.2	0.1
Pyrite	—	0.1	0.2
Calcite	—	0.7	0.1
Total	96.0	97.1	97.3
Atomic ratios			
Mg/Mg+Fe	0.58	0.46	0.41
K/K+Na	0.43	0.36	0.40
Ca/Ca+Na	0.62	0.42	0.61

TABLE 21. Modal analyses (volume percent) of basic dikes.  
(For sample locations, see Table 1.)

Sample no	K 430a*	K 615*
Quartz	+	1
Plagioclase + secondary sericite and epidote	55	58
Pyroxene	25	12
Biotite	+	—
Chlorite	6	12
Epidote	7	13
Calcite	—	1
Opakes	6	3
% An in the plagioclase	40—65	32

\* = chemically analysed sample

— = not detected

+ = present in small quantities (&lt;0.5 %)

### SANDSTONE

Within the Ragunda granite, c. 4 km W. of Ragunda old church, (69998 15245) a brownish red (tuffitic?) sandstone has been found. The sandstone constitutes probably a "dike" since in one place it is possible to observe a few metres of two vertical and roughly parallel contacts of the sandstone. The gap between the contacts indicates that the "dike" might have measured c. 5 m across. The sandstone occurs along the edge of a steep slope. One of its contacts with the Ragunda granite is rectilinear and can be followed c. 200 m in the direction of N. 75° W. Nearest the contacts the sandstone is penetrated by narrow bands of chalcedony lying closely together (Fig. 32). The granite has no chilled margin towards the sandstone, neither the sandstone has been cut by any granitic material.

The sandstone consists mainly of clastic quartz grains, which occasionally adjoin each other but mostly are separated by a matrix of sericitized feldspar. A great deal of somewhat less altered, reddish potash feldspar also occurs between the quartz grains. The grain-size is less than 0.1 mm. Larger quartz grains (c. 0.3 mm) occur sporadically. Opaque minerals are abundantly present.

The sandstone dike is to all appearances a fissure filling and is consequently the last remnant of a sandstone cover which may be supposed to have overlain the Ragunda massif but which has been completely removed by erosion.

The sandstone within the Ragunda massif is probably of Jotnian age as well as the Dala sandstone of Dalecarlia (Hjelmqvist 1966) and the Nordingrå sandstone of Ångermanland (Sobral 1913).

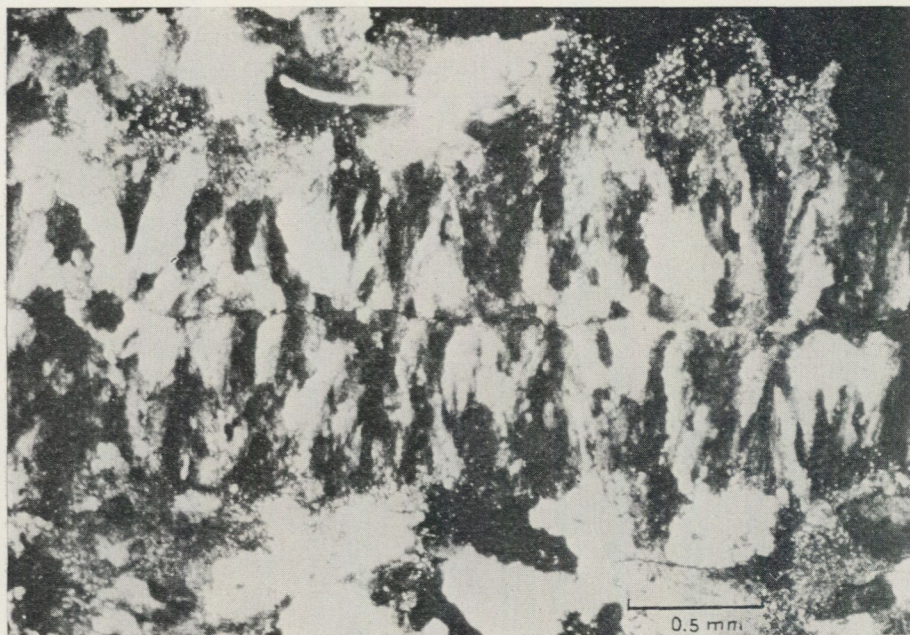


Fig. 32. Band of chalcedony along a fissure within the sandstone. 2 nic. C. 4 km W. of Ragunda old church. Photo K. A. Kornfält.

### JOTNIAN DOLERITE

As is evident from the map (Fig. 1), the investigated area is cut by a number of Åsby dolerite intrusions. These are rather small. The Åsby dolerite, which has got its name from the village Åsbyn in Dalecarlia, is a hypabyssal rock characteristic of regions with fissures opened during the Jotnian. Its magma has risen through fissures with high dips and has then spread along flat-lying fissures, thus solidifying as both dikes and sills. Most Åsby dolerite is found in Central Sweden: Kopparberg, Jämtland, Västernorrland and northernmost Gävleborg Counties (Magnusson et al. 1960, p. 61; Hjelmqvist 1966; Lundegårdh 1967; Lundqvist and Samuelsson 1973).

Within the Ragunda area the contacts of the Åsby dolerite with the wall rocks are as a rule not exposed, but in a few places it has been possible to observe them. The dolerite occurrences at Ammer (70063 15212) and c. 5 km W.S.W. of Ragunda railway station (69935 15256) have both more or less horizontal contacts. The Åsby dolerite seems to lie as rather flat sheets within the older rocks.

The small occurrence of Åsby dolerite at Ammer is the only one penetrating the rocks of the Ragunda massif. In this locality a sheet of fine-grained Åsby

dolerite lies on medium-grained, greenish grey syenite. The contact is almost horizontal, with chilled margins within the dolerite. The syenite grades towards the contact into a fine-grained, greenish grey rock with a composition lying between quartz syenite and quartz-poor granite. The same type of fine-grained, greenish grey rock penetrates the normal syenite on lower levels, partly as half a metre thick sills, partly as more or less vertical dikes. The fine-grained rock may possibly be the result of a melting and mobilization of the normal Ragunda syenite caused by the Åsby dolerite magma.

The Åsby dolerites within the Ragunda area are fine-grained to finely medium-grained. The colour is black or greyish black. The texture is ophitic or subophitic.

Plagioclase, augite, and olivine are the predominant minerals. The plagioclase is zoned and has an anorthite content which normally varies between c. 45% and 70%. There are also occasional small flakes of biotite and a great deal of opaque minerals.

#### DISINTEGRATION OF THE RAPAKIVI ROCKS (RAPAKIVI WEATHERING)

There is in places strong weathering in all the acid and intermediate rocks of the Ragunda massif with the exception of the granite porphyry and the fine-grained granite. The weathering is strongest and most frequent in the syenite and hornblende granite. Greatly weathered areas are particularly found in the hills N. of Holmstrand in the northernmost parts of the Ragunda massif (Figs. 33 and 34).

There are several different theories concerning the reasons for rapakivi weathering. They have been exhaustively discussed by Eskola (1930) and Savolahti (1962, p. 53).

Savolahti calls attention to the fact that the shrinkage of the minerals (and as a consequence the whole rock) may cause cracks and disruption of the minerals — or at least a loosening of their bonds. The shrinkage (owing to the heat coefficient of expansion) occurs when the temperature of the rocks falls. Since the crystallization temperature of the rapakivi rocks is considered to be higher than what is normal for granites, the predisposition to weathering caused by the shrinkage will probably be relatively greater in rapakivi rocks than in other rocks.

Another important reason for the strong rapakivi weathering (emphasized by Eskola and Savolahti) is the presence of shear zones.

Eskola noticed that in places where rapakivi weathering takes place under fresh rock, horizontal joints may occur and develop a kind of horizontal schistos-



Fig. 33. The strongly weathered southern slope of the Ärtriksklippen (70202 15459) near Holmstrand. Hornblende granite. Photo K. A. Kornfält.



Fig. 34. Areas of strong weathering often contain portions of better preserved rock. Hornblende granite. Ärtriksklippen (70202 15459) near Holmstrand. Photo K. A. Kornfält.

ity in the weathered material. He was of the opinion that the surface layer of the rock had moved along such joints and that the greater propensity to weathering here was due to a crushing along the shear surfaces.

Within the Ragunda massif one can in a few places (e.g. at Döviken, 70045 15190) observe horizontal bands of disintegrated rapakivi lying under fresh rock (Fig. 35). These disintegrated bands are composed of horizontal joints lying close together. These can be studied at places where the disintegration is not so advanced (Fig. 36). In these places one can also notice that the rock in this early stage does not rupture along the boundary surfaces between the mineral grains but along the joints, resulting in a weathering gravel composed of more or less parallelepipedic fragments.

Bands with closely-spaced vertical joints, where the weathering is further advanced than in the adjacent parts of the rock has also been observed, e.g. at Ärtrikklippen (70202 15460) N.W. of Holmstrand.

At some places within the Ragunda massif it has been possible to study the fresh rock underlying strongly disintegrated portions. One such locality is the



Fig. 35. Strongly weathered horizontal bands within fresh syenite, Döviken (70045 15190). Photo K. A. Kornfält.

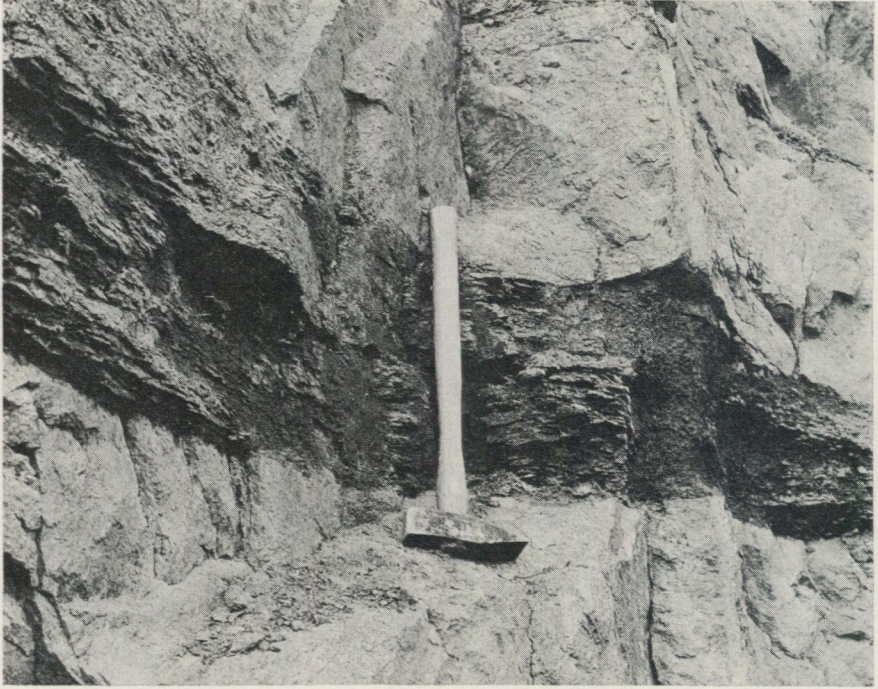


Fig. 36. Detail of strongly weathered band in Fig. 35, showing closely spaced horizontal joints along which the rock is most susceptible to disintegration. Dövikén (70045 15190). Photo K. A. Kornfält.

road cutting 3.5 km W.S.W. of Krångede hydro-power station (K 417a). If one carefully studies a piece of rock from this locality it is possible to notice very fine, closely-spaced, dark bands hardly visible to the naked eye (Fig. 37). In microscopic investigations it appears that these bands are composed of cracks filled with chlorite and amphibole. The amphibole-filled cracks, which penetrate all the mineral grains, seem to be identical with what Savolahti (1956, 1962) calls "weed texture" (see also p. 49). Within the Ragunda massif weed texture occurs in all analysed thin sections of syenite, hornblende granite, and biotite granite, most frequently, however, in syenite and hornblende granite. They are generally invisible to the naked eye but appear to be activated and more salient in certain directions, possibly owing to the effect of tectonic forces.

To sum up, it can be said that the seemingly capricious occurrence of the rapakivi weathering within the rocks of the Ragunda massif can practically always be associated with deformations caused by weak tectonic disturbances within the bedrock. Evidence of slight mechanical deformation affecting the Ragunda

rocks is found in the weak undulatory extinction which is nearly always present in their quartz.

As mentioned above, the syenite and hornblende granite are more susceptible to weathering than the biotite granite. It is not very likely that only tectonic deformation could have affected the rocks in such a selective way. Other factors, e.g. textural, may have predisposed the rocks in different degree. Later on mechanical disturbances have occurred along certain zones and have there caused the strongest disintegration (cf. Eskola 1930; Savolahti 1962).

If some of the mentioned cracks, especially the fine ones, were caused by the above mentioned shrinkage or merely by tectonic forces is difficult to decide. In this connection it can, however, be said that the syenite and hornblende granite of the Ragunda massif are supposed to have crystallized at a higher temperature than the biotite granite (Kornfält 1969). The shrinkage and the resulting fracturing thus ought to be greater in the syenite and hornblende granite than in the biotite granite.

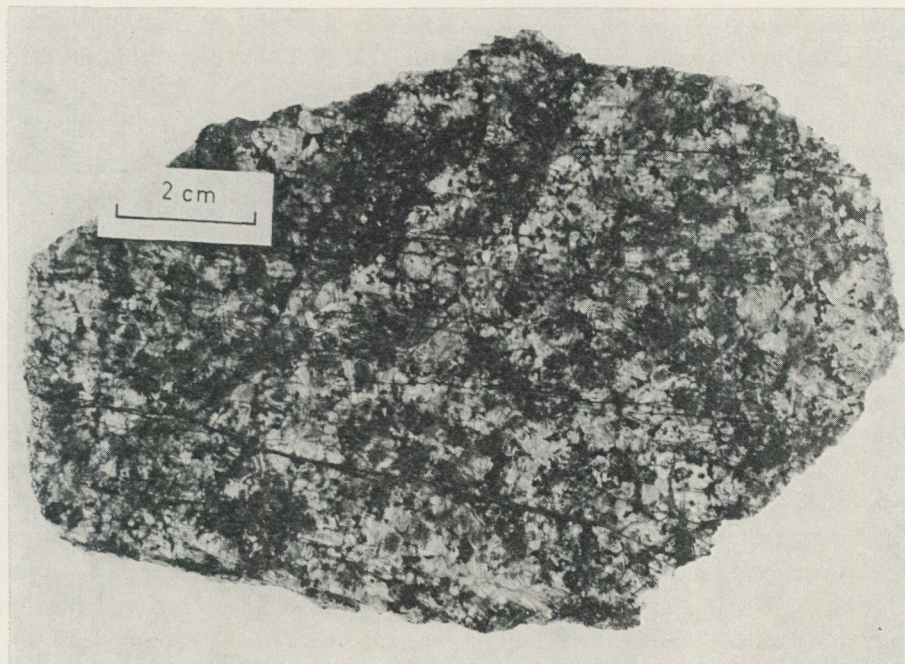


Fig. 37. Fine bands of amphibole and chlorite within a quartz syenite. Polished surface. 3.5 km W. S. W. of Krångede power station (70036 15101). Photo S. Stridsberg.

### IS THE RAGUNDA MASSIF A LACCOLITH?

As early as the end of the last century Högbom came to the conclusion that the Ragunda massif formed a laccolith with a lower basic, and an upper granitic layer within the older rocks (see p. 8).

This theory was supported by von Eckermann (1937b) and has been alive till recent time (Magnusson et al. 1963).

To start with, it is interesting to follow the evolution of this interpretation.

Ramsay (1890) was of the opinion that the intrusions of the rapakivi rocks of Hogland and Viborg were due to tectonical subsidence structures.

In 1891 Sederholm suggested the theory that the rapakivi rocks were created during a period when great thrusts and grabens were formed. He meant that these were also the cause for the formation of the rapakivi rocks. Sederholm supposed that the rapakivi magma had pushed its way forward through these openings as far as the earth's surface.

In a paper from the same year, 1891, Cohen and Deecke expressed their opinion that the rapakivi rocks formed laccoliths. This opinion was criticized by Sederholm (1892).

When Högbom investigated the Ragunda massif (1896—97) it was therefore natural for him to take a great interest in the question of the intrusion mechanism.

Already from the very beginning of the mapping Högbom found it remarkable that the gabbro occurred in the centre of the massif and not along the margins which had proved to be the case within other rapakivi areas (Högbom 1893).

Högbom found the gabbro outcrops along the deep eroded river valley of Indalsälven. These areas were consequently the topographically lowest situated.

On the basis of the mentioned topographic relations and some field observations Högbom put forward a tectonical model for the Ragunda massif. He considered the massif to be a laccolith within the older rocks, where the gabbro formed a lower layer and the granite an upper (see Högbom 1899, p. 11). The erosion had gradually exposed the gabbro of the lowest situated parts along Indalsälven.

During Högbom's mapping it appeared that in the extreme west (at Krångede) gabbro occurred on a higher topographic level than granite. Högbom described this as remarkable and proposed that the gabbro has here been completely cut through by erosion and that the granite forms the base of the gabbro.

In a paper from 1909 Högbom recurred to this modified model (applicable to at least the westernmost parts of the Ragunda massif) in which he thought of

a nucleus or core of gabbro which both on its top side and under side were enclosed by Ragunda granite or syenite (Högbom 1909, p. 350 ff.).

During the new investigations of the Ragunda massif the writer has not been able to support Högbom's hypothesis of a laccolith with a lower basic and an upper, more acid rock layer. This is mainly due to the fact that the new map has been made much more detailed than Högbom's old, small-scale map. Besides, the latter was drawn on a very imperfect topographical basis. During the present mapping it has thus appeared that the gabbro occurs on high topographic levels (Fig. 38). It is not at all confined to the central, lower parts of the massif, but rather to the margins of the massif (Fig. 1).

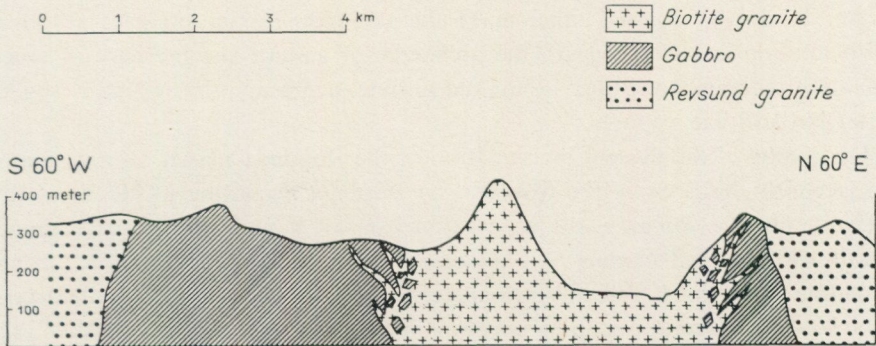


Fig. 38. Profile through the Ragunda rapakivi massif (see Fig. 1). (Cf. Högbom 1899, Fig. 2.)

For obvious reasons Högbom received an impression that the gabbro occurred within the lower parts of the massif and the granite at higher levels. As a matter of fact, if one follows the river Indalsälven from lake Gesunden to Hammarstrand one will only meet the gabbro in the river-bed — apart from the granite and syenite at the Krångede Falls. This may probably be due to the fact that the gabbro has been more resistant to erosion than the acid rocks. The gabbro has consequently remained in the river-bed as thresholds, whereas the rapakivi granite and syenite have been completely removed by erosion. Since the road followed the river — at this time roads were lacking at the top of the rather inaccessible hills — it is easy to understand why Högbom during his very cursory mapping obtained an erroneous view of the distribution of the rocks.

The fact that Högbom's examinations in detail of the bedrock are not in accordance with the results from the present investigation could also possibly be due to his very cursory mapping of the Ragunda massif.

On the other hand von Eckermann's later support of Högbom's laccolith hypothesis after, as he says himself, several visits to the Ragunda area seems more difficult to explain if one does not remember the violent controversy at this time between von Eckermann and Backlund (see Read 1957, pp. 138—142).

Backlund (1938) advocated, as is well known, that the rapakivi granites were formed by a metasomatic replacement of the Jotnian sandstone. Von Eckermann (1937a, b) on the other hand, was of the opinion that the rapakivi granites had a magmatic origin.

It is easy to understand why von Eckermann readily regarded the Ragunda massif as a laccolith. He could then use this supposition as a very strong argument against Backlund's theory. Consequently von Eckermann wrote apropos the Ragunda massif (1937b, p. 516): "... I do not understand how any petrologist could seriously even suggest, still less entertain, the belief of a sedimentary origin. To do so, he must either make the astounding assumption of a Jotnian sedimentation in caves beneath the archaean, or assume the presence of svecofennidic sediments engulfed by the old granite, a presumption which is slightly better but still bad enough".

The results of the present investigation of the Ragunda massif do not support the laccolith character of the massif — at least not according to Högbom's hypothesis. On the contrary, the observations on all boundaries of the Ragunda massif with vertical contacts — sometimes with fine-grained marginal zones, sometimes brecciated — seem to indicate that the rapakivi magma was intruded by a kind of magmatic stoping accompanied by heavy block movements. The Ragunda massif consists probably of several more or less circular, separate intrusions. The gabbro in the westernmost part of the area, with its circular outline, may suggest a ring structure.

The Finnish rapakivi massifs are generally considered to be connected with vertical movements within the earth's crust (Ramsay 1890, Sederholm 1891, Hackman 1934). Bridgwater and Windley (1973) maintain that the intrusion of the postorogenic rapakivi granites, anorthosites, and acid volcanics which occur in a zone from the Ural to western USA, "was commonly controlled by tectonic lineaments and graben-like features."

The intrusion of the Viborg massif was considered to have the shape of a sheet (Wahl 1925) or a batholith (Hackman 1934). Gravity measurements over the Viborg and Ahvenisto massifs in Finland have shown that these can be interpreted as enormous asymmetrical laccoliths with the roots lying at a depth of 18—20 km (Laurén 1970).

Recently Bridgwater et al. (1974, p. 57) have shown that postorogenic intrusions of rapakivi granites in South Greenland are mushroom-shaped. The intrusions are associated with considerable subsidence of the country rocks.

It is very likely that geophysical investigations of the Ragunda massif would contribute much to its intrusionary form.

### THE CONTACTS BETWEEN THE RAGUNDA RAPAKIVI MASSIF AND THE OLDER ROCKS

Wherever the contacts between the rocks of the Ragunda massif and the surrounding rocks are exposed, they are practically always more or less vertical (Fig. 39). Owing to brecciation of the country rocks into large blocks, sometimes with horizontal surfaces, it is possible to find horizontal contacts over short distances, e.g. at Middagsberget (69938 15288) about 2 km W.S.W. of Ragunda railway station. In broad outline the contact is, however, vertical.

In the contact zone against the country rocks the Ragunda granite and syenite have, in some cases, a fine-grained texture (Fig. 39), while in other cases no changes in the grain-size have been observed. Instead, brecciation of the country rock is often met with (Figs. 40 and 41).

These chilled margins and the brecciation of the older granites and meta-sediments prove that the Ragunda granite and syenite are younger than the surrounding rocks.



Fig. 39. Vertical contact between fine-grained Ragunda granite (left) and coarsely porphyritic Revsund granite (right). Middagsberget (69938 15287). Photo K. A. Kornfält.



Fig. 40. Xenolith of coarsely porphyritic Revsund granite in medium-grained Ragunda granite. Hökberget (69991 15224). Photo K. A. Kornfält.

It has, however, been impossible to determine the age relations between the Ragunda gabbro and the surrounding granites and meta-sediments by means of field observation, as the gabbro is always brecciated by Ragunda granite in the contact zone. But no dikes of Revsund or Härnö granites in the Ragunda gabbro have been observed. Further, the grade of amphibolitization is much weaker than would be expected if the gabbro had been a synorogenic one.

In a road cutting c. 5 km S. of Helgum church (70077 15514) there occurs, apart from xenoliths of metagreywacke, also xenoliths of fine-grained, massive gabbro lying within a grey, small-porphyrific rock similar to Härnö granite (Fig. 42). The fine-grained gabbro is of the same type as the above described Ragunda gabbro (p. 27). If the brecciating granite is actually a Härnö granite, the mentioned field observation would imply that the gabbro of the Ragunda massif is older than the Härnö granite.

The granite in which the gabbro xenoliths occur contains pegmatite veins and has, in other respects, a more heterogeneous appearance than the porphyritic Härnö granite (p. 15) which occurs a little further towards the south.

Furthermore, the potash feldspar of the Härnö granite-like rock is orthoclase (triclincity = 0), while the potash feldspar of the Härnö granite proper is most often microcline.



Fig. 41. Ragunda syenite with remnants of metagreywacke brecciating light grey serorogenic granite. C. 4 km W. of Krångede (70035 15101). Photo K. A. Kornfält.



Fig. 42. Xenoliths of Ragunda gabbro in a grey, porphyritic heterogeneous granitoid. C. 5 km S. of Helgum church (70077 15514). Photo K. A. Kornfält.

The brecciating granite is presumably a Härnö granite which in part has been recrystallized and mobilized in connection with the intrusion of the rapakivi rocks. This mobilized Härnö granite has then been able to brecciate the gabbro.

Within the area between the rapakivi granite and the surrounding metagreywackes occurs a narrow zone of medium-grained, grey palingenic granite containing xenoliths of metagreywacke (Fig. 43). As a rule cordierite and orthoclase are present in these xenoliths. This points to a contact-metamorphic alteration of the metagreywacke. Furthermore, contact alterations are occasionally seen in the metagreywacke bordering the rapakivi granite. At Sjöberget (70207 15484) north of Holmstrand, within a maximally 4 metres wide zone outside the contact with the rapakivi granite, the metagreywacke contains diffuse spots consisting of cordierite aggregates in which green spinel and andalusite occur (L. Persson and Th. Lundqvist, personal communication). In addition to the main minerals biotite, quartz, plagioclase( $An_{26}$ ) (and the above mentioned minerals), minor amounts of chlorite, muscovite, sericite, microcline, apatite, and opaque minerals are also present in this rock sample.

No special investigation on the extent of these hornfels formations has been carried out. During the mapping nothing has, however, appeared which would indicate that the hornfels aureole should have considerable extension.



Fig. 43. Xenoliths of metagreywacke in a medium-grained, grey palingenic granite. From the contact zone between Ragunda hornblende granite and metagreywacke. Ärtviksklippen (70202 15459). Photo K. A. Kornfält.

### ON THE CHEMISTRY OF THE RAGUNDA MASSIF

The chemical analyses of the rocks from the Ragunda massif have been summed up in a number of triangular diagrams (Figs. 44, 49, and 51) and variation diagrams (Fig. 46, 47, and 48).

From the ALK-F-M diagram (Fig. 44) it is clear that the analyses of the country rocks (Holmsta, Härnö, and Revsund granite) fall substantially off the trend of the Ragunda granites and syenites. This is due to the low MgO contents of the last mentioned rocks.

In addition to the low MgO content, the Ragunda granite usually contains less CaO and  $\text{Al}_2\text{O}_3$  than "normal" granites. On the other hand, it has in most cases higher contents of  $\text{SiO}_2$  and  $\text{K}_2\text{O}$  than "normal" granites. This is a feature typical of rapakivi granites, a fact pointed out by, among others, Sahama (1945). In certain cases the Ragunda rocks do not contain sufficient  $\text{Al}_2\text{O}_3$  to permit all available alkali to be consumed during the formation of feldspar. The molar ratio  $\text{Na}_2\text{O} + \text{K}_2\text{O}/\text{Al}_2\text{O}_3$  is then  $> 1$  and the rocks can be designated as peralkaline (Shand 1947, p. 228 f.). The conditions are reflected in the CIPW norm which in these cases shows acmite (K 210, Table 19; K 616, Table 14). The rocks in question do not, however, contain alkali pyroxene but alkali amphibole (riebeckite—arfvedsonite). Most of the other syenites and hornblende gra-

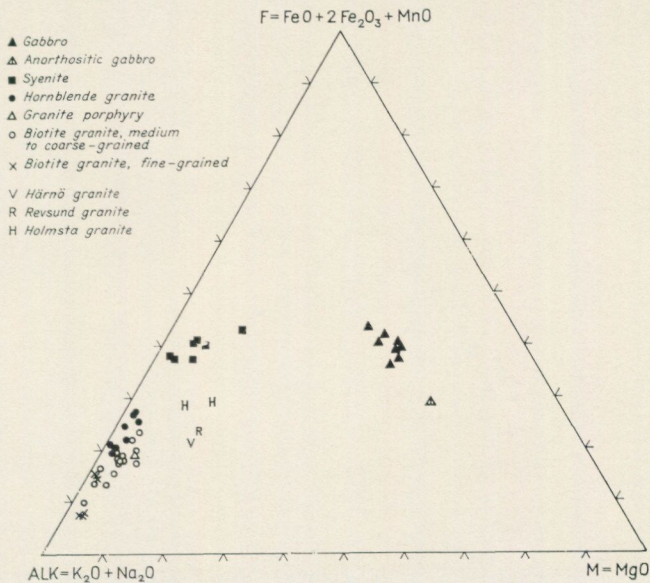


Fig. 44. ALK-F-M diagram (mol. %) for rocks from the Ragunda rapakivi massif and for surrounding older granites (Härnö, Revsund, and Holmsta granite).

nites within the Ragunda massif contain small amounts of alkali amphibole, though the bulk composition of the rock as a rule is peraluminous (i.e.  $\text{Al}_2\text{O}_3 > \text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO}$ ) or metaluminous (i.e.  $\text{Al}_2\text{O}_3 > \text{Na}_2\text{O} + \text{K}_2\text{O}$ ; Shand, op. cit.).

In the ALK-F-M diagram of Fig. 45 the plots of the Nordingrå and Mårdsjö rapakivi massifs in Sweden (von Eckermann 1938, p. 251; Th. Lundqvist, unpublished data; Kornfält, unpublished data) and the Ahvenisto and Viborg rapakivi massifs in Finland (Savolahti 1956, p. 77; Vormaa 1971, p. 8) have been compared to the differentiation trend of the Ragunda massif. The stippled contour line in Fig. 45 shows the area of 99 plotted analyses of Nordingrå gabbro (Gunilla Lundqvist, unpublished lic. thesis). As regards the intermediate and acid rocks from the mentioned massifs, they plot mainly along or quite near the Ragunda trend (broken contour line in Fig. 45). The basic rocks, however, with few exceptions fall clearly outside the area occupied by the Ragunda gabbro. The Ragunda gabbro is not as iron-rich as are most of the other gabbros in the comparative plots. The Rätan and Dala granites (Lundqvist 1968, Table 1a) which are also plotted in Fig. 45, differ rather clearly from the trend displayed by the rapakivi rocks.

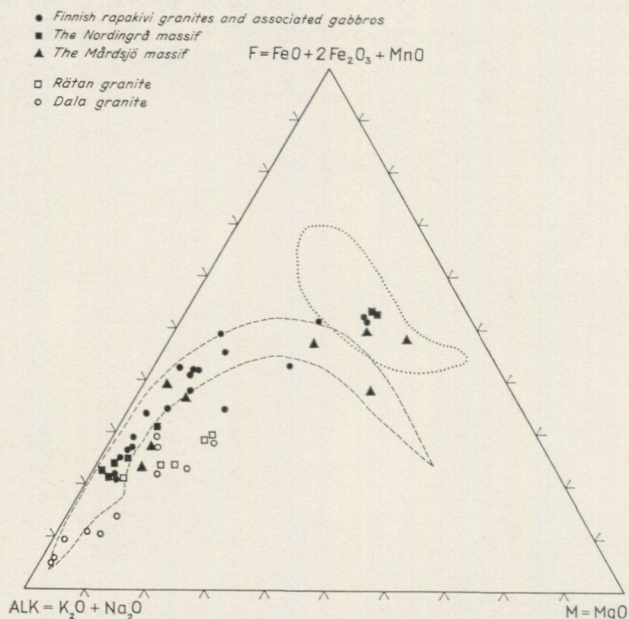


Fig. 45. ALK-F-M diagram (mol. %) for Finnish rapakivi granites and associated gabbros, as well as for the Nordingrå massif and the Mårdsjö massif. The stippled line encloses 99 gabbro analyses from the Nordingrå massif. The broken line encloses the plots given in Fig. 44 of the Ragunda rapakivi suite.

Fig. 46 shows variation diagrams for major elements of the Ragunda rocks. The syenites, hornblende granites and biotite granites show relatively smooth differentiation trends. The gabbros do not, however, plot on these smooth lines. On the contrary they deviate clearly (with the exception of FeO and  $\text{Fe}_2\text{O}_3$ ), indicating that the syenites and granites cannot possibly be continuous differentiation products of a primary basic magma.

The apparently smooth trend of the syenites and granites divides in two, when plotted in a  $\text{Mg}/\text{Mg} + \text{Fe}$  versus  $\text{SiO}_2$  diagram (Fig. 47). This diagram suggests that the syenites and hornblende granites form one specific trend differing from that of the biotite granites. The division in two trends becomes still clearer from Fig. 48 which shows the Ragunda rocks in a  $\text{Mg}/\text{Mg} + \text{Fe}$  versus  $\text{Ca}/\text{Ca} + \text{Na}$  diagram. Also the ALK-F-M diagram (Fig. 44) supports the assumption of a specific syenitic—hornblende granitic trend separated from the biotite granitic trend.

If the plots of the hornblende granites in the isolated massif at Holmstrand (with  $\text{SiO}_2$  between 66 and 72 % in Fig. 46) are removed from the variation diagrams of Fig. 46, the plots of the syenites and granites will cluster in two areas separated from each other by a gap about 13 % in the  $\text{SiO}_2$  content. This absence of rocks with intermediate compositions in the large main massif supports the assumption of the intrusion of two different magmas, one granitic and the other quartz syenitic.

The plots of the hornblende granites of the small massifs (cf. p. 50) surrounded by biotite granite (with  $\text{SiO}_2$  above 73 % in Fig. 46) coincide on the whole with those of the biotite granites. Therefore it seems unlikely that this type of hornblende granite was developed by assimilation of early formed syenite under the influence of the granitic magma (cf. p. 55). If so, the hornblende granites of the mentioned type ought to have fallen on intermediate positions between the syenites and granites in the variation diagrams (Fig. 46).

In the Q-Ab-Or diagram (Fig. 49) most of the analyses of biotite granites and hornblende granites of the Ragunda massif fall within or just outside (shifted towards the Or apex) the area of maximum concentration of analyses of granites in the world (Tuttle and Bowen 1958, p. 79). It also appears from the diagram that most of the biotite granite and hornblende granite analyses group within the quartz—alkali feldspar field boundaries at  $P_{\text{H}_2\text{O}} = 0.5$  kb and 5.0 kb (Tuttle and Bowen 1958; Luth et al. 1964) and on the Or side of the ternary minima or eutectics for the various water pressures shown in Fig. 49.

The three different trends in the variation diagrams (cf. e.g.  $\text{Mg}/\text{Mg} + \text{Fe}$  versus  $\text{SiO}_2$  in Fig. 47) may suggest that at least three major magmas have intruded. The first intrusion had basic composition, the second quartz syenitic and the third granitic. In the quartz syenitic magma, rather considerable in situ fractionation processes must have taken place to produce the hornblende granites of the small massifs and the late sodium-rich derivatives connected with

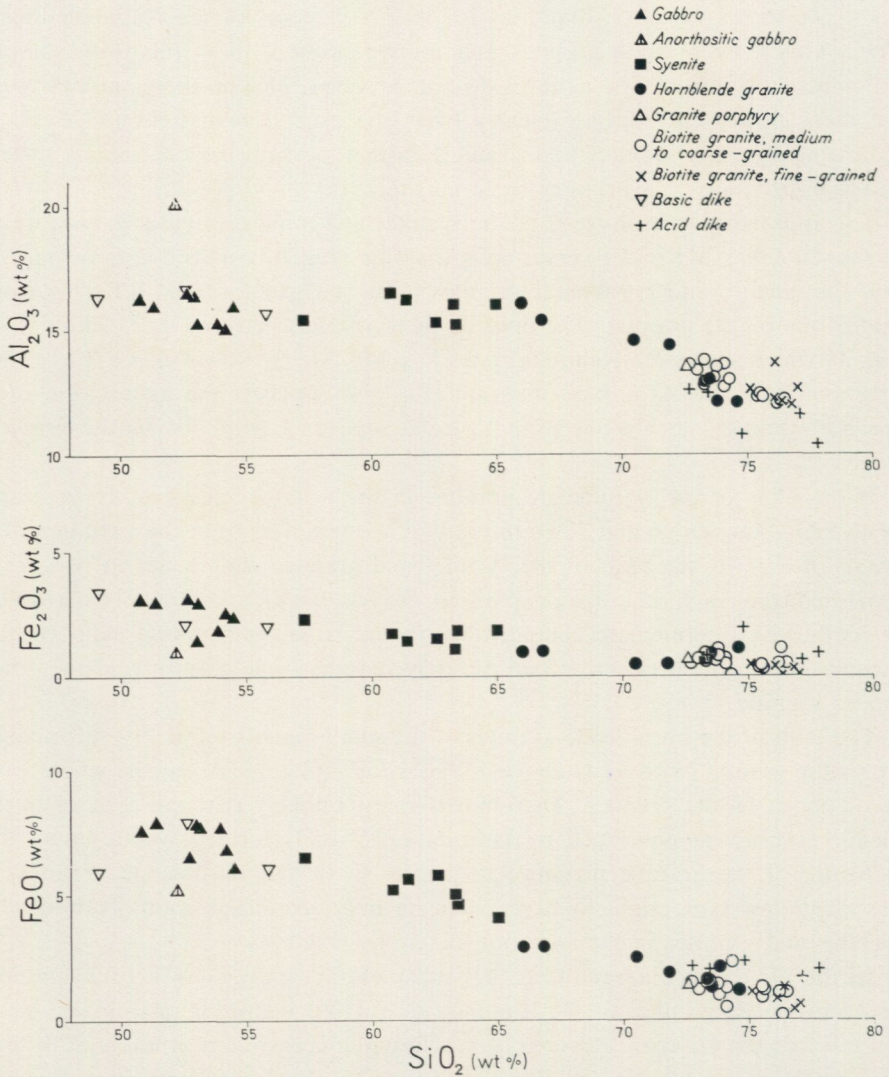


Fig. 46. Silica variation diagrams (wt %) for major elements of the Ragunda rapakivi massif.

these (cf. p. 55). It is at present impossible to decide whether the isolated hornblende granite massif at Holmstrand with its chemically and mineralogically somewhat differing rocks represents a separate magma intrusion or is related to either the quartz syenitic or the granitic magma.

In the ALK-F-M diagram (Fig. 44) the Ragunda rocks form a trend of weak iron enrichment followed by alkali enrichment. Even if the rock groups forming

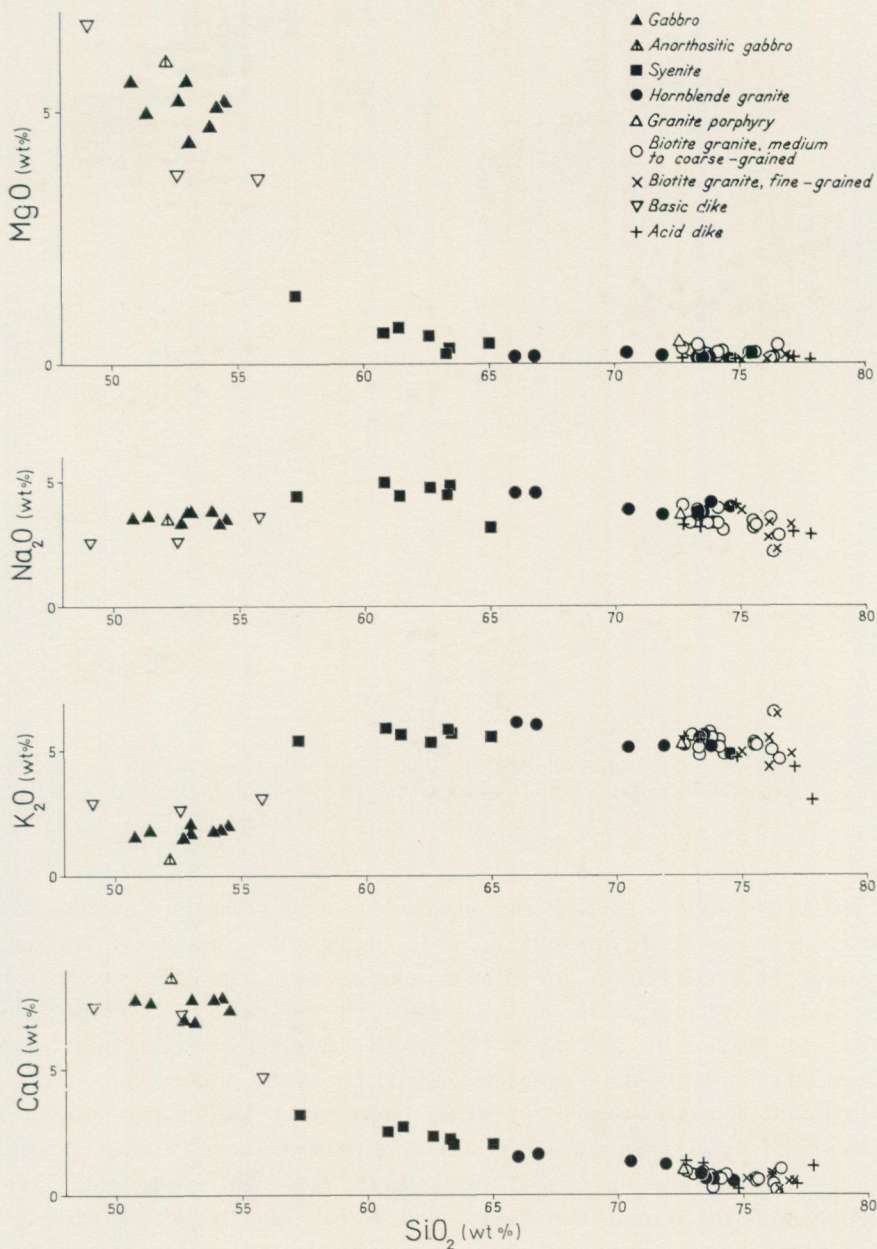


Fig. 46 (continued).

the Ragunda massif belong to separate intrusions as mentioned above, they may broadly suggest a genetic relationship.

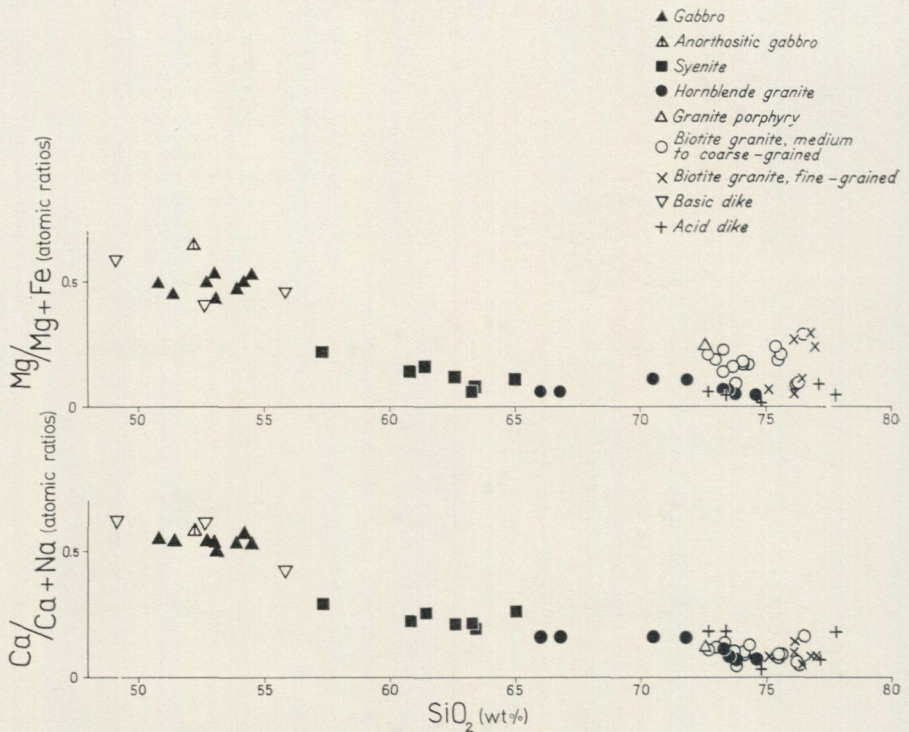


Fig. 47. Plots of atomic ratios  $Mg/Mg+Fe$  and  $Ca/Ca+Na$  versus weight per cent  $SiO_2$  for rocks from the Ragunda rapakivi massif.

The  $K/Rb$  ratios of the acid and intermediate rocks from the Ragunda massif are given in Fig. 50. Taylor (1965, p. 144), among others, has shown that an increase in the  $Rb/K$  ratio is caused by extreme fractionation (cf. Shaw 1968). The "normal"  $K/Rb$  ratio of the earth's crust is 150—300 and the average ratio is about 230 (Taylor, *op. cit.*). From Fig. 50 it is clear that some of the ratios fall outside the limits for the average values. As far as the granites are concerned, their low  $K/Rb$  ratio points to a strong fractionation leading to a relative enrichment of  $Rb$ . This enrichment is still more pronounced in the alkali feldspars (Table 22) which contain most of the  $Rb$  in the Ragunda syenites and granites.

As regards the syenites they have a high  $K/Rb$  ratio. If the original magma has had a syenitic composition with an initially low  $Rb$  content this would be quite natural. If the magma, on the other hand, is formed from crustal material with a normal  $K/Rb$  ratio, a slight enrichment of  $Rb$  would have taken place during the fractional crystallization process (Taylor 1965, p. 147). A strong enrichment of  $Rb$  can take place if the volume of melted liquid is small (Gast 1968). The deficiency of  $Rb$  may, however, be explained by an accumulation of

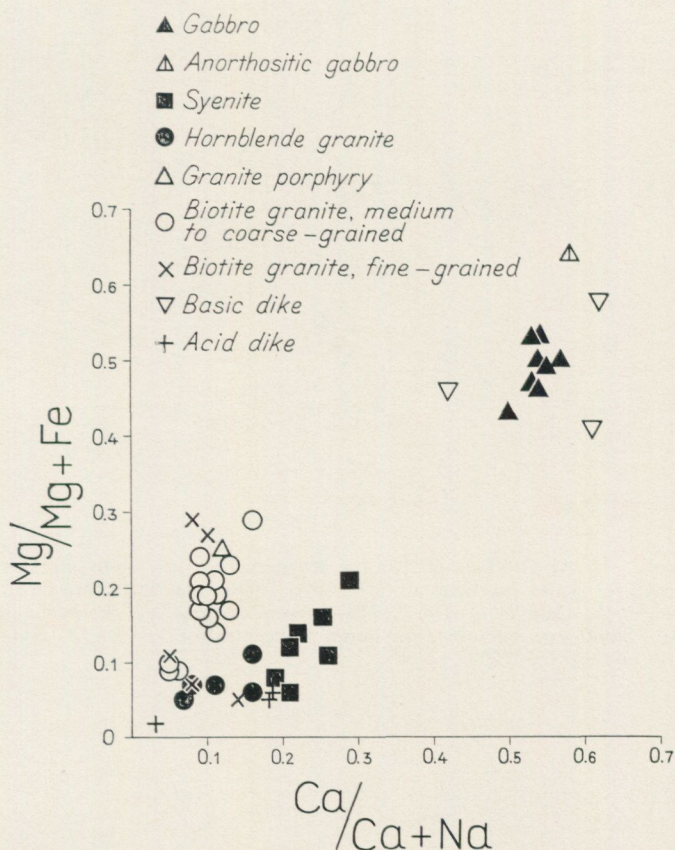


Fig. 48. Plots of atomic ratios  $Mg/Mg+Fe$  versus  $Ca/Ca+Na$  for rocks from the Ragunda rapakivi massif.

early-formed feldspar crystals which themselves have had a deficit of Rb (Taylor op. cit., p. 148; cf. Lundqvist 1968, p. 110). It is impossible to decide from direct field observations whether the Ragunda syenite has formed by accumulation of early feldspar crystals within a more  $SiO_2$ -rich magma or originates from a magma the composition of which, on the whole, is the same as the rock in question. The presence of gabbro penetrated by syenite indicates, however, the existence of a syenitic magma. If the syenite was formed by accumulation of early feldspar crystals, one would expect the CaO content to be substantially higher in the syenites than in the biotite granites. This is not the case, as is evident from Fig. 51.

The decrease of the Ba/K ratio from syenite to granite (Fig. 52) may also be

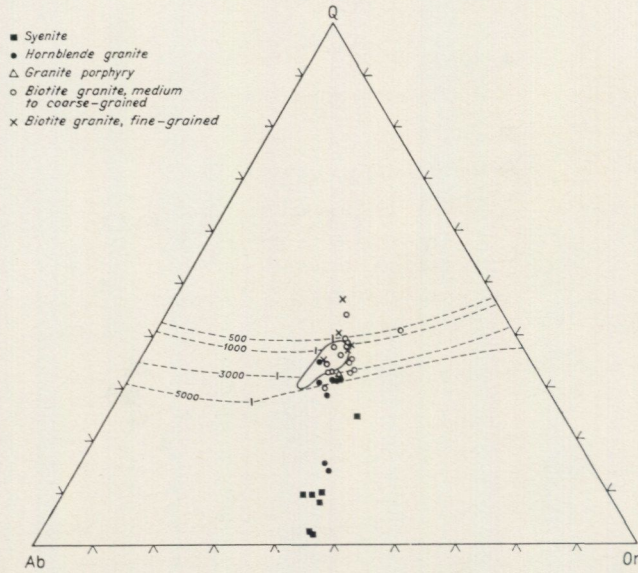


Fig. 49. Normative Q-Ab-Or diagram for the Ragunda rapakivi suite. Broken lines show cotectics for water pressures of 500, 1000, 3000, and 5000 bars (after Tuttle and Bowen 1958, Luth et al. 1964). The ternary minima are denoted with a vertical stroke. Solid line encloses maximum concentration of world granite analyses (Tuttle and Bowen 1958).

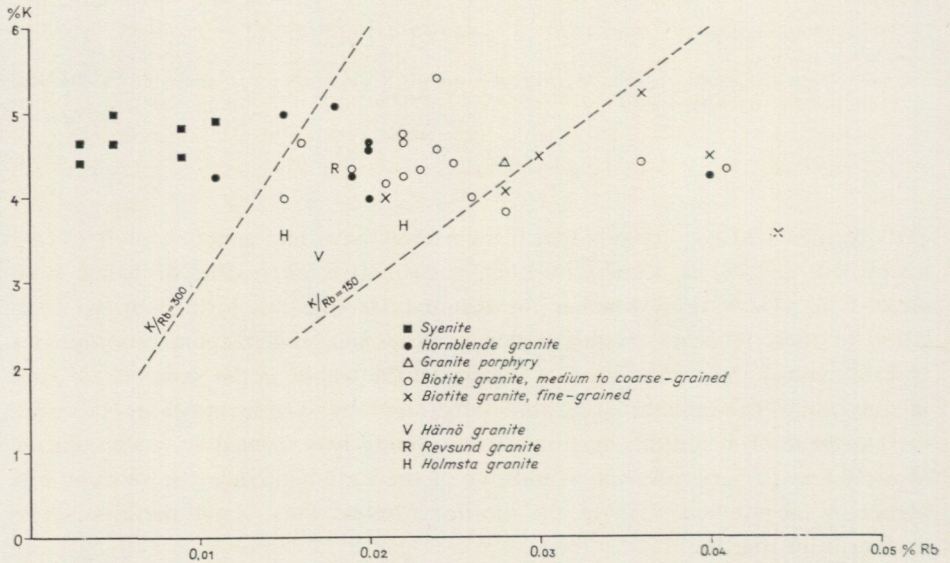


Fig. 50. Plots of Rb against K for the Ragunda rapakivi suite and surrounding rocks.

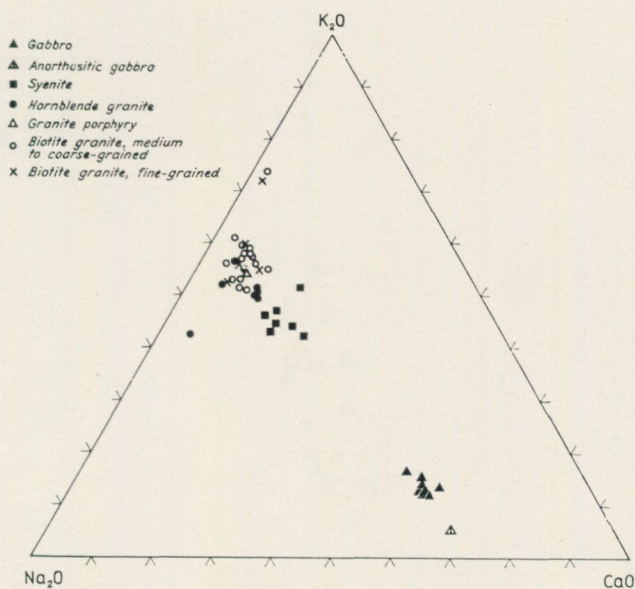


Fig. 51.  $K_2O$ - $Na_2O$ - $CaO$  diagram (atomic ratios) of rocks from the Ragunda rapakivi massif.

interpreted as evidence for a fractional crystallization, as barium has a tendency to become enriched in early formed potassium minerals (Taylor 1965, p. 155). This tendency is also clear in the separated alkali feldspars (Table 22).

The Sr/Ca ratio has not been useful as a fractionation guide, as the content of Sr changes very little during differentiation. This is in accordance with observations made by Rankama and Sahama (1950, p. 475), and is probably due to the capture of Sr in K positions of early-formed alkali feldspars (Taylor 1965, p. 154), which compensates for the increase of Sr relative to Ca during fractionation (cf. Lundqvist 1968). Table 22 shows that also the alkali feldspars of the different Ragunda rocks exhibit relatively little changes in Sr.

Furthermore, Table 22 shows the composition of the potassic phase in the perthitic potash feldspar. This has been determined in separated potash feldspars by X-ray using the equations of Orville and Wright-Stewart (in Wright 1968, p. 97). The method is applicable only when either one (orthoclase) or two (microcline) sharp 131-, respectively 131- and  $\bar{131}$ -reflections occur (see Wright and Stewart 1968, p. 80). The composition of the potassic phase in the perthite can be related to the thermal state of the potash feldspar (cf. Vormo 1972, p. 56 f.). Consequently, the amount of albite in solid solution with potash feldspar is higher in

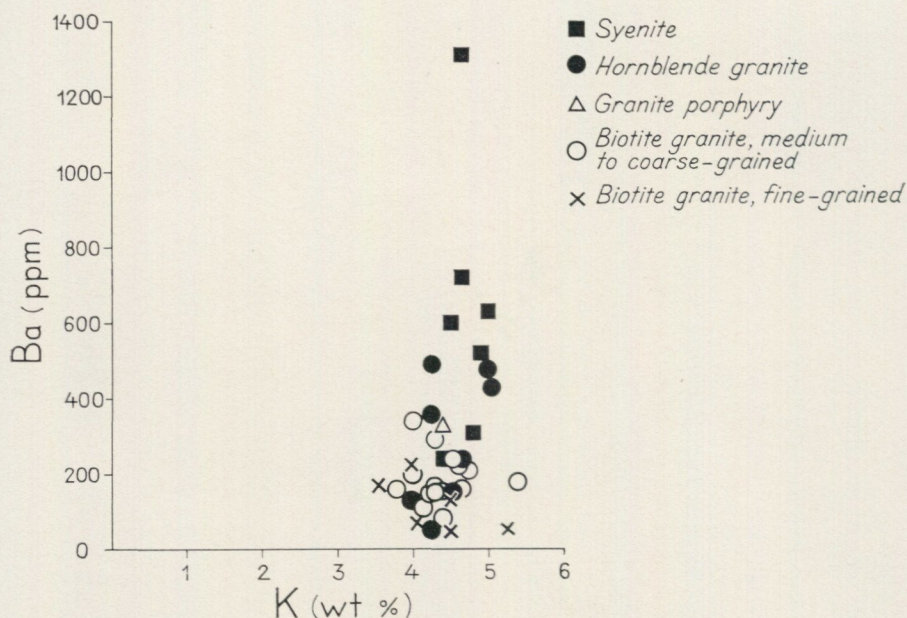


Fig. 52. Plots of Ba against K for rocks from the Ragunda rapakivi massif.

the syenites (where orthoclase predominates) than in the more acid rocks (where microcline predominates). The fairly high contents of albite (c. 10%) in the potassic phase of the syenites indicate that the exsolution of its albite is rather incomplete. This may depend on shortage of volatiles.

The microprobe analyses of the minerals show that the mafic minerals of the syenites and granites (e.g. clinopyroxene, Table 24, p. 105) are considerably poorer in MgO than the corresponding minerals of the gabbro. The reason for these systematic differences will be discussed in the next chapter.

The chemistry of the east Fennoscandian rapakivi granites has been studied by Sahama (1945). He found that these rocks were relatively rich in rare-earth elements (REE) and considered this fact as very remarkable, since "no lanthanide minerals proper have ever been observed in the rapakivi granites" (op. cit., p. 48). In the rocks of the Ragunda massif allanite (Table 28; Fig. 22) appears, however. It occurs mainly in the biotite granite, but it has also been found in a few samples of hornblende granite and syenite. Analyses of REE in the Ragunda massif are at present carried out by Dr. Ove Landström at the laboratories of AB Atomenergi, Studsvik.

TABLE 22. Partial chemical analyses, compositions (weight % or, in two cases, ppm) and triclinicity ( $\Delta$ ) of some perthitic alkali feldspars from the Ragunda massif.  
(For sample locations, see Table 1.)

No	Rock	Or	Ab	An	Fe <sub>2</sub> O <sub>3</sub>	FeO	BaO	Rb (ppm)	Sr (ppm)	Or in the potassic phase	$\Delta^1$
K 229	Quartz syenite	50.5	45.8	3.6	0.21	0.34	0.07	80	85		0.0—0.71
K 259	Syenite	49.6	48.9	1.4	0.34	0.41	0.03	105	50	88.4	0.0
K 417b	Syenite	54.5	42.5	2.8	0.11	0.43	0.08	155	95	90.6	0.0
Nr 132	Hornblende granite	65.3	32.7	1.9	0.08	0.16	0.08	325	90	95.8	0.66
Nr 137	Hornblende granite	66.5	32.3	1.1	0.11	0.14	0.08	365	90		(0.0) 0.70
K 209	Biotite granite	64.9	34.0	0.9	0.22	0.09	0.04	425	65		(0.0) 0.71
K 336	Biotite granite	56.2	42.0	1.6	0.29	0.10	0.06	285	85		(0.0) 0.68
K 391	Biotite granite	56.8	41.1	1.9	0.15	0.13	0.05	300	90		(0.0) 0.70
K 580	Biotite granite	67.4	31.5	1.0	0.15	0.14	0.01	600	55	93.5	0.78
K 250	Biotite granite, fine-grained	58.6	40.5	0.8	0.21	0.14	0.01	605	15	93.9	0.84

<sup>1</sup> Brackets = subordinate amounts

### SUMMARY AND CONCLUSIONS

To all appearances the rapakivi rocks of the Ragunda massif have a magmatic origin which is clear from the distinct intrusion contacts with either fine-grained, chilled contacts, or contact breccias.

The rapakivi magma probably had a fairly high temperature. The hornfels occurrences and the lack of pegmatite and aplite point to this. The hornfels aureole of the Ragunda area seems to be very restricted, which may be due to a relatively small and quite shallow intrusion. Vormaa (1972, p. 9) calculates the intrusion temperature of the Viborg massif (where pyroxene-hornfels facies occurs within the contact aureole) to be somewhat higher than 800° C. By means of the composition of the titaniferous magnetite, Sviridenko (1968) has been able to estimate the crystallization temperatures for the rocks of the Salmi rapakivi massif as 880°—940° C.

The plagioclase of the Ragunda syenite occurs together with potash feldspar only as perthite (film, string, vein, and patch perthite) which mainly has formed by unmixing during the cooling process. This indicates that the rock crystallized at a temperature above the solvus in the binary system  $\text{NaAlSi}_3\text{O}_8$ — $\text{KAlSi}_3\text{O}_8$  (Tuttle and Bowen 1958, p. 128). Film perthite is present only in the syenites. In these, the vein and patch perthites are not as strongly developed as in the granites. The latter have fairly wide veins and numerous patches of plagioclase within the potash feldspar grains. The exsolution of plagioclase from the potash feldspar has here proceeded further than in the syenites. This is also clear from Table 22 which shows that the amount of albite in solid solution with the potash feldspar is larger in the syenite than in the granite. In the Ragunda granites plagioclase also occurs as discrete crystals between the potash feldspars. Tuttle and Bowen (op. cit.) have shown that the solubility between sodium feldspar and potash feldspar decreases with falling temperature. The fact that the syenites do not exhibit the same high-grade exsolution as the granites may be due to the fluxing power of volatiles in the latter. Exsolution will take place readily if there is a copious supply of volatiles. This is clear from laboratory experiments by Tuttle and Bowen (op. cit.).

The perthitic patches within the potash feldspar crystals may occasionally have developed a band with uniform extinction, along the margin of the potash feldspars. In some cases this band is found a bit into the potash feldspar grain (see Kornfält 1969, Fig. 5). It is quite clear that exsolved and perhaps migrated sodium feldspar forming perthite sometimes forms those mantles which sporadically occur around the potash feldspar of the Ragunda massif.

Exsolution and a certain migration of sodium material as an explanation of

the rapakivi texture has already been discussed by Gates (in Emmons et al., 1953, pp. 67—69), Hutchinson (1956), Neuvonen (1957), and Sylvester (1962). In this connection, it should be mentioned that there are other theories which instead explain the origin of the rapakivi texture as the result of magmatic crystallization processes or metasomatic exchange (see discussion in Vorma 1971, p. 59). Presumably there is no general explanation of the rapakivi texture, but in accordance with Vorma (op. cit.; cf. Elders 1968), one has to assume that different factors may have influenced the formation to different degrees depending on, among other things, the type of intrusion.

In spite of the high intrusion temperatures of the rapakivi magma the country rocks within the Ragunda area have not been affected to such a degree that they have melted or mobilized. However, the temperature ought to have been sufficient for an anatexis of the metagreywacke (Winkler 1967, p. 208), but presumably the intrusion has occurred near the crust implying that the water pressure was not sufficient. Besides the fluid phase of the rapakivi magma, which could have facilitated the transformation of the country rock, must have escaped upwards. This is evidenced by the fact that the country rocks (except the gabbro) have never been metasomatically altered by the rapakivi magma (cf. Vorma 1972, p. 18). The stoping-like intrusion model with more or less vertical contacts may also have contributed to the incapability of the rising heat and the fluid phase to alter the country rock.

It is possible that the mentioned processes instead were concentrated to the rocks resting immediately over the intruding rapakivi magma. At least at greater depths, the  $P_{H_2O}$  and  $T$  of the rapakivi magma ought to have been enough to melt and mobilize parts of the overlying rocks. In this way the Holmsta granite (p. 19) may have formed. This is probably then a recrystallized and mobilized Härnö or Revsund granite or, possibly, a palingenic granite originating directly from a metagreywacke. This secondary Holmsta granite magma — formed at depth by influence from the intruding rapakivi magma — was later able to intrude into the gabbros and metagreywackes of the crust immediately before the rapakivi granite. It is very likely that the rapakivi massif at Holmstrand, which is an isolated part of the Ragunda massif proper, is connected with the main massif at deeper levels. Examples in favour of this hypothesis are the fairly numerous dikes and small massifs of fine-grained rapakivi granite which constitute part of the bedrock within this area.

The acid and intermediate rocks of the Ragunda massif present such chemical variations in both major and minor elements that they could have been formed by fractionation of a quartz syenitic magma. The chemical analyses reveal, however, two separate trends which may suggest that the Ragunda syenite and granite originated from two different major magmas, one of them quartz syenitic and the other granitic. This assumption is also supported by the absence of rocks of intermediate composition in the main massif (cf. p. 89). The two

magmas intruded in different pulses. The quartz syenite magma which intruded before the granite magma, differentiated after the emplacement into more quartz-rich components (of a composition corresponding to the hornblende granite of the small massifs) which were concentrated in the upper part of the syenitic body (cf. p. 55). This primary magma had sodium-rich derivatives from which alkali amphiboles, albite, and quartz were formed. It may well be that the very fine bands of amphibole which are present in the syenites and in certain granites (weed texture) and which probably give the rocks their green colour consist of alkali amphibole since the content of alkali and the colour of the rock can be related to each other (see p. 54). Upton (1964) has shown that saturated syenite magmas can produce peralkaline granites (see also Sørensen 1974, p. 535 ff.). The peralkaline rocks are obviously associated with the syenite and not with the granite. This is clear from the fact that the bluish grey, arfvedsonite—riebeckite bearing dikes cut the syenite and not the granite. These dikes have probably formed from rest solutions of the quartz syenite magma. Moreover, the above mentioned patches and needles of alkali amphibole are only present in the syenite and in the hornblende granite.

The second magma intrusion had a granitic composition. The granite porphyry is an early crystallization product of this phase. The intrusion was followed by a magmatic differentiation leading to an increase in the amount of volatiles. This process contributed to the ordering of the potash feldspars in the direction of stable microcline and to an increased exsolution of the potash feldspar. The volatiles gave also rise to miarolitic cavities where quartz and fluorite crystallized.

Upton (1960) has described an intrusive complex of syenites and gabbros from the Kûngnât Fjeld, S. W. Greenland. Upton (1960, p. 133) assumes that a large body of alkali olivine-basalt was initially lying beneath a thick insulating cover of gneiss. From this magma there was a diffusion of volatiles accompanied by silica and alkalis to the uppermost portions of the chamber. The relatively "wet" magma thus produced reacted with and caused palingenesis of the gneiss cover. This process could have given rise to a subsidiary cupola above the main magma reservoir. The cupola may have contained a "secondary" syenite melt composed of materials partly derived from the primary basalt magma and partly derived from remobilisation of the cover. At the same time it may have been a slow but steady fractionation by crystal settling in the basalt magma.

Barker et al. (1975) assume that the magmas which originated the granitic and syenitic rocks of the Pikes Peak batholith were formed by what they call a "reaction melting system" in which a basaltic magma of mantle origin reacted with and partially melted the lower to intermediate crust. This hypothesis is based upon Bowen's (1928) classic theories concerning inclusions of igneous rocks, together with later experiments by Winkler and von Platen, among others (see Winkler 1967, pp. 194—216), on the processes of partial melting of rocks

that give granitic or near-granitic compositions. Barker et al. (1975) assume that mantle-derived, convecting alkali olivine-basaltic magma first reacted with lower crust (of granulitic facies and largely depleted of its original granitic fraction) to produce magma of quartz syenitic composition. The syenitic liquid in turn reacted with granodioritic to granitic intermediate crust of amphibolite facies to produce the predominant fayalite-free granites of the Pikes Peak batholith.

Bridgwater et al. (1973, p. 73 ff.) assume that the rapakivi rocks have originated from secondary magmas formed by the melting of the lower crustal rocks. These secondary magmas have probably been mixed with new mantle material. The introduction of a major basic magma at depth is thought to have caused this process.

The results from the investigation of the Ragunda massif may, as far as the genesis is concerned, be genetically interpreted according to the model presented by Barker et al. (1975) for the Pikes Peak batholith, which is based upon an earlier hypothesis by Upton (1960) described above.

The following hypothetical interpretation of the genesis of the Ragunda rocks is thus possible. Beneath the area there was initially a large body of magma material originating from the mantle. Crustal layers with their lowest parts in granulite facies overlaid the basic magma. The first intrusion to higher levels of Ragunda gabbro magma had a composition slightly enriched in alkalis and silica as the upper parts of the basic magma had begun to react with the overlying crust.

The basic magma body continued to give off heat towards the roof with the result that minor quantities of the overlying crust began to melt. Furthermore, a chemical exchange between the basic magma and the anatectic melt took place. The temperature was lowered somewhat within the basic magma, and the first (Mg-rich) minerals began to crystallize and separate. The (Mg-depleted) anatectic magma which now had a quartz syenitic composition subsequently intruded into the crust.

After the intrusion a fractional crystallization of the quartz syenite magma began, which gradually gave rise to more quartz-rich derivatives, such as those forming the hornblende granite. At the end of the crystallization of the quartz syenite magma the alkali/aluminium ratio of the residual liquids gradually changed to a slightly peralkaline composition. The peralkaline residual liquids altered part of the already crystallized amphibole of the syenites to alkali amphibole and penetrated also the syenite as acid dikes (e.g. K 210).

The large, basic magma body continued to give off heat which melted more and more of the overlying intermediate crust (in amphibolite facies?). During these melting and reaction processes some exchange of material took place between the basic magma and the melted roofrocks. The anatectic melt was thus somewhat depleted in magnesium which concentrated in early crystallizing, relatively magnesium-rich olivine and pyroxene which separated from the liquid.

The secondary magma of granitic composition intruded later on into higher levels of the crust and brecciated the now crystallized gabbro. The residual liquids of the granitic magma penetrated the crystallized Ragunda granite and surrounding rocks at a late stage, forming dikes.

When the syenitic and granitic magmas intruded they had such a high temperature that they could influence and melt portions of the surrounding rocks. In this way the Holmsta granite — which is supposed to be a melted and mobilized Härnö or Revsund granite — may have been formed. (Another supposition is that the Holmsta granite formed from the mentioned country rocks by the direct influence of the large, primary basic magma. If this were the case one would, however, expect recrystallized rocks of the Holmsta granite type to be much more common within the area.)

The basic, often potash-bearing dikes are thought to have emanated from the large primary, basic magma which remained active during this whole period and which at the time for the intrusion of the dikes, by differentiation or element exchange with the overlying rocks, had a more potassium-rich composition.

The Ragunda syenite and granite have an Rb—Sr age of  $1\,320 \pm 30$  Ma (Welin, Lundqvist, and Kornfält, in prep.). The initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio  $0.718 \pm 0.006$  is very high and implies a complex evolution of the granite in the earth's crust. In the same investigation two samples of the gabbro of the Ragunda massif have also been analysed. The gabbro samples plot below the syenite — granite isochron of the Ragunda massif and an estimated initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio is 0.701—0.704, suggesting a mantle origin (see e.g. Welin 1968, p. 558 f.). In the neighbouring Nordingrå area (Welin, Lundqvist, and Kornfält, in prep.) the rapakivi granite has an age of  $1\,445 \pm 20$  Ma with an initial Sr isotope ratio of  $0.725 \pm 0.003$ . The age of the gabbro and the anorthosite in this area is  $1\,585 \pm 50$  Ma and the initial Sr isotope ratio is  $0.7059 \pm 0.0005$  which latter value is slightly higher than the estimated initial ratio of the Ragunda gabbro.

Not only the Ragunda massif but also other rapakivi massifs are associated with basic rocks — sometimes with anorthositic derivatives. Basic rocks are e.g. reported from Nordingrå (Sobral 1913; von Eckermann 1938), Mårdsjö (Högbom 1920, p. 37), Åland (Sederholm 1934), and Ahvenisto (Savolahti 1956). Those authors, who have worked on the rapakivi rocks, usually consider that there is a close genetic relationship between the basic and the acid rocks of the rapakivi massifs.

Savolahti (1956, p. 80), however, doubts such a relationship, since he has observed within the Ahvenisto massif a microcline granite cutting the gabbro — anorthosite complex but not the rapakivi granites. This points to a considerable difference in time between the intrusions of the gabbro — anorthosite and the rapakivi granite. Savolahti (op. cit., p. 81) considers that the geographical association between the rapakivi granites and the basic rocks do "not necessarily prove a close genetic or temporary connection between them, for the occurrence

of both kinds of rocks in the same tracts may simply be due to the tectonic conditions”.

The intrusion of the rapakivi magmas probably took place into a relatively stable platform structure, in connection with heavy block movements. It is, of course, possible that the movements in these rigid platforms were released along the same tectonic zones on several occasions during an anorogenic period. The results of the chemical analyses and the field geological observations from the Ragunda massif, including the great number of reports from other rapakivi massifs with co-existing granites and gabbros, point to a close genetic relationship between these two rock varieties in spite of possible differences in age.

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### MICROPROBE ANALYSES

#### TABLES 23-28

TABLE 23. OLIVINE. Chemical microprobe analyses (weight percent) and the number of ions calculated on the basis of 4 oxygens. (For sample locations, see Table 1.)

	Olivine in anorthositic gabbro Nr 60	Olivine in quartz gabbro K 582	Olivine in syenite K 463
SiO <sub>2</sub>	37.80	34.63	31.19
TiO <sub>2</sub>	n.d.	n.d.	0.05
Al <sub>2</sub> O <sub>3</sub>	n.d.	n.d.	0.21
Fe(tot)=FeO	27.79	37.10	65.35
MnO	0.38	0.50	1.84
MgO	32.15	26.00	2.52
CaO	n.d.	n.d.	0.30
Na <sub>2</sub> O	n.d.	n.d.	0.19
K <sub>2</sub> O	n.d.	n.d.	0.11
Total	98.12	98.23	101.77
Si	1.027	0.994	1.007
Al	—	—	0.008
Ti	—	—	0.012
Fe	0.632	0.888	1.765
Mn	0.010	0.012	0.045
Mg	1.303	1.111	0.122
Ca	—	—	0.010
Atomic ratios			
Fe	32.7	44.4	93.5
Mg	67.3	55.6	6.5

TABLE 24. PYROXENE. Microprobe analyses (weight percent). The number of ions calculated on the basis of 6 oxygens.  
(For sample locations, see Table 1.)

	Orthopyroxene in gabbro K 430b	Clinopyroxene in gabbro K 430b	Clinopyroxene in syenite K 463
SiO <sub>2</sub>	51.88	51.26	50.22
TiO <sub>2</sub>	0.16	0.13	0.67
Al <sub>2</sub> O <sub>3</sub>	0.06	0.02	0.99
Fe(tot)=FeO	29.50	13.91	23.99
MnO	0.62	0.32	0.76
MgO	16.03	11.65	4.45
CaO	1.43	17.12	18.33
Na <sub>2</sub> O	0.13	0.31	0.45
K <sub>2</sub> O	0.10	0.11	0.13
Total	99.90	94.83	99.99
Si	1.997	2.040	2.000
Al	0.003	—	—
Al	0.025	0.000	0.047
Ti	0.005	0.005	0.019
Fe	0.950	0.464	0.799
Mn	0.021	0.012	0.026
Mg	0.920	0.691	0.263
Ca	0.058	0.729	0.782
Na	0.009	0.024	0.033
K	0.005	0.005	0.005
Atomic ratios			
Mg	47.7	36.7	14.3
Fe	49.3	24.6	43.3
Ca	3.0	38.7	42.4

TABLE 25. AMPHIBOLE. Microprobe analyses (weight percent). The number of ions calculated on the basis of 23 oxygens. (For sample locations, see Table 1.)

	Gabbro Nr 64	Syenite K 463	Hornblende granite Nr 137
SiO <sub>2</sub>	46.02	40.27	41.79
TiO <sub>2</sub>	1.15	2.90	1.87
Al <sub>2</sub> O <sub>3</sub>	6.07	7.70	7.79
Fe(tot)=FeO	19.83	29.14	30.94
MnO	0.32	0.48	0.34
MgO	11.30	3.75	1.59
CaO	11.33	11.61	10.22
Na <sub>2</sub> O	1.07	2.13	2.01
K <sub>2</sub> O	0.69	1.20	1.42
Total	97.78	99.18	97.98
Si	6.97	6.42	6.75
Al(tetr)	1.03	1.46	1.25
Al(oct)	0.06	—	0.23
Ti	0.13	0.34	0.22
Fe	2.51	3.89	4.18
Mn	0.05	0.07	0.05
Mg	2.55	0.89	0.38
Ca	1.84	1.98	1.77
Na	0.31	0.65	0.62
K	0.13	0.25	0.29
100 Mg			
Mg + Fe + Mn	49.9	18.4	8.2

TABLE 26. ALKALI AMPHIBOLE. Microprobe analyses (weight percent). The number of ions calculated on the basis of 23 oxygens. (For sample locations, see Table 1.)

	Hornblende granite Nr 115	Hornblende granite K 252
SiO <sub>2</sub>	49.56	49.50
TiO <sub>2</sub>	0.30	1.03
Al <sub>2</sub> O <sub>3</sub>	0.49	1.84
Fe(tot)=FeO	36.32	38.16
MnO	0.49	0.65
MgO	0.28	0.12
CaO	3.15	5.81
Na <sub>2</sub> O	6.20	2.90
K <sub>2</sub> O	0.90	0.65
	97.69	100.65
Si	8.04	7.80
Al(tetr)	—	0.20
Al(oct)	0.10	0.14
Ti	0.04	0.12
Fe	4.93	5.03
Mn	0.07	0.09
Mg	0.07	0.03
Ca	0.55	0.99
Na	1.95	0.89
K	0.19	0.13
100 Mg		
Mg + Fe + Mn	1.38	0.58

TABLE 27. BIOTITE. Microprobe analyses (weight percent). The number of ions calculated on the basis of 22 oxygens. (For sample locations, see Table 1.)

	Gabbro Nr 64	Hornblende granite Nr 137	Biotite granite K 391
SiO <sub>2</sub>	36.22	35.28	35.42
TiO <sub>2</sub>	4.63	3.57	3.64
Al <sub>2</sub> O <sub>3</sub>	12.43	11.85	11.80
Fe(tot)=FeO	22.48	35.10	30.23
MnO	0.13	0.40	0.76
MgO	9.51	1.02	4.77
CaO	0.09	0.08	0.06
Na <sub>2</sub> O	0.15	0.16	0.35
K <sub>2</sub> O	9.17	9.24	8.19
Total	94.80	96.71	95.21
Si	5.670	5.781	5.733
Ti	0.545	0.443	0.447
Al(tetr)	2.294	2.219	2.254
Al(oct)	—	0.066	—
Fe	2.943	4.816	4.091
Mn	0.019	0.059	0.107
Mg	2.219	0.246	1.147
Ca	0.019	0.010	0.010
Na	0.038	0.059	0.117
K	1.824	1.930	1.691
100 Mg			
Mg + Fe + Mn	42.83	4.80	21.46

TABLE 28. ALLANITE in quartz syenite K 417a. Microprobe analysis (weight percent). (For sample locations, see Table 1.)

SiO <sub>2</sub>	32.6
TiO <sub>2</sub>	3.0
Al <sub>2</sub> O <sub>3</sub>	10.6
Fe(tot)=FeO	17.4
Ce <sub>2</sub> O <sub>3</sub>	16.3
La <sub>2</sub> O <sub>3</sub>	6.0
MgO	0.4
CaO	11.3
Total	97.6

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