SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 636 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 62 NR 7

KARL-AXEL KORNFÄLT

X-RAY AND OPTICAL OBSERVATIONS ON THE K-FELDSPARS FROM THE RAGUNDA AREA, CENTRAL SWEDEN

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Original manuscript received March 12, 1968.

Editor: Per H. Lundegårdh

Stockholm 1969

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ABSTRACT

106 K-feldspar samples from the Ragunda rapakivi massif and surrounding rocks (mainly Revsund granite), were investigated with respect to the variation of their triclinicity (Δ). The optic axial angle (2V) was also measured in some specimens.

The data obtained for average K-feldspar fractions from specimens of the rapakivi rocks vary from monoclinic in the syenite (oldest) to near maximally triclinic in the pegmatite (youngest).

The heat from the rapakivi intrusion has in a rather wide zone converted the original triclinic K-feldspar of the surrounding, porphyritic, late-Svecofennian granite into strictly monoclinic. Areas further away from the contact with the rapakivi massif, and situated within the late-Svecofennian granite, may contain K-feldspars of inferior triclinicity. These feldspars are thought to have been thermally affected by rapakivi masses situated below the present earth-surface.

Резюме

Автор исследовал 106 образцов калиевых полевых шпатов из массива Рагунда рапакиви и окружающих его горных пород (состоящих главным из Ревсунд гранита), чтобы установить вариацию в их триклинности (Δ). Угол оптических осей (2 V) измерялся в некоторых образцах.

Результаты исследования показывают, калиевые полевые шпаты из пород рапакиви состоят из моноклинных в сиените (раннем) до почти максимально триклинных в пегматите (позднем).

Под влиянием высокой температуры интрузии рапакиви произошло на обширной территории преобразование первобытного триклинного КПШ в окружающем порфировом позднем Свекофенском граните в моноклинный. Зона отдалена от контактов с массивом рапакиви и расположена в границах Свекофенского гранита может содержать КПШ с низкой триклинностью. Автор предполагает, что эти полевые шпаты подверглись термическому влиянию пород рапакиви, находящихся под поверхностью земли.

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INTRODUCTION, INCLUDING A BRIEF DESCRIPTION OF THE ROCKS IN THE AREA

The Ragunda massif was first described by A. G. Högbom in 1894. In 1896 and 1897 Högbom mapped the Jämtland County part of the massif. The results were published in 1899. The same author treated the main tectonic problems of the area in a paper printed in 1909.

The continuation of the Ragunda massif into the Helgum parish, Västernorrland County, was called the Helgum massif by Hj. Lundbohm. It was briefly accounted for in Lundbohm's description to the map of the rocks of Vesternorrland (Västernorrland) County (Lundbohm 1899).

As the main part of the massif is situated in the parish of Ragunda, both the Jämtland and Västernorrland parts of the massif will be called the Ragunda massif in the following. This, including the surrounding rocks, was mapped by the author in the summers 1962 to 1965. The collected material is being investigated petrologically at present.

The map shows that the eastern part of the Ragunda massif is mainly surrounded by structurally well-preserved metagreywackes and migmatites derived from them. The western part of the massif borders upon coarsely porphyritic, grey, late-Svecofennian Revsund granite (Magnusson et al. 1963).

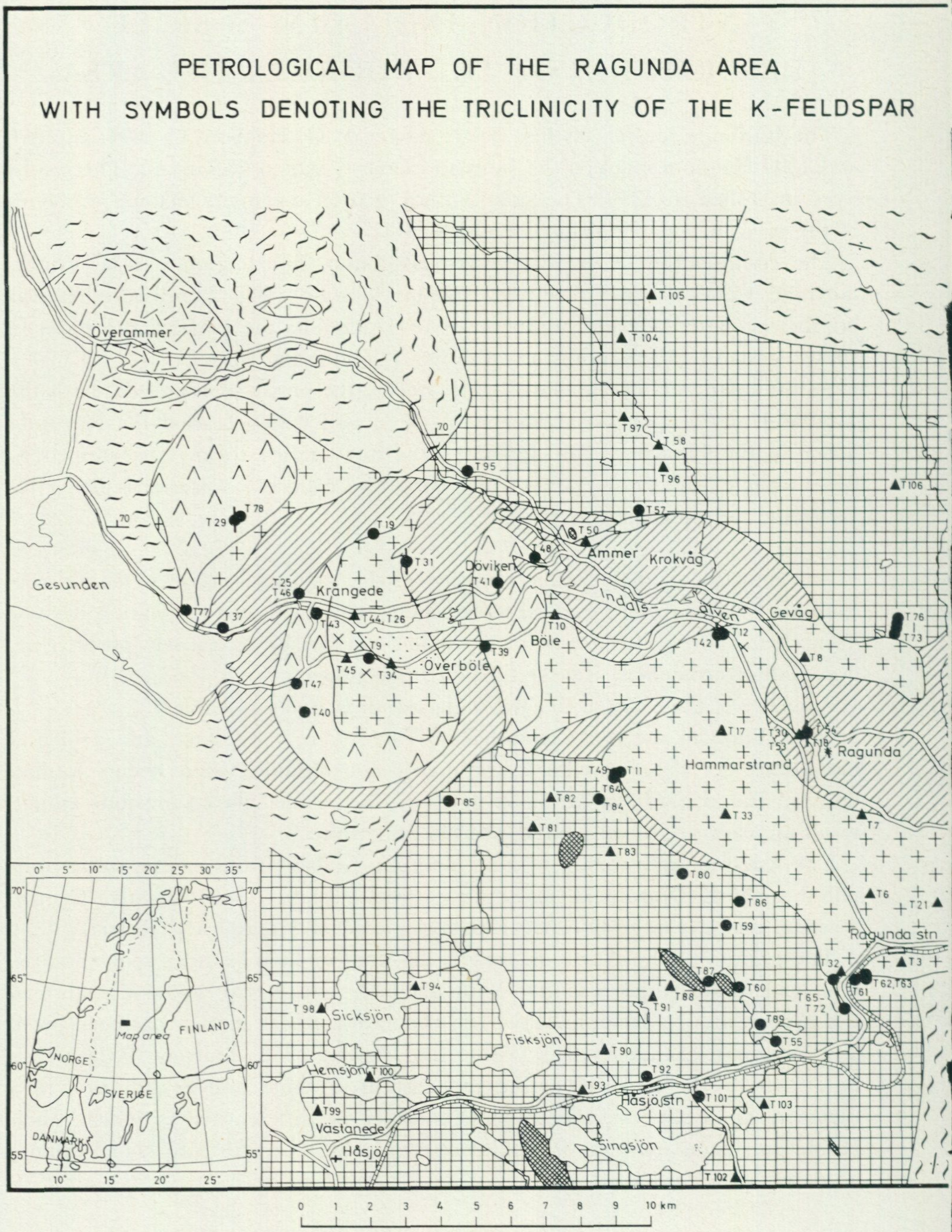
A survey of the rocks of the Ragunda massif is given in Table 1.

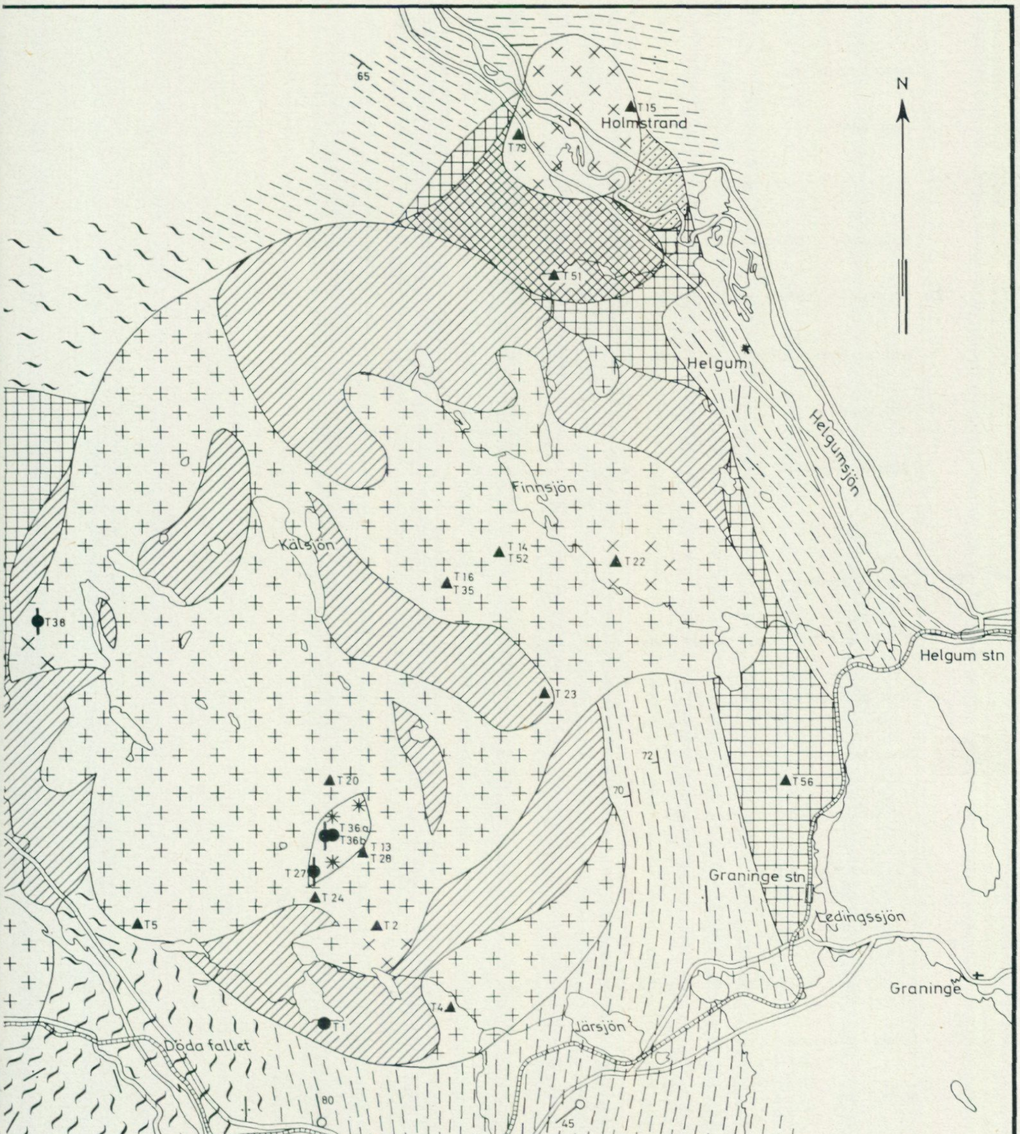
In addition to the rocks recorded in Table 1, red pegmatite and acid and basic dikes are also met with in the massif. Furthermore, there occurs Jotnian dolerite (Lundegårdh et al. 1967, p. 132), and in one place sandstone which, to all appearance, fills a joint in the biotite granite.

The Ragunda massif is in tectonic position, probably also in age, to be compared with the Nordingrå massif in eastern Västernorrland County, Central Sweden, and the large so-called rapakivi massifs in Finland and Russia.

The granite of the Ragunda massif, like that of many other rapakivi areas, is devoid of K-feldspar mantled with plagioclase, i. e. the rapakivi texture in the proper sense is lacking. However, the term rapakivi granite has been given a wider sense (Sahama 1945, Tuttle and Bowen 1958, Marmo 1962) and is now used by the majority of the geologists in Finland and Scandinavia as a common name for the postorogenic granites of different types which, their K-feldspars being mantled or not, have certain characteristic features in common, e. g. two generations of quartz.

Through careful study of K-feldspar from granites and other acid rocks, it is possible to get petrogenetical information. This has been pointed out by, among others, Marmo (1956, Marmo et al. 1963).


PETROLOGICAL MAP OF THE RAGUNDA AREA
WITH SYMBOLS DENOTING THE TRICLINICITY OF THE K-FELDSPAR
Överammer
Gesunden
Krångede
Döviken
Ammer
Krokvåg
Indalsälven
Gevåg
Böle
Överböle
Hammarstrand
Ragunda
Ragunda stn
Sicksjön
Fisksjön
Hemsjön
Västanede
Håsjö
Håsjö stn
Singsjön
70
T 105
T 104
T 97
T 58
T 96
T 106
T 95
T 57
T 50
T 48
T 29
T 78
T 19
T 31
T 41
T 25
T 46
T 77
T 37
T 43
T 44, T 26
T 10
T 9
T 45
T 34
T 39
T 42
T 12
T 76
T 73
T 8
T 47
T 40
T 17
T 30
T 54
T 53
T 18
T 49
T 11
T 64
T 84
T 82
T 85
T 81
T 83
T 33
T 7
T 80
T 86
T 59
T 6
T 21
T 32
T 3
T 62, T 63
T 61
T 65-T 72
T 87
T 88
T 91
T 60
T 89
T 55
T 94
T 98
T 100
T 99
T 90
T 92
T 93
T 101
T 103
T 102
0° 5° 10° 15° 20° 25° 30° 35°
70°
65°
60°
55°
10° 15° 20° 25°
NORGE
SVERIGE
FINLAND
DANMARK
Map area
0 1 2 3 4 5 6 7 8 9 10 km



Legend, see p. 8

LEGEND

☰	Metagreywacke
≈	Migmatite
▩	Primorogenic metagabbro
⟋⟍	Palingenic granite and pegmatite, grey
▦	Palingenic granite, grey, with phenocrysts
▨	Gabbro (penetrated by granite)
▨	Anorthosite
∧ ∧	Quartz syenite
× ×	Hornblende granite
✳ ✳	Granite porphyry
+ +	Biotite granite (Ragunda granite)
⁘	Fine-grained granite
■	Dolerite
⟋ 70	Schistosity with indicated dip
⟋	Do. with high dip
⟋	Do. vertical
⟋	Do. with unknown or variable dip
45 ⟋○	Linear structure
▲	Microcline
●	Orthoclase
⧫	Randomly disordered K-feldspar

Table 1. The rocks of the Ragunda massif

Rock type	Chief minerals (> 25 %)	Essential minerals (5—25 %)	Minor minerals (1—5 %)	Accessories (<1 %)
gabbro (penetrated by granite)	plagioclase	augite hornblende biotite	quartz chlorite sericite	ore apatite
anorthosite	plagioclase	mafic minerals		ore
quartz syenite	K-feldspar	quartz plagioclase	augite hornblende olivine	apatite zircon ore biotite sericite fluorite
hornblende granite	K-feldspar quartz	plagioclase	hornblende biotite	ore olivine iddingsite fluorite zircon apatite
granite porphyry	K-feldspar quartz	plagioclase	biotite sericite	ore zircon fluorite apatite
biotite granite	K-feldspar quartz	plagioclase	biotite chlorite sericite	hornblende zircon fluorite apatite titanite
fine-grained granite	K-feldspar quartz	plagioclase	biotite	fluorite sericite zircon ore apatite

The present work on the K-feldspars from the Ragunda area has been performed in order to try to elucidate the following questions. Which modification of K-feldspar dominates in the rapakivi granites of the Ragunda massif? Have the K-feldspars in the different types of rapakivi granites so different triclinicity values that they can be used for petrogenetic discussions? Is it possible to trace any influence from the rapakivi massif on surrounding rocks, by studying the triclinicity of the K-feldspar in the latter?

METHODS

SAMPLING

The K-feldspars of the coarsely porphyritic Revsund granite and the granite porphyry from locality K 631 were picked out by hand. The other rocks were crushed and passed through a sieve to get a grain size of 1—0.5 mm. By mixing tetrabromoethane and benzene, a liquid with the density 2.59 was prepared. By means of this heavy liquid, the K-feldspar was separated from other minerals (Krumbein and Pettijohn 1938, p. 325, van der Plas 1966, p. 59). The K-feldspar thus obtained always proved to contain quartz and albite in varying quantities.

X-RAY INVESTIGATION

The powdered K-feldspar specimens were examined on a Philips X-ray diffractometer. (CuK_{α}-radiation, Ni-filter, scanning speed 1°/4 minutes.) Graphs in the region $2\ \theta : 20.5°—31.5°$ were generally taken. However, the K-feldspar of the Revsund granite has been examined only in the region $2\ \theta : 29.0°—31.5°$. The X-ray patterns were estimated in accordance with the method worked out by Dietrich (1962, p. 397).

The Δ-value or triclinicity is defined as $\Delta = 12.5\ [d_{131}—d_{1\bar{3}1}]$ (Goldsmith and Laves 1954 a, b). The designation triclinicity for this quantity is considered to be inappropriate by some authors, as a structure either is monoclinic or triclinic. They instead propose 'obliquity' (Dietrich 1962, Deer, Howie and Zussman 1963). Bambauer uses the designation 'Triklinität' (Tröger 1967). In the following text the designation triclinicity on the Δ-value will be used.

In the present paper the values of $2\ \theta_{1\bar{3}0}—2\ \theta_{130}$ (MacKenzie 1954, p. 355) have also been reported in some cases.

OPTICAL INVESTIGATION

The size of the optic axial angle (2 V) in the K-feldspars was measured by U-stage techniques. The maximum extinction angle $\gamma \wedge \perp(010)$, which is a measure of triclinicity, could not be determined in thin sections, as the (010) cleavage was practically entirely absent.

RESULTS OF THE X-RAY DETERMINATIONS

THE ROCKS OF THE RAGUNDA MASSIF

The following types of X-ray patterns were obtained:

1. One peak (= 'orthoclase'), which can be more or less broad and diffuse, indicating the presence of domains with triclinic symmetry.
2. Two peaks (= 'microcline') which give medium to high Δ-values.

3. Between the two types above, there are a variety of transition forms, sometimes with three, often diffuse, peaks, where
   a) either the reflections of the 'orthoclase' or 'microcline' are the strongest;
   b) no maximum exists. The peaks are diffuse within a limited measurable region ('randomly disordered', see Christie 1962). (Cf. Marfunin 1961, Smithson 1962, Retief 1962, Tröger 1967.)

In Tables 2—9, a complete list of the Δ-values arranged according to the rock types is given. On the map the locations of the samples are presented with symbols (partly according to Nilssen and Smithson 1965), denoting the distribution of the Δ-values.

As evident from Table 2, the K-feldspar of the syenite has either $\Delta = 0$ or no maximum, and is accordingly for the main part orthoclase.

The K-feldspar of the hornblende granite (Table 3) has varying triclinicity, and is consequently either orthoclase, microcline or transitional forms between these two.

In the phenocrysts of the granite porphyry the triclinicity has an inferior value, while in the matrix it is higher. This is clear from samples T 36 a) and b) in Table 4.

In the porphyritic granite which penetrates the gabbro, part of the K-feldspar consists of orthoclase and part of it of microcline.

The most common granite of the area is the pale reddish, medium to coarse-grained biotite granite (Ragunda granite). In this rock the K-feldspar generally has medium to high Δ-values. As evident from Table 6, transitional forms between orthoclase and microcline are common.

Samples T 11 (Table 6) and T 62 (Table 8) have $\Delta = 0$. Both these samples are collected very close to the contact with the Revsund granite.

At location K 631, fine-grained biotite granite (T 28) penetrates medium to coarse-grained biotite granite (T 13). Table 8 and Table 6 show that the fine-grained granite has a high Δ-value and consequently is microcline, while in the medium to coarse-grained granite is found only a very weak maximum for microcline.

At location Nr 53 one could observe thin reddish brown veins (about 10—20 cm across) in the otherwise greyish brown granite. Disregarded from this difference in colour, the mineral composition and texture are on the whole identical in the two types. The determinations of triclinicity indicated that the reddish brown granite (T 52, Table 6) has K-feldspars with a higher Δ-value than the grey-brown variety (T 14, Table 6). Accordingly, a correlation seems to exist between colour and triclinicity. The same relationship holds for K-feldspars from other parts of the massif.

The K-feldspar in the rarely found reddish pegmatite has $\Delta = 0.93$, which is the highest Δ-value in the rocks of the Ragunda massif (T 53, Table 9).

THE SURROUNDING ROCKS (MAINLY REVSUND GRANITE)

Along an approximate line from K 322/T 65 (at the margin of the massif) to K 328/T 72 (1 000 metres south-southeast of the massif), samples were taken with unequal interspaces (T 65—T 72, Table 10). In all these samples the K-feldspars show the triclinicity 0.0. In sample T 101/K 718 (from the neighbourhood of Håsjö railway station, 5 000 metres from the nearest contact with the rocks of the Ragunda massif), the K-feldspar has a Δ-value of 0.0—0.76, with a distinct maximum at 0.0 (Table 11).

In the Revsund granite from location K 174 (about 6 000 metres west of Ragunda church), samples have been taken partly at the contact (T 49, Table 10), partly about 100 metres south of the contact with the Ragunda granite (T 64, Table 10). In these two samples the K-feldspar shows $\Delta = 0.0$. In sample T 84/K 193, collected about 600 metres west of the contact, the Δ-value is likewise 0.0. At location K 186, at a distance of about 1 200 metres from the contact with the Ragunda massif, sample T 82 was taken. In this, the K-feldspar shows $\Delta = 0.90$ (Table 11).

At Krokvåg, in the northern part of the massif, there is a minor area with Ragunda granite which borders in the north upon Revsund granite. A sample was collected in the Revsund granite about 50 metres from the contact (T 57/K 493, Table 10). The X-ray pattern has one, rather distinct, 'orthoclase-peak' which is broader at the base, indicating the presence of domains with triclinic symmetry. At K 491, about 1 500 metres north-northeast of the location above, the K-feldspar shows $\Delta = 0.84$ (T 96, Table 11).

In the Revsund granite from the region about 4 000 metres north-east of Ragunda church, four samples were taken on an approximate line between K 528 at the contact with the Ragunda granite, and K 521 about 400 metres in a north-northeasterly direction from the contact (Table 10, T 73—T 76). From Figure 1 it is apparent that the X-ray pattern changes when the distance from the contact with the granite of the Ragunda massif increases. The patterns c and d in Figure 1 are on the whole identical and have both distinct traces of triclinic domains.

In the porphyritic late-Svecofennian granite from the eastern part of the area, two samples have been collected (T 51/Nr 63 and T 56/Nr 61, Table 11) at distances of about 2 000 (T 51) and 3 000 metres (T 56) from the nearest contact with the Ragunda massif. T 56 is 'homogeneous' microcline, whereas T 51 has diffuse peaks, indicating a certain degree of inhomogeneity.

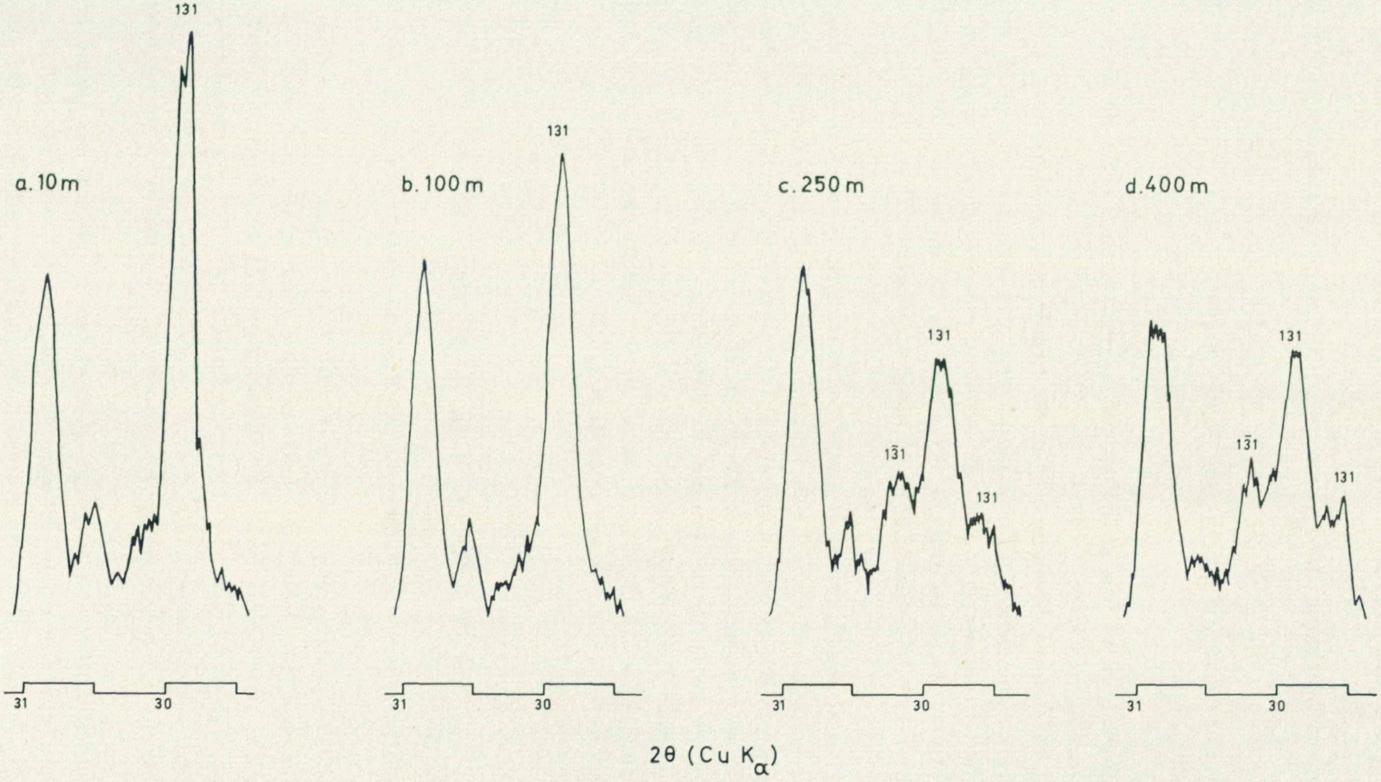


Figure 1. Parts of X-ray diffractometer patterns of K-feldspars in Revsund granite at an approximate distance of 10—400 metres from the contact with the Ragunda granite.

RESULTS OF THE OPTICAL DETERMINATIONS

According to Marfunin (1961) there are two groups of parameters for K-feldspars:

1. Optical orientation, triclinicity and lattice angles.
2. Optic axial angle.

The parameters of the first group depend on the degree of order-disorder and on submicroscopic twinning.

The optic axial angle depends only on the degree of order-disorder.

A K-feldspar, the X-ray diffraction pattern of which has one peak, may thus be either orthoclase or microcline with 'submicroscopically' and 'sub-X-ray' twinned microcline. In order to determine the structural state of a K-feldspar, it is necessary to measure also the optic axial angle (2V).

The optic axial angle (2V) of a number of K-feldspar grains was determined in thin sections prepared from the same hand specimens as were used for X-ray determinations on K-feldspars. The values of $2V_\alpha$ have been recorded in Tables 2—11. Obviously the variations of 2V in one thin section are quite wide. Such variations of 2V seem to be common in K-feldspars (Retief 1962, Marmo et al. 1963, Smithson 1963, Nilssen and Smithson 1965).

As a matter of fact, increasing Δ-values in the K-feldspars investigated are accompanied by increasing optic axial angles (2V).

THE ROCKS OF THE RAGUNDA MASSIF

The K-feldspars in the acid rocks of the Ragunda massif are highly perthitic.

The perthite appears as vein perthite (Figure 2) or as patch perthite (Figure 3, see Andersen 1928). Vein and patch perthite often grade into each other (Figure 4). The patch perthite has sometimes grown as a rectangular band in the K-feldspar grain (Figure 5). There appears to be no correlation between triclinicity and perthite types.

The fine-grained biotite granite as a rule has a granophyric development (Figure 6).

As mentioned above, the Ragunda granite has in general no plagioclase mantle around the K-feldspar. Mantled K-feldspars may, however, sometimes appear in the medium to coarse-grained biotite granite, and somewhat more often in the porphyritic granite intersecting the gabbro.

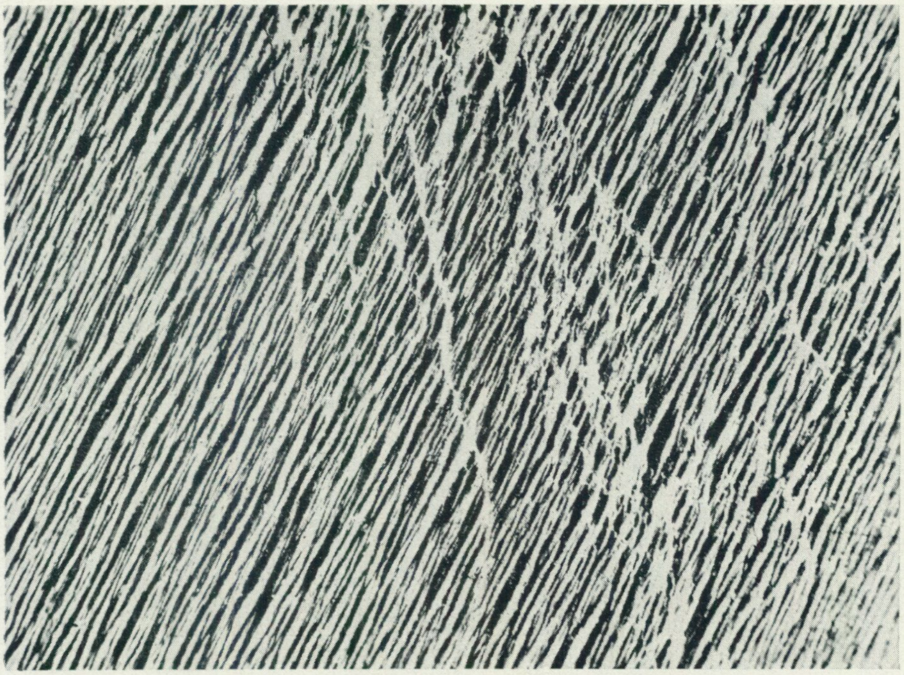


Figure 2. Vein perthite in microcline. 2 nic., × 50. (Hornblende granite: T 22/Nr 115.)

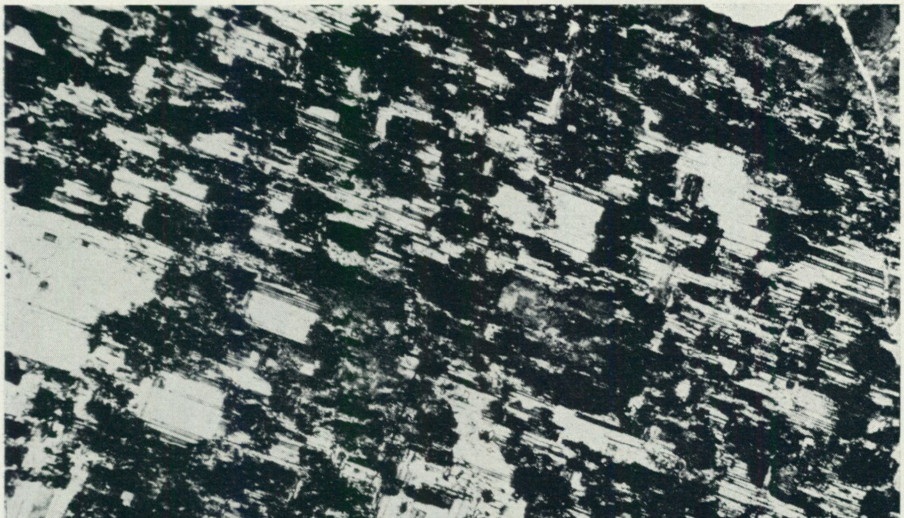


Figure 3. Patch perthite. 2 nic., × 50. (Biotite granite: T 6/K 391.)

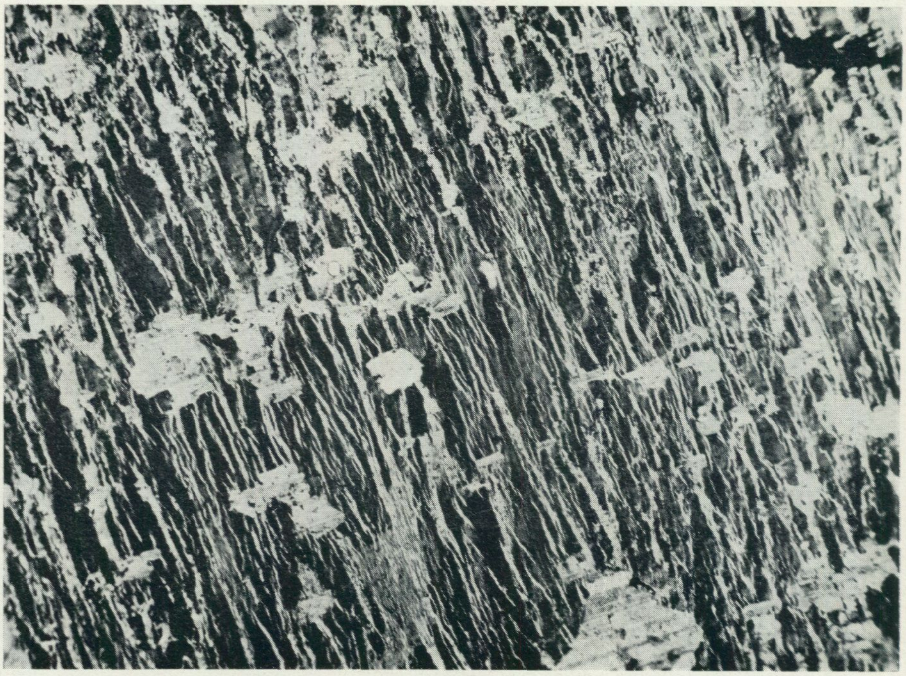


Figure 4. Vein perthite and patch perthite in the same grain. 2 nic., × 50. (Hornblende granite: T 15/Nr 137.)

Figure 5. K-feldspar grain with a rectangular band of plagioclase partially altered to sericite. The plagioclase in the different parts of the band has the same optic orientation. The K-feldspar outside the plagioclase band has the same optic orientation and character as the internal K-feldspar. 2 nic., × 20. (Biotite granite: T 50/K 500.)

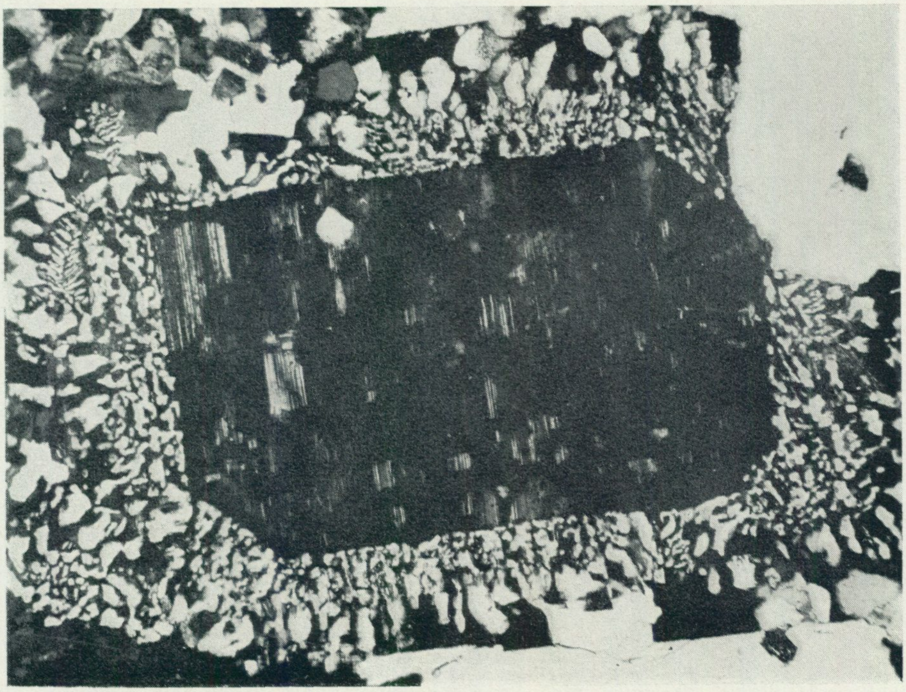


Figure 6. Granophyric development around euhedral grain of perthitic K-feldspar. 2 nic., × 50. (Fine-grained biotite granite: T 31/K 470.)

THE SURROUNDING ROCKS

In the late-Svecofennian Revsund granite outside the Ragunda massif, the optic axial angle (2V) has been determined in only five thin sections. The samples with high triclinicity, T 56 and T 58, in general also show a beautiful cross-hatching in the K-feldspars. However, several grains without cross-hatching are found. Even these are microclines, which is clear from the values of 2V. (Cf. Marmo et al. 1963 and Nilssen and Smithson 1965.)

In sample T 55 (Table 11) from Revsund granite, both X-ray and optical data point to orthoclase. In a K-feldspar grain with $2V_a = 52°$ appear yet small areas with cross-hatched twins (Figure 7), which in this case possibly can be remnants of an earlier microcline (cf. p. 22). Goldsmith and Laves (1954 b), Marmo et al. (1963) and Nilssen and Smithson (1965) have found K-feldspars that appear to be monoclinic when investigated by means of X-ray methods, although they exhibit small amounts of cross-hatching optically.

Figure 7. Orthoclase with small areas of cross-hatched twinned microcline. 2 nic., × 50. (Revsund granite: T 55/K 276.)

DISCUSSION AND CONCLUSIONS

It has since long been a general conception that orthoclase should be the dominating K-feldspar in rapakivi granite (Mäkinen 1917, Eskola 1929, Marmo 1962).

The K-feldspar of the rapakivi granites in Sweden has not earlier been examined by X-ray methods. In Finland, however, Neuvonen (1957) has investigated K-feldspars in rapakivi granites by means of X-ray analysis. His results have also been quoted in a paper by Savolahti from 1962. Neuvonen found that in 'Viborgite' (coarse-grained granite with mantled K-feldspar, see Wahl 1925), monoclinic or weakly triclinic K-feldspar is most common. In porphyritic types, all degrees of triclinicity are equally represented. In 'Pyterlite' (rapakivi granite without mantled K-feldspar, see Wahl 1925) and even-grained varieties, there is a weak distribution maximum at $\Delta = 0.0$—0.3 and another maximum at $\Delta = 0.75$.

In an investigation on the pre-Quaternary geology of the bottom of the Bothnian Sea, Veltheim (1962) used triclinicity determinations of the K-feldspars in order to identify rapakivi granites. Granites with low Δ-values were classed as rapakivi-like granites, whereas granites with high Δ-values were not included in the rapakivi-group, even if they were rapakivi-like.

Lehijärvi and Lonka (1964) have investigated a hornblende rapakivi dike at Jaala-Iitti, just outside the north-west border of the great Viipuri (Viborg) rapakivi region. They determined also the triclinicity of the K-feldspar in that rock. The reddish brown hornblende granite shows Δ-values between 0.2 and 0.7. In this granite occurs, as a marginal variety, a dark green rapakivi type with a Δ-value of 0.0—0.2. In the even-grained rapakivi granite, which also occurs in the area, the Δ-value varies between 0.2 and 0.7.

According to Laves (1952) there are two stable modifications of K-feldspar. The monoclinic form, sanidine, is stable at high temperatures, and the triclinic form, microcline, at low temperatures. A disordered monoclinic K-feldspar, formed either metastably at low temperatures, or stably at high temperatures, but subsequently cooled below the order-disorder transformation temperature, tends to invert in the direction of the stable microcline. The degree of inversion to microcline depends chiefly upon time and temperature.

Marfunin (1962), on the other hand, is of the opinion that minerals, and among them K-feldspar, can form continuous series with two end-components, one completely disordered and the other with maximum order. The ordered state is always the low-temperature state. Intermediate states can be equilibrium ones.

Accordingly, intermediate phases between the monoclinic high-temperature phase and the triclinic low-temperature phase, in the light of present knowledge, are supposed to have grown either as stable phases in a specific stability field or as metastable phases in the stability field of a more ordered phase.

According to Marmo (1959, Marmo et al. 1963), triclinic K-feldspar will result if temperature is sufficiently low and the growth of the mineral is slow. A K-feldspar of inferior triclinicity will be formed if temperature is raised, or if crystallization takes place more rapidly.

However, still other factors may be responsible for variations in triclinicity. Nilssen and Smithson (1965) as well as other investigators have pointed out the significance of volatiles as a catalyzing agent in this respect. Also deformations are considered to facilate inversions from orthoclase to microcline (Karamata 1961, Nilssen and Smithson 1965). In the rapakivi granites of the Ragunda massif, deformations can hardly have affected the triclinicity more than locally. Here it must also be mentioned that some K-feldspars may show changes towards higher triclinicity when being exposed to X-rays (Shmakin and Afonina 1967).

As mentioned above, there is a correlation between colour and triclinicity in the rocks of the Ragunda massif. Dietrich (1962), who has determined the Δ-values in a large number of K-feldspars from various rocks and localities, did not find any similar correlation. But at various places in the Ragunda massif (e. g. T 52, T 14/Nr 53) the triclinicity increases when the colour of the rocks grows more reddish. This can be explained by the fact that rocks with distinct reddish colours occur in zones of shearing stress. The deformation may have here effected a higher degree of ordering of the K-feldspar than in the surrounding, more intact rocks. The reason why (which is often observed in the massif) rocks have got a more reddish colour in shear zones than outside is beyond the scope of this investigation.

THE ROCKS OF THE RAGUNDA MASSIF

Högbom (1920) describes the Ragunda granite as an orthoclase-rich granite.

As mentioned above the X-ray investigation of the K-feldspar in the acid rocks of the Ragunda massif has indicated that only the K-feldspar of the syenite can be classed as an orthoclase. The syenite is the oldest of the acid rocks of the massif.

The hornblende granite, the age-relations of which have not yet been definitely established, consists of two types. One is petrographically closely associated with the syenite and differs from the latter only by a higher content of quartz. This type has on the whole $\Delta = 0.0$. The second hornblende granite type, though green in colour, petrographically more resembles the biotite granite and, like the latter, has a low content of mafic minerals. This type has medium to high Δ-values.

The K-feldspar of the biotite granite shows both high and low Δ-values in the same sample.

The fine-grained, even-grained biotite granite and the pegmatite have K-feldspars with medium to high Δ-values ($\Delta = 0.93$ in pegmatite).

The rapakivi granites are considered to have a magmatic origin (Wahl 1925, Eskola 1928, Savolahti 1956) and to have crystallized at high temperature (Simonen 1961).

As stated above, monoclinic K-feldspar can form metastably at low temperature. Low Δ-values do not necessarily indicate high temperatures of formation of the K-feldspar. However, we may assume that in the Ragunda massif orthoclase is formed mainly as a stable phase and that it is on the whole a triclinization at lower temperatures which determines the Δ-value. With this assumption, the obtained series, with increasing Δ-values from older to younger rocks, could reflect a rising content of volatiles during a magmatic differentiation.

The following interpretation is possible. The magmatic crystallization which developed the syenite of the Ragunda massif started at a rather high temperature and therefore gave rise to monoclinic feldspar. When temperature afterwards was slowly lowered, the K-feldspar crystallizing in the granites began to order in the direction of stable microcline. The existence of a marked underrepresentation of intermediate ordering (triclinicity), can, according to Laves (discussion in Dietrich 1961, p. 20), be explained by assuming that the intermediate states are passed by relatively quickly when the crystal, under certain conditions, is rapidly ordered. (It is of course possible that two generations of K-feldspars may exist in the Ragunda granite. The first should have formed at high temperature as orthoclase and the second at low temperature as microcline. However, the result of the microscopic investigation contradicts this assumption.) At still lower temperature, when the K-feldspar had been completely transformed to microcline, the fine-grained, even-grained granite and the pegmatite crystallized.

Nearest the contact with the surrounding rocks a rapid lowering of the temperature occurred, petrographically resulting in a finer texture, and crystallographically in a 'freezing down' of the low Δ-values.

A similar, rapid lowering of the temperature explains the low Δ-values in the K-feldspar phenocrysts of the granite porphyry.

THE SURROUNDING ROCKS

According to Goldsmith and Laves (1954a) a gradual transformation from microcline to sanidine occurs at 1050° C on dry heating. Hydrothermally this conversion was observed to take place already at a temperature of 525° C.

Heier (1957) and Rao (1960) have found that the Permian intrusive rocks in the Oslo area have caused a thermometamorphic action upon the K-feldspars in the adjoining old gneisses so that the original microcline has been converted to orthoclase nearest to the contact.

In a gneissic xenolith within a hyperite dike at Hökås in Southern Sweden, Ljunggren (1959) has found that the original microcline has been converted to orthoclase as a result of the heat action of the hyperite magma.

Marmo et al. (1963) have investigated the Δ-values in a great number of K-feldspars from acid rocks in Finland, among others from the environments of rapakivi massifs. They point out that the regional distribution of monoclinic K-feldspar at first seemed to indicate that the formation of orthoclase were a result of thermometamorphism caused by the rapakivi granite. But, since they found low Δ-values also in areas where no rapakivi granite occurs, they are of the opinion that it is not necessary to take into consideration the influence of rapakivi granites. Marmo et al. (1963, p. 68) say: "In addition, the regular occurrence of almost maximum microcline in potash feldspar of pegmatite dikes, older than the rapakivi itself, quite near the contact zone of rapakivi granite, indicates that the thermal influence of rapakivi granites on the triclinicity of potash feldspar has been negligible."

Marmo et al. (op. cit.) have found that monoclinic K-feldspar occurs to a much larger extent in Finnish Precambrian rocks than had been supposed earlier. These inferior Δ-values are found within well-defined, limited areas.

As mentioned above, the Ragunda massif is partly surrounded by a coarse-grained, grey, late-Svecofennian granite (Revsund granite). This granite is characterized by phenocrysts of microcline most frequently measuring 2—5 cm in length and scattered in a groundmass of microcline, oligoclase, quartz and biotite, sometimes also hornblende and garnet (Magnusson 1960, p. 23). X-ray investigations have not earlier been performed on the K-feldspar of the Revsund granite, but optical measurements have indicated that the K-feldspar of this granite is microcline (Högbom 1920, Gavelin 1955, Ödman 1957).

As has been pointed out earlier, it is evident from the present investigation that the K-feldspar of the Revsund granite shows low Δ-values close to the Ragunda massif and higher Δ-values further away from the massif (Tables 10—11, Figure 1). In the area north-east of Håsjö railway station, there exist low Δ-values for as long a distance as 5 000 metres from the nearest contact with the Ragunda massif.

It is possible that also in certain well-defined areas belonging to the Swedish Precambrian there exist K-feldspars with inferior Δ-values similar to those found by Marmo et al. in Finland. It is, on the other hand, less probable that the Ragunda massif quite by chance has become part of such an area. On the contrary the present author is of the opinion that we have to take into consideration that the postorogenic rocks of the Ragunda massif caused a thermometamorphic action on the K-feldspar of the surrounding Revsund granite, resulting in a conversion of its microcline to orthoclase. A proof of this may be the above (p. 17) mentioned relict cross-hatching in sample T 55/K 276. This K-feldspar is, according to the X-ray determination and because of its low $2V_{\alpha}$-value, an orthoclase.

It is clear from the results of this investigation (cf. the map) that the K-feldspar of the Ragunda granite in general shows Δ-values higher than those of the surrounding Revsund granite. An exception is formed by the K-feldspar from the immediate vicinity of the contact with the Revsund granite. Here, the K-feldspars of the Revsund granite and the Ragunda granite have on the whole the same Δ-values.

Judging from the observations of K-feldspars, the following events probably took place in connection with the intrusion of the Ragunda granite. In the Revsund granite nearest the contact with the Ragunda granite, a rise of temperature took place which transformed the microcline into orthoclase. Later, when temperature was lowered in the Ragunda massif, the monoclinic K-feldspar modification of the Revsund granite nearest the Ragunda massif remained unchanged. The monoclinic K-feldspar in the crystallizing Ragunda granite, on the other hand, may have been ordered in the direction of microcline under influence of factors which facilitated the ordering process in the K-feldspar crystals.

Factors which are of importance for the ordering process are, according to Smithson (1962), the amount of volatiles present, the growth rate, temperature and deformation. (Cf. p. 19.) Wenk (1967) pointed, on the whole, to the same factors. Regarding the Ragunda granite one may suppose that volatiles, together with slow cooling, have facilitated the ordering process in the K-feldspar crystals. The rapakivi magma is considered to have been relatively dry. It is true that pegmatites are rare in the Ragunda granite, but they exist. On the other hand, the Ragunda granite, like other rapakivi granites, contains more fluorine than ordinary granites. (Cf. Sahama 1945.)

The interpretation given above must be considered very hypothetical. Furthermore, it is quite possible that not the granite but the gabbro of the Ragunda massif caused the conversion of the K-feldspars in the surrounding Revsund granite. It is true that the samples of the Revsund granite have been taken in regions where no gabbro appears together with the Ragunda granite, but gabbro may there very well occur at deeper levels of the crust.

The contacts between Ragunda granite and Revsund granite are, at those few places where they have been observed, often more or less vertical (Figure 8), but it is possible that the contact zone on the whole runs more horizontally and that the Ragunda granite thus stretches far under the Revsund granite at present exposed.

The inferior Δ-values observed at a greater distance from the massif, e. g. north-east of Håsjö railway station, could accordingly be due to thermometamorphic action emerging from parts of the massif extending at greater depths.

Postorogenic rapakivi massifs of highly variable sizes are common within a zone stretching from western Central Sweden through Åland and Southern Finland to Ladoga in Russia. Outside these massifs occur in Jämtland and Västernorrland Counties dikes, which probably belong to the rapakivi massifs. These may indicate the presence of greater granite masses below the present earth-surface.

It does not seem unreasonable that some of the inferior Δ-values of K-feldspars found by Marmo et al. in Finland could be explained by thermometamorphic action caused by postorogenic granite massifs wholly situated in the crust.

Acknowledgements: It is a pleasure to acknowledge the encouragement and help of my teacher Prof. S. Hjelmqvist during the course of this study. The author is also deeply indebted to Dr. Th. Lundqvist for valuable suggestions and critical discussions. He has also read the manuscript and proposed valuable improvements. Prof. O. Mellis and Docent Dr. P. H. Lundegårdh have read and criticized

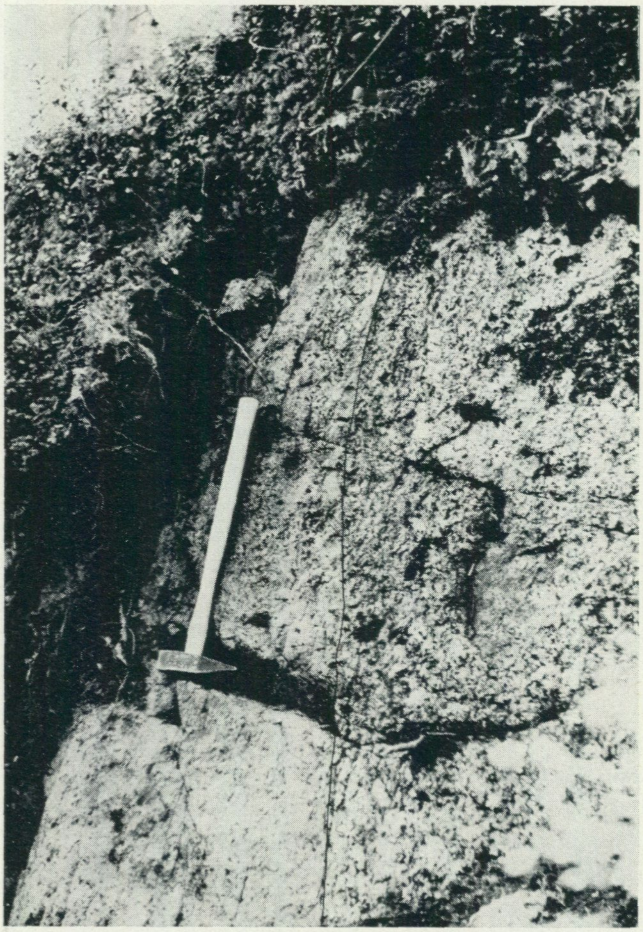


Figure 8. Contact between brownish red Ragunda granite (left) and grey Revsund granite. In a rather broad zone nearest the contact, the Ragunda granite shows fine-grained texture. Middagsberget (K 323) about 2000 metres west-southwest of Ragunda railway station.

the manuscript in a most helpful way. Many thanks are due to Mr. K.-M. Ehrenberg for help in separation with heavy liquids, to Dr. U. Regnéll and Mr. Z. Solyom for help with some X-ray 'runs', and to Mr. I. Tell for interesting discussions concerning hydrothermal synthesis. The writer also wishes to thank Miss Anna-Stina Haraldson who drew the map.

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TABLES

Table 2. X-ray and optical data for K-feldspar from syenite

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_a$	Remarks
T 39	K 229	0.0—0.71; diffuse, no max.	—	52, 62, 68, 84	medium to coarse-grained
T 40	K 259	0.0	—	—	,,
T 41	K 463	0.0—0.70; diffuse, no max.	—	—	,,
T 43	K 311	0.0	—	—	,,
T 47	K 261	0.0	—	—	medium to fine-grained
T 48	K 454	0.0—0.2	—	—	fine to medium-grained
T 77	K 417	0.0	—	—	medium to coarse-grained
T 78	K 404	0.0	—	—	,,

Table 3. X-ray and optical data for K-feldspar from hornblende granite

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_a$	Remarks
T 2	K 616	0.76	0.73	—	medium to coarse-grained, granophyric
T 9	K 251	0.0—0.65; weak max. at 0.0	—	—	medium to coarse-grained
T 12	K 197	0.0—0.65; max. at 0.0	—	64, 67, 68, 71, 74, 78	medium to coarse-grained, reddish brown
T 15	Nr 137	0.0—0.70; diffuse, weak max. at 0.70	0.64	76, 78, 80, 82, 84	medium-grained
T 22	Nr 115	0.80	0.70	82, 84, 85, 86	medium-grained
T 25	K 432	0.0—0.2; diffuse	—	—	medium to fine-grained, grey
T 38	K 524	0.0—0.63; no max.	0.64	—	medium to coarse-grained
T 42	K 197	0.0—0.68; no max.	0.66	—	medium to coarse-grained, greyish green
T 44	K 828	0.81	0.73	—	medium to coarse-grained
T 45	K 252	0.0—0.72; max. at 0.72	0.69	—	medium to coarse-grained
T 46	K 432	0.0	—	46, 50, 60, 62, 64	medium to fine-grained
T 79	Nr 91	0.76	0.66	—	medium-grained

Table 4. X-ray and optical data for K-feldspar from granite porphyry

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_{\alpha}$	Remarks
T 27	K 630	0.0—0.75; no max.	0.70	56, 60	phenocrysts
T 36a	K 620	0.0—0.1	—	68, 68, 72	phenocrysts
T 36b	K 620	0.0—0.71; diffuse, no max.	—	—	phenocrysts + matrix

Table 5. X-ray and optical data for K-feldspar from porphyritic granite penetrating the gabbro

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_{\alpha}$	Remarks
T 1	K 611	0.0—0.59; max. at 0.0	0.56	—	
T 18	K 163	0.0—0.71; no max.	—	48, 68, 69, 70, 76	an about 2 metres broad dike.
T 23	Nr 14	0.0—0.74; max. at 0.74	0.66	—	
T 37	K 430	0.0	—	—	
T 54	K 163	0.0—0.73; diffuse, no max.	0.60	—	

Table 6. X-ray and optical data for K-feldspar from medium to coarse-grained biotite-granite

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_{\alpha}$	Remarks
T 3	K 336	0.0—0.68; max. at 0.68	0.64	54, 62, 68, 69, 72, 72, 74, 82	
T 4	K 623	0.71; diffuse	0.57	—	
T 5	K 590	0.0—0.76; max. at 0.76	0.69	—	
T 6	K 391	0.0—0.70; weak max. at 0.70	0.66	—	
T 7	K 392	0.88	0.76	—	
T 8	K 580	0.78	0.70	60, 60, 68, 68, 72, 73, 80	
T 10	K 209	0.0—0.71; diffuse, max. at 0.71	0.73	—	
T 11	K 174	0.0—0.1	—	52, 64, 68, 70, 72	from the contact with Revsund granite
T 13	K 631	0.0—0.76; max. at 0.76	0.68	—	
T 14	Nr 53	0.0—0.74; max. at 0.74	0.68	68, 70	greyish brown granite
T 16	Nr 26	0.0—0.66; diffuse, weak max. at 0.66	0.59	—	
T 17	K 164	0.0—0.73; diffuse, max. at 0.73	0.68	—	
T 50	K 500	0.0—0.73; max. at 0.73	0.63	60, 66, 67, 70, 71, 72	
T 52	Nr 53	0.76	0.65	70, 72, 74	brownish red granite

Table 7. X-ray and optical data for K-feldspar from medium-grained biotite-granite

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_\alpha$	Remarks
T 19	K 468	0.0—0.76; diffuse, max. at 0.0	—	—	from the contact with gabbro
T 20	K 641	0.0—0.69; diffuse, weak max. at 0.69	0.57	—	
T 21	K 386	0.0—0.74; diffuse, max. at 0.74	0.62	—	
T 24	K 608	0.86	0.75	—	medium to fine-grained, even-grained
T 26	K 828	0.78	0.69	—	

Table 8. X-ray and optical data for K-feldspar from fine-grained biotite-granite

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_\alpha$	Remarks
T 28	K 631	0.81	0.72	70, 72, 80, 80, 82	miarolitic
T 29	K 404	0.0—0.70; diffuse, no max.	0.59	—	dike in syenite
T 30	K 163	0.0—0.74; weak max. at 0.74	0.64	—	dike in gabbro
T 31	K 470	0.0—0.68; diffuse, no max.	0.62	62, 66, 69, 72	” ” ”
T 32	K 322	0.0—0.68; diffuse, weak max. at 0.68	—	—	close to the contact with Revsund granite
T 33	K 166	0.76	0.68	68, 74, 75, 76, 76	
T 34	K 250	0.84	0.72	—	
T 35	Nr 26	0.0—0.68; diffuse, max. at 0.68	0.62	—	
T 62	K 334	0.0	—	—	from the contact with Revsund granite

Table 9. X-ray and optical data for K-feldspar from red pegmatite

Sample no.	Locality	Triclinicity (*Δ*)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_a$	Remarks
T 53	K 163	0.93	0.76	—	

Table 10. X-ray and optical data for K-feldspar from coarsely porphyritic, grey, late-Svecofennian granite (Revsund granite)

Sample no.	Locality	Triclinicity (*Δ*)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_a$	Remarks
T 49	K 174	0.0	—	50, 52 62, 66	from the contact with Ragunda granite
T 64	K 174	0.0	—	—	100 metres S. of the contact
T 57	K 493	0.0—? diffuse, max. at 0.0	0.58	—	50 metres from the contact
T 65	K 322	0.0	—	—	0.1 m ,, ,, ,,
T 66	The samples collected along an approximate line between K 322 and K 328	0.0	—	—	0.5 m ,, ,, ,,
T 67		0.0	—	—	1 m ,, ,, ,,
T 68		0.0	—	—	15 m ,, ,, ,,
T 69		0.0	—	—	50 m ,, ,, ,,
T 70		0.0	—	—	110 m ,, ,, ,,
T 71		0.0	—	—	500 m ,, ,, ,,
T 72	K 328	0.0	—	59, 60, 62	1000 m ,, ,, ,,
T 63	K 334	0.0	—	—	0.5 m ,, ,, ,,
T 61	K 333	0.0	—	—	100 m ,, ,, ,,
T 73	K 528	0.0	—	—	10 m ,, ,, ,,
T 74	Collected between K 528 and K 521	0.0	—	—	100 m ,, ,, ,,
T 75		0.0—0.70; max. at 0.0	—	—	250 m ,, ,, ,,
T 76	K 521	0.0—0.78; max. at 0.0	—	—	400 m ,, ,, ,,

Table 11. X-ray and optical data for K-feldspar from coarsely porphyritic, grey, late-Svecofennian granite (Revsund granite)

Sample no.	Locality	Triclinicity (Δ)	$2\theta_{1\bar{3}0}$—$2\theta_{130}$	$2V_\alpha$	Remarks
T 51	Nr 63	0.71; diffuse	0.66	—	'Rätan granite', in gabbro
T 55	K 276	0.0	—	46, 52	cross-hatched twinning in the grain with $2V_\alpha = 52°$
T 56	Nr 61	0.95	0.82	82, 83, 84, 86	fine-porphyritic Härnö granite
T 58	K 492	0.91	0.78	80, 80, 81	
T 59	K 266	0.0	—	—	
T 60	N. W. of K 275	0.0	—	—	
T 80	400 m S. K 172	0.0—0.71; diffuse, max. at 0.0	—	—	
T 81	K 185	0.91	—	—	
T 82	K 186	0.90	—	—	
T 83	350 m E. K 190	0.93	—	—	
T 84	K 193	0.0	—	—	
T 85	K 220	0.0	—	—	
T 86	K 264	0.0—0.1	—	—	
T 87	K 269	0.0	—	—	
T 88	K 272	0.88	—	—	
T 89	700 m N.W. K 276	0.0	—	—	
T 90	K 331	0.0—0.90; weak max. at 0.90	—	—	
T 91	K 364	0.90	—	—	

Table 11 (continuation). X-ray data for K-feldspar from coarsely porphyritic, grey, late-Svecofennian granite (Revsund granite).

Sample no.	Locality	Triclinicity (Δ)	Remarks
T 92	500 m S.W. K 374	0.0—0.83; diffuse, no max.	
T 93	K 379	0.90	
T 94	K 380	0.95	
T 95	K 477	0.0	
T 96	K 491	0.84	
T 97	K 507	0.95	
T 98	K 702	0.96	
T 99	K 705	0.91	
T 100	K 706	0.93	
T 101	K 718	0.0—0.76; diffuse, max. at 0.0	
T 102	K 723	0.94	
T 103	K 735	0.0—0.84; max. at 0.84	
T 104	500 m N. K 797	0.88	
T 105	K 802	0.93	
T 106	K 826	0.90	

PRISKLASS B

Distribution
SVENSKA REPRODUKTIONS AB
FACK, 162 10 VÄLLINGBY 1

Stockholm 1969

Kungl. Boktryckeriet P. A. Norstedt & Söner

Printed in Sweden