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Contribution to the mineralogy of rapakivi granites: I. Zircon of the Laitila rapakivi, southwestern Finland

by Atso Vorma and Tuula Paasivirta

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CONTRIBUTION TO THE MINERALOGY OF RAPAKIVI GRANITES: I. ZIRCON OF THE LAITILA RAPAKIVI, SOUTHWESTERN FINLAND

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ATSO VORMA AND TUULA PAASIVIRTA

30 figures and 5 tables in the text

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The hafnium content and the Hf/Zr ratio in zircon indicate a progressive enrichment of hafnium in relation to zirconium with advancing differentiation of the Laitila rapakivi granite. The Hf/Zr ratio in zircon is about 0.023 in the prevailing rapakivi variety, which is the normal rapakivi granite and occupies more than 90 per cent of the massif. In the rock itself, it is 0.025, indicating possibly a very small fractionation of hafnium and zirconium between the zircon and other minerals.

The contact varieties contain zircon with a lower Hf/Zr ratio than the samples farther from the contact. When zoning is detected in the zircon, the cores are usually poorer than the marginal parts in hafnium.

Zircons in lighter density fractions show a higher Hf/Zr ratio than those in the heavier fractions. In addition, it is most likely that the zircons in the lighter density fractions are richer in uranium and therefore susceptible to metamictization.

The study is based on 331 microprobe analyses of hafnium and zirconium in zircon and 37 instrumental activation analyses of these elements in the corresponding rock samples.

Key words: rapakivi, granite, mineralogy, geochemistry, zircon, zirconium, hafnium, metamict, magma, crystallization, differentiation, Finland.

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CONTENTS

INTRODUCTION

During recent years, rapakivi granite has received considerable attention in Finland not merely because of its attractive texture (see, e.g., Vorma 1971) but also owing to its mineralogy and petrology (Simonen and Vorma 1969, Vorma 1971, 1972, 1975 and 1976, and Haapala 1977 a), metallogeny (Haapala 1973, 1974, 1977 a and 1977 b, Haapala and Ojanperä 1969 and 1972), and geochronology (Vaasjoki 1977).

The Laitila rapakivi massif in southwestern Finland is at present the main object of the rapakivi studies of one of the present authors (A. V.). An important part of these studies is the investigation of accessory minerals. Among the accessory minerals characteristic of rapakivi, zircon is of utmost importance. The study therefore begins with zircon. Similar studies on apatite, monazite, allanite, etc., will be undertaken soon.

The general evolution of the Laitila massif was traced by Vorma in 1976. Haapala, in 1977, gave a thorough description of the northwestern part of the massif. Vaasjoki, also in 1977, discussed the age relations between different rapakivi varieties of the Laitila massif. These studies form the background to the present study.

The purpose of this study was to determine whether any correlation between the Hf/Zr ratio in zircon and the differentiation of the massif could be found. With this in view, 331 microprobe analyses of hafnium and zirconium from zircons and 37 instrumental neutron activation analyses of hafnium and zirconium from the corresponding rock samples were performed. In addition, silicate analyses made from the rock samples are available.

Atso Vorma is responsible for providing the samples and for setting up the problems posed by this study, and Tuula Paasivirta for the microprobe analyses. The manuscript was compiled and the conclusions were drawn jointly.

LAITILA RAPAKIVI

The Laitila massif, which comprises an area of ca. 1 400 sq. km in southwestern Finland, is a composite pluton. The rock types and their mutual relations can be briefly characterized, after Vorma (1976, pp. 37—56):

The bulk of the massif consists of normal Laitila rapakivi, which is similar in texture to the classical pyterlite of the Wiborg massif but closer in mineral and chemical composition to wiborgite than pyterlite. The ovoidal texture is well developed, and only thin plagioclase mantles around alkali feldspar ovoids are sparsely present. The normal Laitila rapakivi is either a hornblende-biotite rapakivi or biotite rapakivi. It is highly probable that these different varieties represent different intrusive phases.

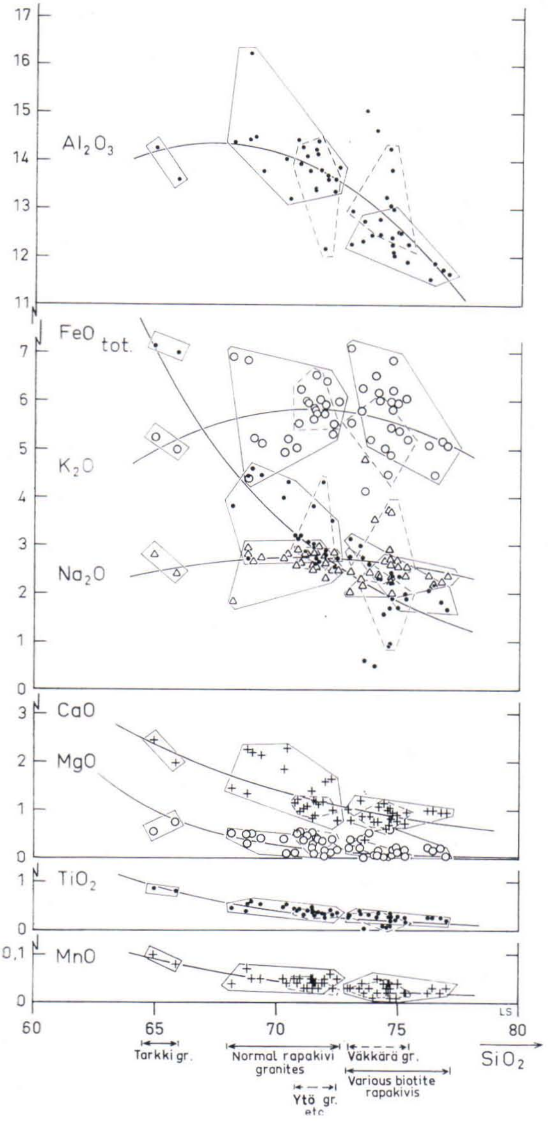

Fig. 1. Harker diagram of the granitic rocks from the Laitila rapakivi massif (from Vorma 1976, p. 58).

Different textural varieties also occur, such as, e.g., even-grained marginal granite and granite-porphyritic, as well as evidently marginal granite.

A minor part of the Laitila massif consists of different rapakivi varieties. These deviate from the normal Laitila rapakivi in their textural features so much that they have been designated by special names. Some of these are evidently of an autolithic nature formed from magma chilled earlier and brecciated by the same magma. A part certainly is a result of early segregation. Some of the granites were evidently produced by autointrusion. Finally, some of the small granite bodies, as, for instance, those of Ytö and Suutila (see Vorma 1976, Plate 1), formed from intrusion phases different from those represented by the normal rapakivi.

The Lellainen-type, even-grained biotite rapakivis form a quite coherent group in the eastern part of the massif. In places, they seem to change gradually to the normal Laitila rapakivi, but in other places the contact is sharp. A contact variety occurs in certain places against the normal rapakivi. All these features can be understood if these granites are taken to be a product of differentation of the normal rapakivi (magma) and of autointrusion.

So-called spotted granites form a special group among the biotite rapakivis. It is characteristic of these granites that there are abundant black biotite aggregates in the small or medium-grained matrix. The occurrences of spotted rapakivi are small. Being possibly of anatectic origin, the rock is evidently younger than the normal rapakivi.

Distinct from the foregoing biotite rapakivis, there are certain coarse- to fine-grained biotite and hornblende-biotite granites that occur as small bodies in the normal Laitila rapakivi. Some of these are evidently produced by autointrusion from the same intrusive phase from which the normal Laitila rapakivi crystallized. Some are derived from thoroughly different intrusive phases, such as, e.g., the Ytö granite and related rocks. Their emplacement evidently took place by the mechanism of underground cauldron subsidence. According to Vaasjoki (1977), the age of these granites is 1 540 ± 10 Ma while the age of normal Laitila rapakivi is 1 573 ± 8 Ma. The Ytö granite and related rocks constitute two concentric bodies, in which the marginal granites are coarse-grained and porphyritic, the central granites small-grained and aplitic. In the Ytö complex both the marginal and the central granite are called Ytö granites. In the Katinhäntä-Suutila complex the marginal granite is known as Suutila granite and the central granite Katinhäntä aplite. A feature peculiar to the marginal Ytö granite and Suutila granite is the presence of fine-grained gray autoliths, which range from only a few to tens of centimeters in diameter. They are similar to the central Ytö granite and Katinhäntä aplite. Characteristic of the Ytö granite and related rocks is the presence in them of muscovite and monazite.

At the northwestern margin of the Laitila massif, there is a satellite rapakivi body, called the Eurajoki complex. It consists of a marginal hornblende rapakivi, known as Tarkki granite, and a younger central biotite granite, called Väkkärä granite. A detailed description of this complex can be found in Haapala 1977 a.

The Laitila massif and its country rocks are cut by different kinds of rapakivitic dike rocks: pegmatite-, granite-, aplite-, porphyry aplite-, granite porphyry-, quartz porphyry- and quartz dikes. So far, quartz porphyry dikes have been encountered only in connection with the Eurajoki complex. For details, see Vorma 1976 and Haapala 1977 a.

Figure 1 (reproduced from Fig. 29 in Vorma 1976) shows the over-all chemical features of the rocks from the Laitila massif. In addition to the chemical analyses of samples to be studied in the present paper, the figure also contains some chemical analyses from the literature.

ROCK SAMPLE DESCRIPTION

Sampling

The samples studied for zircon (Table 1) are the same as those described by Vorma in 1976 (pp. 37—78 and Appendix 1). The sampling sites can be found in *op.cit.* Plate 1. Silicate analyses including the trace elements F, Li, Rb, Sr, Ba and Zr can be found in Appendix 2, Niggli values and CIPW norms in Appendix 3, and REE, Hf, Th and U contents in Appendix 4 of *op.cit.* The numbering of the samples in the present paper (Table 1) follows that in the *op.cit.*

The samples in Table 1 can be grouped as follows (Table 2):

No. 1 is a representative of the hornblende-bearing marginal granite, so-called Tarkki granite, of the Eurajoki complex. No. 48 is of the younger central granite, so-called Väkkärä granite, of the same complex. Nos. 3—16 apply to the group consisting of normal Laitila rapakivi. This includes, it is true, some granite-porphyritic varieties, viz., Nos. 14—16, and even-grained contact varieties, viz., Nos. 12 and 13. No. 12 is, in fact, a coarse-grained rapakivi in the central part of the massif, which gradually changes to normal rapakivi. No. 11, consisting of the porphyritic Kokemäki granite, is here classified with the normal Laitila rapakivi. They are separated from each other by the rift valley of Satakunta, which is filled with Jotnian sandstones. The rock is a hornblende-biotite granite, containing the typical accessory minerals of rapakivi.

Nos. 17—31 form a group of various, mostly even-grained biotite rapakivis. Of these, Nos. 17—22, and 27 can be described as Lellainen-

Table 1.

List of rapakivi granite samples, studied for zircon, from the Laitila rapakivi massif.

Sample No. 1)	Rock type	Field No.	Locality
1	Tarkki granite	85/IH/67	Lapijoki, Eurajoki
3	Normal Laitila rapakivi	30—2/AV/67—73	Hinnerjoki, Eura
4	» » » (small ovoidic)	27/AV/66—73	Lamssijärvi, Yläne
5	» » » (90 m from the contact of the massif)	511/LC/68—73	Kylmäkorpi, Kalanti
6	Normal Laitila rapakivi	327/LC/68—73	Untamala, Laitila
7	» » »	28/AV/66—73	Lemmi, Mynämäki
11	Kokemäki granite	29/AV/67—73	Peipohja, Kokemäki
12	Coarse-grained rapakivi with a gradual change to normal Laitila rapakivi	329/MT/67—73	Löyttilä, Eura
13	Marginal even-grained modification of normal Laitila rapakivi	32/KV/67—74	Elijärvi, Yläne
14	Granite porphyry	20/AV/66—73	Sydänmaa, Eurajoki
15	» »	232 a/MT/67—73	Haukkavuori, Säkylä
16	Marginal granite porphyry of normal rapakivi	111/AV/74	Ihode, Pyhäranta
17	Even-grained rapakivi	205/MT/67—73	Lellainen, Eura
18	» »	17/AV/66—73	Lamminjärvi, Eura
19	» »	30—1/AV/67—73	Hinnerjoki, Eura
20	» »	30/KV/67—73	Elijärvi, Yläne
21	» » (with scattered ovoids)	18/AV/66—73	Turajärvi, Eura
22	» »	110/AV/74	Neittamo, Eura
23	» » (topaz bearing)	237/MT/67—74	Laajoki, Karjala
24	» » (coarse grained)	320/MT/67—74	Honkilahti, Eura
25	» » (dark coloured)	166/MVA/72—74	Malko, Laitila
26	» »	169/MVA/72—74	Haaro, Laitila
27	Porphyry aplite	56/MT/67—73	Latvajärvi, Eura
29	Spotted granite	21/AV/66—73	Kodisjoki
31	» »	164/MT/67—74	Lamssijärvi, Yläne
33	Marginal Ytö granite	1—1/AV/66—73	Kusni, Laitila
34	Central Ytö granite	102/AV/74	Kuloistensuo, Laitila
35	Autolith in the marginal Ytö granite	1—2/AV/66—73	Kusni, Laitila
36	» » » » » »	124/MVA/72—74	Ytö, Laitila
37	Suutila granite	23—1/AV/66—73	Suutila, Karjala
38	» »	100/AV/74	Karjalankylä, Karjala
39	Autolith in the Suutila granite	23—2/AV/66—73	Suutila, Karjala
40	» » » » »	101/AV/74	Karjalankylä, Karjala
41	Katinhäntä aplite (central Suutila granite)	2/AV/66—73	Katinhäntä, Laitila
48	Väkkärä granite	98/MK/67/ER/73	Eurajoki
49	Even-grained rapakivi dike	24/AV/66—74	Kohomussuo, Honkilahti, Eura
51	Granite porphyry dike	45/KV/67—74	Heinjoki, Yläne

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1) The sample numbers are the same as in Vorma 1976, Appendix 1.

type rapakivis. Among them, sample No. 21 is from the small Turajärvi granite body. The granite evidently changes gradually into normal rapakivi. The rock is inhomogeneous, in places even-grained and in same cases with scattered ovoids turning into porphyry aplite. In certain instances, the ovoids increase in quantity, and the grain size of the matrix decreases to designate the rock as granite porphyry. Sample No. 21 closely resembles granite porphyry. However, there are not so many alkali feldspar ovoids as in the rapakivi granite porphyries proper. No. 27 is from a porphyry-aplitic portion of even-grained rapakivi in another small granite body. Sample No. 19 is of a Lellainen-type granite occurrence. It was taken 2 m

Table 2.

Grouping and subgrouping of the rapakivi granite samples studied for zircon. The numbers refer to Table 1.

Tarkki granite	Group of normal rapakivi	Various biotite rapakivis	Ytö granite and related rocks	Väkkärä granite	Dike rocks
1	3—16	17—31	33—41	48	49, 51
No subgrouping	Normal rapakivi 3—11	Lellainen-type granite 17—22, 24, 27	Marginal, porphyritic 33, 37, 38	No subgrouping	Even grained 49
	From contact zone 5, 12, 13	Topaz granite 23	Central, aplitic 34, 41		Granite porphyry 51
	Granite porphyritic 14—16	Dark Schlieren 25	Autoliths 35, 36, 39, 40		
		»Haaro» granite 26			
		Spotted granite 29, 31			

from the contact against normal rapakivi. Between the sampling site and the contact, there is a banded chilled contact variety of Lellainen-type rapakivi. The contact line itself is sharp.

Distinct from the even-grained biotite rapakivis mentioned in the foregoing, there is the coarse, even-grained Haaro granite (No. 26). It contains in places a few pyterlitic, even wiborgitic ovoids per square meter. It is a brownish-red biotite granite with a sharp contact against the normal rapakivi.

Sample No. 25 is from a presumably autointrusion body in the normal Laitila rapakivi. It is from a darkish subhorizontal schlieren measuring up to 1 m in thickness. The rock is dark, like the typical tirilite rapakivi of the Wiborg massif.

Sample No. 23 is from an intrusive phase presumably younger than that of the normal Laitila rapakivi. It is from a small occurrence of topaz-bearing, medium-grained red rapakivi. The granite contains an abundance of fluorite. Zircon, muscovite and monazite are additional characteristic accessory minerals. In appearance, the rock is identical with the even-grained variety of the Väkkärä granite of the Eurajoki complex.

Two samples are representatives of spotted granites. The biotite spots measure up to 1—2 mm in diameter in the fine-grained variety (No. 29) and up to 1 cm in diameter in the medium-grained variety (No. 31).

Samples Nos. 33—41 are from the group of Ytö granite and related rocks. Sample No. 33 is from the marginal Ytö granite. Nos. 37 and 38 are from the Suutila granite, i.e., from the marginal granite of the Katinhäntä-Suutila complex. Sample No. 34 is from the small-grained central Ytö granite. No. 41 is from the Katinhäntä aplite, i.e., from the central granite of the Katinhäntä-Suutila complex. Samples Nos. 35, 36, 39 and 40 are from small-grained autoliths from the marginal Ytö and Suutila granites.

Samples Nos. 49 and 51 are representatives of rapakivitic dike rocks cutting the normal Laitila rapakivi. No. 49 is from a light-coloured medium-grained biotite rapakivi dike. No. 51 is from a rapakivi granite porphyry dike more than 10 meters wide.

Zirconium and hafnium contents

All the samples assembled for zircon study were studied for their zirconium and hafnium using instrumental neutron activation analysis.1) The results are given in Table 3. Each zirconium and hafnium figure is the mean of at least three determinations. Because of the analysis method used, the hafnium values can be regarded as quite good. The standard deviation of a single determination ranges from 0.1 to 1.6 ppm. But the zirconium values are not so good, the standard deviation ranging from 10 to 150 ppm. Table 3 also gives the Hf/Zr ratio of the rock samples studied. The normative zircon content of the rock calculated from each Zr-Hf pair is given in Table 3, too. In addition, Larsen's differentiation index (Larsen 1938) is given.

The Hf/Zr ratios vary in quite narrow limits. For the group of normal Laitila rapakivis, they range from 0.020 to 0.030, the mean being 0.025 ± 0.003 (SD); for the group of various biotite rapakivis, from 0.023 to 0.041, and 0.034 ± 0.006, respectively; and for Ytö granite and related rocks, from 0.024 to 0.040, and 0.029 ± 0.005, respectively. Hence there is a slight tendency for the Hf/Zr ratio to increase from normal Laitila rapakivis via Ytö granite and related rocks to various biotite rapakivis. The same tendency is to be found in Fig. 2, where hafnium is plotted against zirconium. It can also be seen in Fig. 3, in which the hafnium and Hf/Zr ratio are plotted on a Larsen diagram (Larsen 1938), i.e., against $^1/_3SiO_2 + K_2O$ — $FeO_{tot.}$ — MgO — CaO (in wt. %) of the rock. Even though the variation along the abscissa is slight, Fig. 3 shows a clear decrease in the hafnium content of the rock with increasing

Table 3.

Differentiation index (DI) 1), instrumental neutron activation analyses of Zr and Hf, the Hf/Zr ratio and the normative zircon of rock samples studied for zircon. Activation analyses by Riitta Zilliacus.

Sample No.	DI	Zr ppm	Hf ppm	Hf/Zr		Normative zircon wt.-%
1	17.20	(610)2)	17.0	0.028		0.126
3	22.15	550	12.8	.023	0.025 ±0.003	.112
4	24.13	380	9.8	.026		.078
5	26.47	300	9.1	.030		.062
6	25.47	620	12.2	.020		.126
7	22.06	630	13.8	.022		.129
11	25.75	400	10.0	.025		.082
12	24.04	370	9.3	.025		.076
13	21.21	400	11.2	.028		.082
14	20.94	380	10.4	.027		.078
15	24.18	260	8.4	.023		.054
16	25.75	270	7.3	.027		.055
17	28.12	300	6.9	.023	0.034 ±0.006	.061
18	27.78	290	8.7	.030		.060
19	26.66	230	9.4	.041		.048
20	27.02	250	8.2	.033		.051
21	26.76	350	12.6	.036		.072
22	27.24	270	9.8	.036		.056
23	28.24	260	8.4	.032		.054
24	25.83	350	8.6	.025		.072
25	25.90	420	11.9	.028		.086
26	26.25	380	9.9	.026		.078
27	27.98	230	9.5	.041		.048
29	27.80	470	11.9	.025		.096
31	27.85	320	10.9	.034		.066
33	25.27	230	7.2	.031	0.029 ±0.005	.047
34	25.70	220	7.1	.032		.045
35	26.81	140	4.1	.029		.029
36	25.42	200	4.9	.025		.040
37	23.83	390	9.4	.024		.080
38	24.28	340	8.6	.025		.070
39	25.18	560	14.9	.027		.118
40	25.11	270	10.9	.040		.056
41	25.17	480	12.0	.025		.098
48	28.14	170	4.6	.029		.035
49	28.27	280	9.8	.035		.056
51	25.25	460	10.6	.023		.094

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1) Differentiation index, $^1/_3 SiO_2 + K_2O$ — $FeO_{tot.}$ — MgO — CaO, calculated from the data in Appendix 2 in Vorma 1976.

2) By emission spectrographic analysis.

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1) The zirconium and hafnium values of each sample are, it is true, to be found in Vorma 1976. It was thought reasonable, however, to reanalyze the samples using the one and the same method of analysis for both of these elements. In the *op. cit.*, the hafnium values were obtained by neutron activation analysis, the zirconium values by X-ray fluorescence analysis. The checking of the analyses in this way indicated certain of the previously published analyses to be significantly different from the new ones.

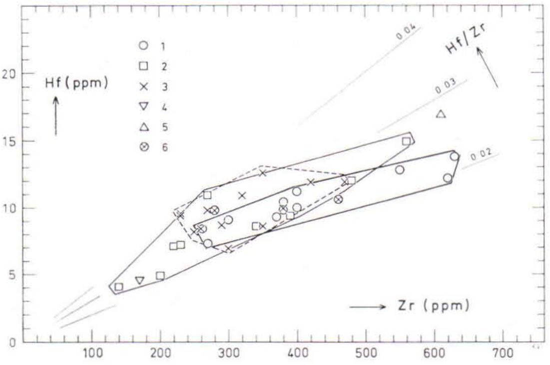

Fig. 2. The Hf vs. Zr diagram of granitic rocks from the Laitila rapakivi massif. The data are from Table 3. 1 = group of normal Laitila rapakivi, 2 = Ytö granite and related rocks, 3 = various biotite rapakivis, 4 = Väkkärä granite, 5 = Tarkki granite, 6 = rapakivitic dike rocks.

differentiation. The increase in the Hf/Zr ratio with differentiation of rapakivi is not so marked, even though the tendency is unambiguous. All this indicates, provided that most of the zirconium and hafnium are contained in the zircon, that in rapakivi zircon is an early mineral to crystallize. It is enriched in the more basic varieties of rapakivi, while the late, more siliceous differentiates are poorer in it. It should be emphasized that the rocks contained in Figs. 2 and 3 are from several intrusive phases. Ytö granite and related rocks are, for example, about 30 Ma younger, than the normal Laitila rapakivi (Vaasjoki 1977). Thus the scatter of the data in the figures is certainly caused in part by several subparallel trends.

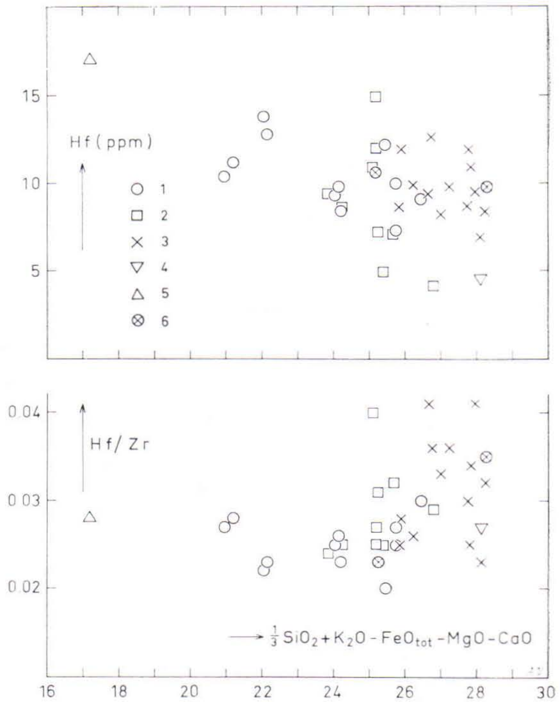

Fig. 3. Hafnium and Hf/Zr ratio in granitic rocks from the Laitila rapakivi massif plotted against Larsen's differentiation index. The data are from Table 3. 1 = group of normal Laitila rapakivi, 2 = Ytö granite and related rocks, 3 = various biotite rapakivis, 4 = Väkkärä granite, 5 = Tarkki granite, 6 = rapakivitic dike rocks.

MODE OF OCCURRENCE OF ZIRCON IN RAPAKIVI

The majority of the zircon is contained in the irregular aggregates consisting of biotite, hornblende, ± fayalite (and/or its alteration product iddingsite), ± grunerite, opaques (ilmenite, in places altered into anatase, and magnetite), and apatite (Figs. 4 and 5). Late quartz and fluorite frequently replace the ferromagnesian silicates. The zircon occurs mostly as idiomorphic crystals in these aggregates. In places, it also shows allotriomorphic outlines, especially against apatite and opaques.

A smaller part of the zircon is to be found as idiomorphic grains between larger feldspar or quartz grains (Fig. 6). Especially in certain even-grained biotite rapakivis, most of the zircon occurs in this way.

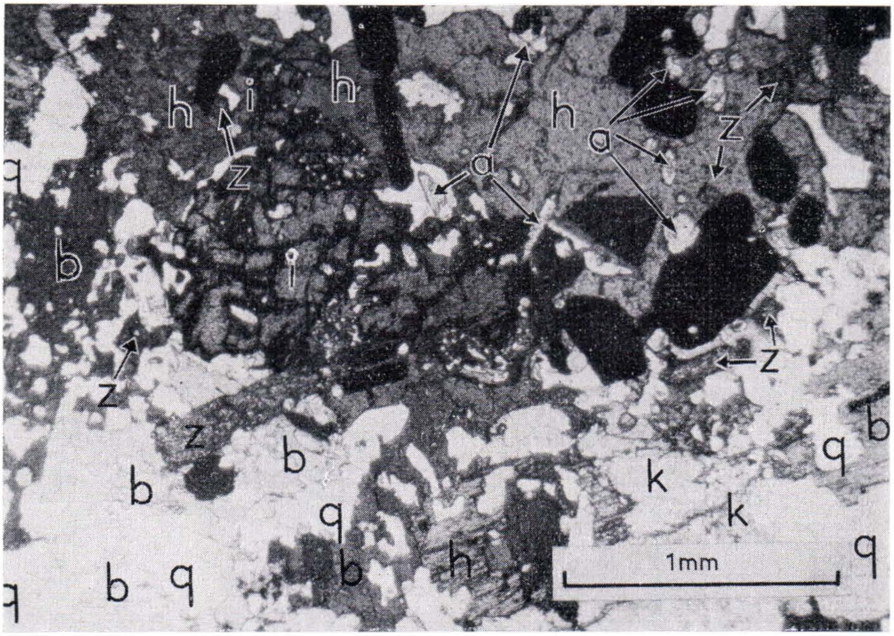

Fig. 4. Occurrence of zircon (z) with apatite (a) and opaques in the aggregates composed of hornblende (h), biotite (b), and iddingsite (i). Other indicated minerals: potassium feldspar (k) and quartz (q). Marginal even-grained modification of normal Laitila rapakivi. Sample No. 13.

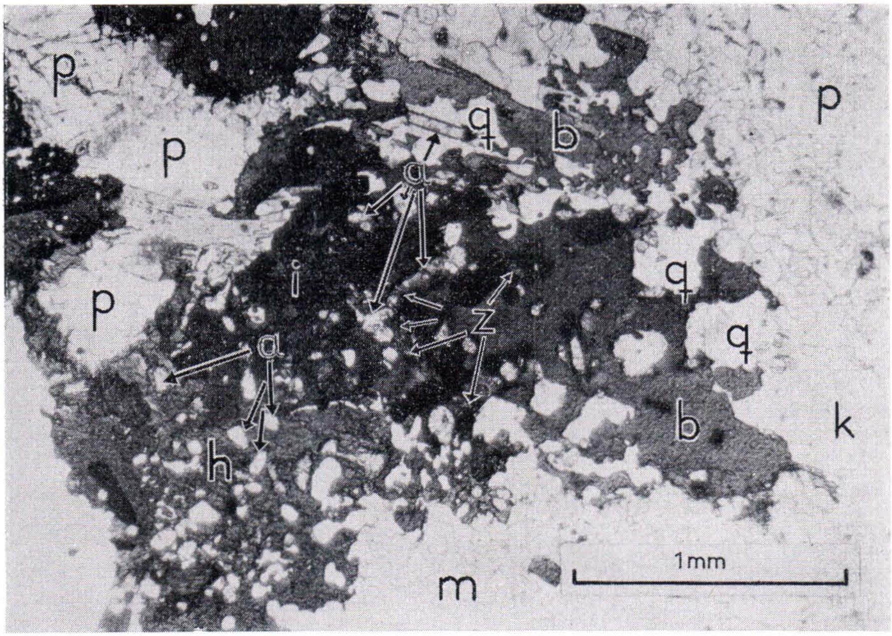

Fig. 5. Occurrence of zircon (z) in a late biotite (b) aggregate. Other indicated minerals: apatite (a), iddingsite (i), quartz (q), potassium feldspar (k), micropegmatite (m), and plagioclase (p). Note also the concentration of opaques in the aggregate. Same sample as in Fig. 4.

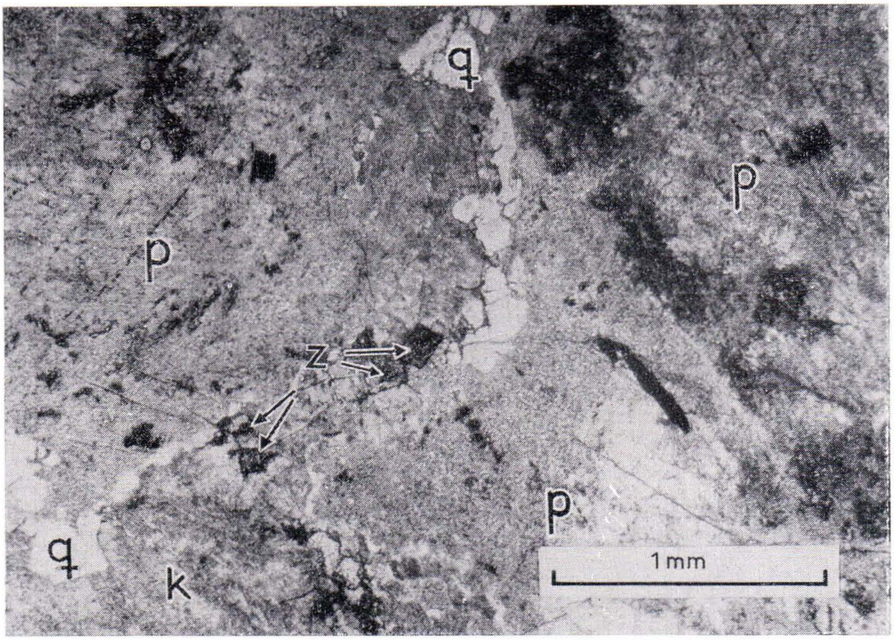

Fig. 6. Occurrence of zircon (z) in the seam between large plagioclase (p) grains. Other indicated minerals: potassium feldspar (k) and quartz (q). Even-grained Lellainen-type rapakivi. Sample No. 24.

Scattered idiomorphic zircon crystals are to be found as inclusions in potassium feldspar, both ovoidic and the ground-mass feldspar, plagioclase and quartz. Zircon occurs in the same way in late poikilitic biotite, sometimes also in the poikilitic hornblende. In these, only seldom scattered zircon crystals are met with as inclusions.

This kind of occurrence of zircon in rapakivi can easily be explained by simply calling attention to the odd crystallization order of rapakivi minerals. It has been pointed out (see, e.g., Sederholm 1928 and Savolahti 1962) that in rapakivi granites ferro-magnesian silicates crystallized at a quite late stage compared with the main part of the crystallization of quartz and feldspars. On the other hand, zircon is regarded as having crystallized at an early phase in granitic melts. If so, then the zircon (with apatite, ilmenite and magnetite) crystals were pushed out of the way when the feldspar and quartz grains grew larger and larger. Only a very small fraction of the crystals became engulfed in the growing feldspar and quartz grains. In this way, zircon became concentrated with other early accessory minerals in the residual melt from which the ferro-magnesian minerals, particularly biotite and hornblende, crystallized. Thus zircon remained as inclusions in them. The last stage in the development of the aggregates was the crystallization of the late quartz and fluorite and the connected replacement phenomena.

When the feldspar and quartz grains grew larger, some of the zircon grains pushed in front of them became entrapped between two coalescing grains. That explains the common occurrence of zircon at such grains margins.

This crystallization mechanism is also in accord with the sparse occurrence of zircon as inclusions in the late poikilitic biotite or hornblende.

Microscopical study reveals that either the zircon grains are quite homogeneous, or they show very fine-scaled zoning in the peripheral parts. Also idiomorphic zircon crystals zoned throughout are frequently met with. In addition, allotriomorphic older cores in otherwise idiomorphic zircon crystals are sometimes seen (compare Fig. 7 a). These cores are similar to those described by Vaasjoki (1977) from the even-grained variety of Vehmaa rapakivi. From this rock, Vaasjoki studied, besides the idiomorphic zircon (ca. 1 600 Ma old), a zircon population with a rounded morphology. It resembles very closely the older cores of allotriomorphic zircon in otherwise idiomorphic zircon crystals, also described by Vaasjoki. From this zircon, a 207 Pb/206 Pb age of 2 750 Ma was obtained, suggesting that the rounded cores are remnants of a much older rock.

The crystal size of zircon varies quite considerably, from less than 0.05 mm to more than 0.25 mm in length. On the average, the crystal size is smallest in the autoliths of the marginal Ytö granite and Suutila granite as well as in the Katinhäntä aplite, which is the central granite of the Katinhäntä-Suutila complex.

ABUNDANCE OF ZIRCON IN RAPAKIVI

Owing to the small quantity of zircon present in the rock, the zircon content of the chemically analyzed samples was estimated in two different ways: that of normative zircon and that of the modal zircon.

The normative zircon contained in the samples is given in Table 3. The mean of the rock groups appears in Table 4, where the normative zircon is also converted into percentages by volume.

The modal zircon was determined from thin sections using the point counting method modified by Rein (1961). By this method — using the micrometer ocular instead of the normal ocular —, a 100-fold lengthening of the normal distance of integration is received. In the present case, from 100 000 to 150 000 points were counted per thin section. A computer was used instead of the customary Swift control unit to facilitate quick counting. The

Table 4.

Amount of zircon in the different rapakivi groups of the Laitila massif.

Rock group	N	Normative zircon			Modal zircon	
		Wt.-%	SD	Vol.-%	Vol.-%	SD
Tarkki granite	1	0.12		0.071	n.d.	
Normal Laitila rapakivis	11	0.084	.026	0.050	0.045	.035
Various biotite rapakivis	13	0.065	.015	0.038	0.036	.033
Ytö granite and related rocks	9	0.065	.029	0.038	0.010	.004
Väkkärä granite	1	0.035		0.021	n.d.	
Dike rocks						
Even-grained granite	1	0.056		0.033	0.032	
Granite porphyry	1	0.094		0.055	0.064	

Normative zircon from Table 3. When normative zircon in wt.-% is converted into vol.-%, densities of 4.5 and 2.65 for zircon and rapakivi are used.

N = number of samples studied for zircon. The thin sections come from the same samples from which the chemical analyses are made.

SD = standard deviation of the mean.

n.d. = not determined.

modal zircon thus derived for the different rapakivi groups is given in Table 4.

When the normative zircons (converted into percentages by volume) are compared with the modal zircon contents, it is seen that both estimations give highly similar results. The exception is that of the group of Ytö granite and related rocks. In these rocks, which are very rich in monazite, many of the minute zircon grains evidently became counted as monazite.

When the results in Table 4 are compared with the data in Fig. 1, it can be seen that, considered roughly, the zircon is enriched in the more basic rock types in the rapakivi suite (Tarkki granite). It can also be seen that the amount of zircon decreases with an increasing SiO_2 content in the rock, viz., Tarkki granite — normal Laitila rapakivis — various biotite rapakivis. Väkkärä granite (see also Haapala 1977 a) is the poorest in zircon. Since the normal Laitila rapakivi is by far the most common rapakivi variety in the Laitila massif, there is justification for stating that, on the average, the Laitila massif contains some 0.05 vol. per cent zircon.

ZIRCON ANALYSIS

Sample preparation and description

The rock samples were crushed and sieved through a 70- mesh nylon sieve. The sieved grains were throughly washed free of fine dust. After this, bromoform (D = 2.8 g/ml) ¹) was used to separate the feldspars and quartz out of the samples. The fractions heavier than 2.8 were treated with methylene iodide (D = 3.3) and Clerici's solutions with densities of 3.5 and 4.2. The magnetite and pyyrhotite were removed from the heavy mineral concentrates with a hand magnet. Thus four nonmagnetic fractions of heavy minerals were obtained from each sample ,²) viz.,

1. density more than 4.2
2. » 3.5 — 4.2
3. » 3.3 — 3.5
4. » 2.8 — 3.3

A polished grain thin section was prepared from each fraction, bringing the number of thin sections to be studied to 145. It should be emphasized that the mineral fractions are concentrates of heavy minerals and not monomineralic. ¹) The heaviest fraction is richest in zircon, while in the two lightest fractions accessory heavy minerals occur only in minor amounts. Such rock-forming minerals as hornblende and biotite prevail. In addition, separate grains of low-density metamict zircon are found in the heavy fractions. Well-preserved unmetamict zircon crystals are also met with in the lightest fractions. Therefore, when comparing the results of different density fractions, not too much emphasis should be paid to any single determination.

Microscopical study of the grain thin sections reveals differences in zircons of different density fractions. In the heaviest fraction (D > 4.2), unzoned idiomorphic zircon crystals or splinterns of unzoned crystals are enriched. These were originally considerable larger than the 70- mesh size. In some of the large crystals, fine zoning appears in the marginal parts. A

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¹) Hereafter the unit symbol g/ml will be abandoned in the present text. The symbol D refers to density.

²) From the samples Nos. 35, 36 and 40, only three density fractions were separated, viz., those with densities of more than 3.5, and 3.3 — 3.5 and 2.8 — 3.3.

¹) Besides zircon, the fractions contain opaques (mainly ilmenite), monazite, fayalite, allanite, anatase, topaz, hornblende, grunerite, epidote, iddingsite, biotite, fluorite, apatite, muscovite, chlorite, etc. The same thin sections will later be used for the study of other heavy minerals in rapakivi.

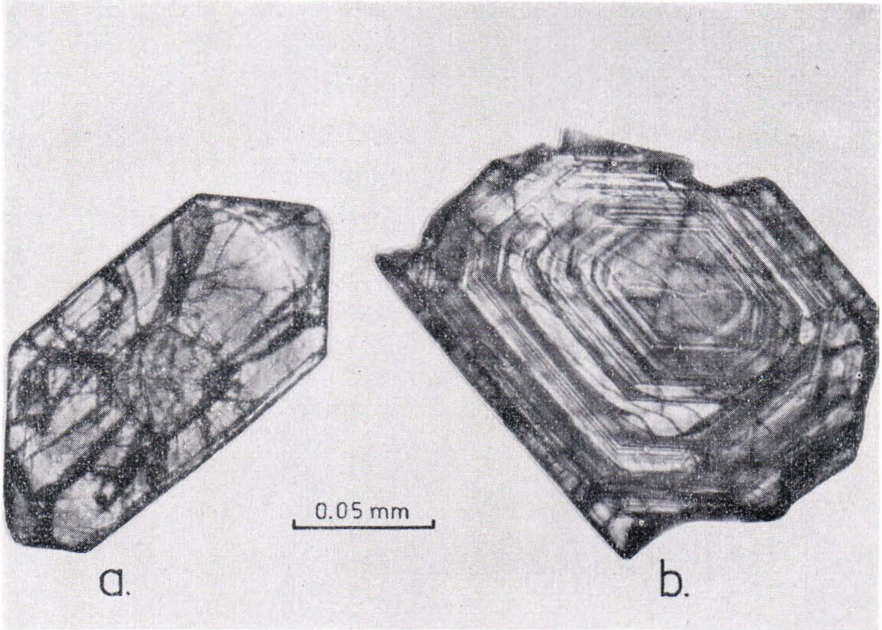

Fig. 7. An example of the occurrence of an old allotriomorphic core in an idiomorphic younger zircon from sample No. 12, figure *a*, and an example of the occurrence of zircon finely zoned throughout from sample No. 11, figure *b*.

few zircon crystals finely zoned throughout occur, moreover, in this fraction. Fig. 7 b illustrates such an example from the Kokemäki granite, sample No. 11. Every now and then, allotriomorphic cores of older zircon are met with. Fig. 7 a illustrates such a case contained in the coarse-grained rapakivi, No. 12. It is a transitional variety between normal rapakivi and even-grained Lellainen-type rapakivi. The allotriomorphic core in this case is thoroughly metamict. The alteration of core zircon has taken place at least partly after the crystallization of the younger zircon. This conclusion can be made because of the radial fractures in the surrounding idiomorphic zircon.

The finely zoned zircon is enriched into the density fraction 3.5—4.2. Also unzoned zircon occurs sporadically in this fraction. This may be due to incomplete separation. The crystal size is somewhat smaller than in the heaviest fraction. Splinterns of larger zircon crystals are not very common, either. Elongation of zircon crystals in this fraction seems to be somewhat better developed than in the heaviest density fraction.

The two lightest density fractions contain only sporadic zircon grains. Their crystal form is only seldom well developed. The grains are often turbid and the alteration of the mineral far advanced. Some specimens did not yield a single grain of zircon into the lightest density fraction.

The grain size and the crystal form tend to be similar in most of the rapakivi samples studied. Representative samples are illustrated in Figs. 8—19. In the coarse-grained varieties of rapakivi, large crystals or splinterns, passed through the 70-mesh sieve in their longitudial direction, seem to be slightly more abundantly present than in the medium-grained varieties (Figs. 8—11 and 14—15). Even the granite-porphyritic rapakivi dike (Figs. 12—13) shows almost the same kind of coarse zircon as that in the coarse-ovoidic normal rapakivi. This

Fig. 8. Zircon in the density fraction D > 4.2. Other minerals present: ilmenite, fayalite, and iddingsite. Normal Laitila rapakivi. Sample No. 6.

Fig. 9. Zircon in the density fraction 3.5 — 4.2. Other minerals present: hornblende, iddingsite, and allanite. Same sample as in Fig. 8.

Fig. 10. Zircon in the density fraction D > 4.2. Other minerals present: ilmenite and hornblende. A transitional rapakivi variety between normal Laitila rapakivi and Lellainen granite. Sample No. 12.

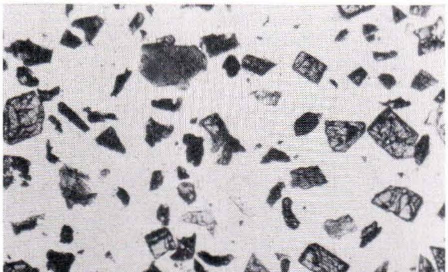

Fig. 11. Zircon in the density fraction 3.5 — 4.2. In addition, hornblende present. Same sample as in Fig. 10.

Fig. 12. Zircon in the density fraction D > 4.2. In addition, ilmenite present. Granite porphyry. Sample No. 51.

Fig. 13. Zircon in the density fraction 3.5 — 4.2. Other minerals present: ilmenite, feldspars, and biotite. Same sample as in Fig. 12.

Fig. 14. Zircon in the density fraction D > 4.2. In addition, biotite present. Lellainen granite. Sample No. 17.

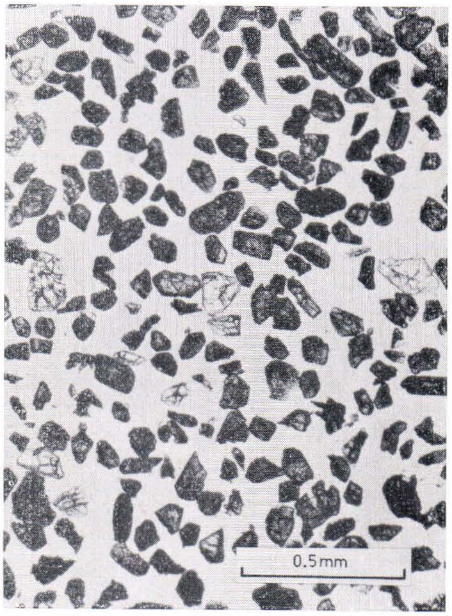

Fig. 15. Zircon in the density fraction 3.5 — 4.2. Other minerals present: feldspars, quartz, anatase, and biotite. Same sample as in Fig. 14.

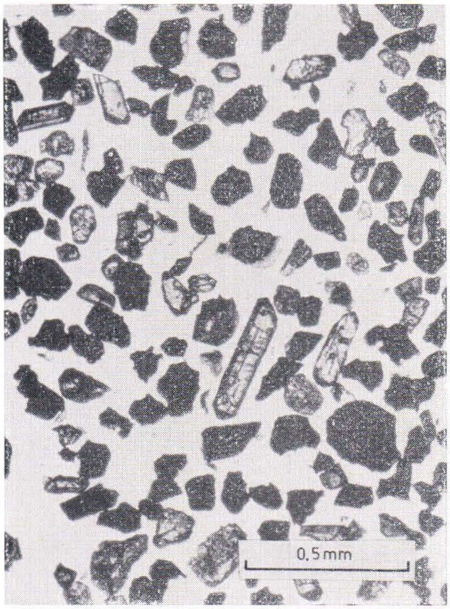

Fig. 16. Zircon in the density fraction D > 4.2. Other minerals present: monazite and ilmenite. Marginal Ytö granite. Sample No. 33.

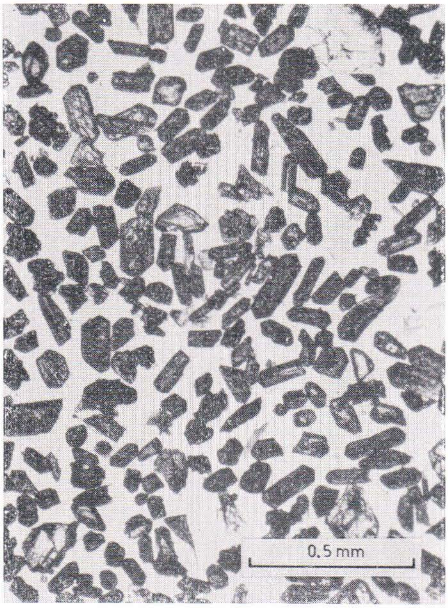

Fig. 17. Zircon in the density fraction 3.5 — 4.2. Other minerals present: feldspars, quartz, monazite, and anatase. Same sample as in Fig. 16.

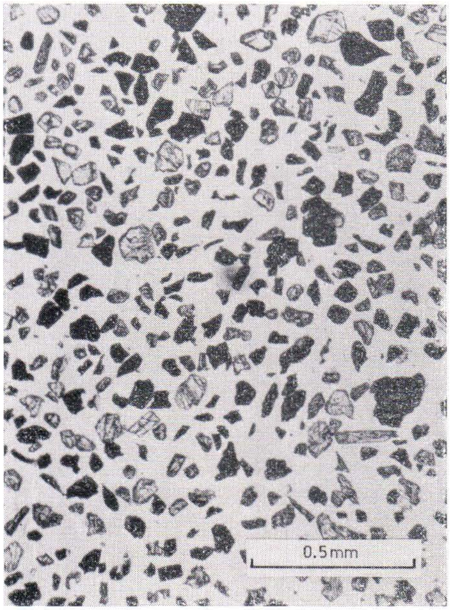

Fig. 18. Zircon in the density fraction D > 4.2. Other minerals present: monazite and ilmenite. Autolith in the Suutila granite. Sample No. 39.

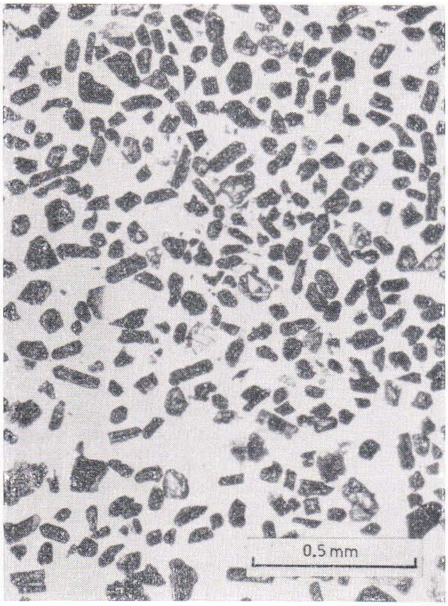

Fig. 19. Zircon in the density fraction 3.5 — 4.2. Other minerals present: feldspars, opaques, monazite, apatite, hornblende, clinopyroxene, and anatase. Same sample as in Fig. 18.

indicates that the zircon had been growing in the granite-porphyry dike during the emplacement of the melt.

A correlation between the grain size of the host rock and that of zircon can be found only in the group of Ytö granite. Figs. 16 and 17 show typical zircon of the coarse-grained marginal Ytö granite. In the Suutila granite, i.e., in the marginal coarse granite of the Katinhäntä-Suutila complex, the zircon is of the same grain size. Figs. 18 and 19 show the crystal form and the small grain size of the zircon contained in a small-grained autolith in the Suutila granite. The Katinhäntä aplite also contains similar small-grained zircon. Most of the zircon in the specimens of this granite group is very finely zoned. Contrary to the foregoing observations, the small-grained central Ytö granite sample contains coarse zircon similar to the marginal coarse-grained Ytö granite. All these observations indicate that possibly only a small part of the zircons contained in the Ytö and Katinhäntä-Suutila complexes were intratelluric.

Methods

All the preparations were analyzed for zircon using a Geoscan electron probe microanalyser with accelerating potential of 30 kV, specimen current of 0.06 μA and beam diameter of about 3 μm. The zirconium and hafnium were measured using pure elements as standards. From many of the samples, also silicium, and from some of the samples, calcium, iron, uranium, phosphorus, yttrium and ytterbium were determined. With the exception of silicium, these elements were found in very small quantities. The present study is concerned only with zirconium and hafnium because of the high probability that the foregoing elements are contained in inclusions in zircon.[1] Two or more zircon crystals were analyzed from each thin section. Exceptions were those preparations from which no zircon grains or only one could be found. Two or more points in each crystal were analyzed. These points were situated from the core to the margin. The beam diameter did not allow for the study of the separate zones in the finely zoned crystals. The analyses thus represent averages of many adjacent zones. When no clear differences in the amounts of hafnium and zirconium in the different points of a single crystal could be detected, the result given is the mean of the analyses. Otherwise, the analyses corresponding to the core and the marginal parts of the zircon crystal are treated separately.

The nature of the preparations causes ambiguity in the interpretation of the results. In the polished grain thin section, most of the zircon crystals lie with their *c*-axis parallel to the glass slide. The upper surface is ground and polished. Different crystals became cut parallel to their *c*-axis at different depths. The point to be analyzed was selected under the microscope in transmitted light. This brings it about that many of the points thought to be representative of the cores might in fact belong to the marginal parts of the crystal. This might also explain why there are so many zircon crystals thoroughly homogeneous in composition, even though microscopical investigation indicates that the zoning is more common than the analytical results reveal.

The raw microprobe data were corrected using the computer program of Rucklidge and Gasparrini (1969).

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[1] It is noteworthy that in the zircon of the Salmi rapakivi, located northeast of Lake Ladoga, USSR, the small yttrium and phosphorus contents have been shown to be caused by minute xenotime inclusions (Rub and Loseva 1974).

Results

The Hf/Zr ratios, hafnium and zirconium contents and their sums as well as the SiO_2 are given in Table 5. The SiO_2 content given is a calculated value. It is calculated on the basis of HfO_2 and ZrO_2 values measured to correspond to (Zr, Hf) SiO_4. The sum $ZrO_2 + HfO_2 + SiO_2$ gives some kind of an estimation for the alteration (breakdown, hydration, silicification, metamictization) of ziron. Most of the zircons, to be sure, were also analyzed for SiO_2. It was, however, considered better to replace the measured values by calculated ones expressly for the foregoing reason.

The data in Table 5 are graphically shown in Figs. 20—30. In Fig. 20, the emphasis is on the fractionation of hafnium and zirconium with differentiation of rapakivi. In Figs. 21—26, it is on the Hf/Zr ratio vs. rapakivi variety and density fraction of zircon, and in Figs. 27—30 on the metamictization of zircon.

The analytical data on the zircon crystal illustrated in Fig. 7 a are the only ones in Table 5 (Nos. 12 ac and im) that are not included in the graphical illustrations of Figs. 21, 22 and 27. The allotriomorphic core has a smaller Hf/Zr ratio (0.025) than the idiomorphic margin (0.028). Also the sum of the oxides in the core deviates more from 100 than in the marginal part. This is in accord with the microscopical observation that the core is isotropic (metamict) and the marginal parts are anisotropic between crossed nicols.

Zircon composition vs. rock composition

The zircon data from Table 5 are plotted in Fig. 20 against Larsen's differentiation index from Table 3. The over-all increase in both the hafnium content and the Hf/Zr ratio in zircon with increasing differentiation of the rock is clear even though the scatter of the data is very large. This scatter is certainly due in part to several subparallel trends, and in part to secondary changes in the Hf/Zr ratio in zircon. The data in Table 5 show that all the unusually high hafnium contents and Hf/Zr ratios are connected with analyses where the sum of oxides deviates most from 100 per cent. Therefore, only such analyses with $HfO_2 + ZrO_2 + SiO_2 > 96$ per cent are accepted for inclusion in the diagrams of Fig. 20.

Comparison of the zircon data in Fig. 20 with the rock data in Fig. 3 shows that in both figures the Hf/Zr ratio increases with an increasing differentiation index of the rock. The Hf/Zr ratio for the rock samples is slightly higher than that for zircon. The hafnium content in the rock specimens decreases clearly, and it increases in the mineral zircon with the differentiation of rapakivi. These data indicate that:

- there has taken place a slight fractionation of the hafnium and zirconium between the zircon and other rock forming minerals, and
- zircon was a mineral that crystallized at an early stage from the rapakivi melt and became enriched in the more basic differentiates of the rapakivi suite.

Hf/Zr ratio

The Hf/Zr ratios of the zircons in the four density fractions are collected in the four corresponding histograms of Fig. 21. The rapakivi group is indicated by its special symbol in each histogram. The following features can be read from the histograms:

- The uppermost histogram (a), which is also regarded as the most representative of the rapakivi zircons, shows an over-all Hf/Zr ratio of ca. 0.023. If the different rock groups

Table 5.

Hf/Zr ratio 1), HfO_2, ZrO_2, $HfO_2 + ZrO_2$, and SiO_2 (calc.) in wt. %, of zircon from the Laitila rapakivi.

Sample No.	D > 4.2					3.5 < D < 4.2				
	Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2	Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2
1	.021	1.12	60.41	61.53	29.78	.018	1.07	65.87	66.94	32.42
	.022	1.27	63.64	64.91	31.39	.021	1.24	67.36	68.60	33.20
	.043	1.85	48.62	50.47	24.24	—	—	—	—	—
3	.026	1.47	65.21	66.68	32.22	.032	1.78	62.41	64.19	30.94
	.025	1.44	64.86	66.30	32.04	.028	1.55	61.13	62.68	30.25
	.023	1.27	61.57	62.84	30.39	—	—	—	—	—
4	.023	1.31	65.00	66.31	32.07	.023	1.30	64.22	65.52	31.68
	.022	1.27	64.48	65.75	31.80	—	—	—	—	—
4 c 2)	—	—	—	—	—	.023	1.33	65.47	66.80	32.30
4 m 2)	—	—	—	—	—	.044	2.35	60.52	62.87	30.18
5	.020	1.16	65.00	66.16	32.03	.017	.85	57.19	58.04	28.13
	.017	.99	65.41	66.40	32.18	—	—	—	—	—
5 c	.026	1.45	62.13	63.58	30.71	.016	.79	55.46	56.25	27.27
5 m	.023	1.30	63.74	65.04	31.45	.017	.91	58.53	59.44	28.80
6	.027	1.38	58.41	59.79	28.88	.020	1.13	62.97	64.10	31.03
	.027	1.46	61.66	63.12	30.48	—	—	—	—	—
6 c	—	—	—	—	—	.017	.96	62.51	63.47	30.76
6 m	—	—	—	—	—	.023	1.33	63.95	65.28	31.56
7	.030	1.71	64.68	66.39	32.03	.017	1.01	65.07	66.08	32.02
	.027	1.61	66.97	68.58	33.12	.036	1.84	58.46	60.30	29.03
	—	—	—	—	—	.023	1.32	65.89	67.21	32.51
11	.022	1.27	66.09	67.36	32.59	.028	1.57	62.92	64.49	31.13
	.022	1.27	65.63	66.90	32.36	.027	1.56	63.89	65.45	31.60
	—	—	—	—	—	—	—	—	—	—
12	.023	1.32	63.30	64.62	31.24	.022	1.29	64.54	65.83	31.84
	.025	1.43	63.91	65.34	31.57	.025	1.39	62.74	64.13	30.99
12 ac 3)	.025	1.33	60.53	61.86	29.90	—	—	—	—	—
12 im 3)	.028	1.50	61.10	62.60	30.22	—	—	—	—	—
13	.026	1.39	60.15	61.54	29.73	.021	1.23	64.22	65.45	31.67
	.030	1.69	62.54	64.23	30.98	.024	1.34	64.28	65.62	31.73
	.023	1.35	64.55	65.90	31.86	—	—	—	—	—
14	.023	1.19	59.34	60.53	29.28	.021	1.17	62.28	63.45	30.70
	.020	1.05	57.24	58.29	28.21	—	—	—	—	—
14 c	—	—	—	—	—	.030	1.69	62.50	64.19	30.96
14 m	—	—	—	—	—	.022	1.27	63.70	64.97	31.42
15	.025	1.47	66.80	68.27	32.99	.023	1.32	65.78	67.10	32.45
	.025	1.47	66.39	67.86	32.79	—	—	—	—	—
15 c	—	—	—	—	—	.029	1.70	66.09	67.79	32.71
15 m	—	—	—	—	—	.035	1.94	62.86	64.80	31.21
16	.022	1.30	66.47	67.77	32.78	.021	1.21	63.82	65.03	31.47
	.022	1.30	66.88	68.18	32.98	—	—	—	—	—
16 c	—	—	—	—	—	.024	1.40	64.92	66.32	32.06
16 m	—	—	—	—	—	.029	1.61	63.07	64.68	31.21
17	.019	1.06	62.49	63.55	30.77	.020	1.12	61.33	62.45	30.23
	.020	1.06	60.91	61.97	30.00	.024	1.20	55.59	56.79	27.45
	—	—	—	—	—	.027	1.56	65.68	67.24	32.47
18	.027	1.51	62.60	64.11	30.96	.026	1.47	63.63	65.10	31.45
	.024	1.27	59.86	61.13	29.55	.030	1.66	63.72	65.38	31.55
	.027	1.46	60.15	61.61	29.75	—	—	—	—	—
18 c	—	—	—	—	—	.027	1.40	58.95	60.35	29.15
18 m	—	—	—	—	—	.043	2.13	56.46	58.59	28.14
19	.024	1.40	64.02	65.42	31.62	.025	1.42	65.44	66.86	32.32
	.024	1.36	62.97	64.33	31.09	.023	1.37	66.15	67.52	32.65
	—	—	—	—	—	.025	1.42	64.80	66.22	32.00
19 c	—	—	—	—	—	—	—	—	—	—
19 m	—	—	—	—	—	—	—	—	—	—
19 c	—	—	—	—	—	—	—	—	—	—
19 m	—	—	—	—	—	—	—	—	—	—

$3.3 < D < 3.5$					$2.8 < D < 3.3$					Sample No.
Hf/Zr	HfO_2	ZrO_2	HfO_2+ ZrO_2	SiO_2	Hf/Zr	HfO_2	ZrO_2	HfO_2+ ZrO_2	SiO_2	
—	—	—	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
.028	1.50	61.30	62.80	30.32	.031	1.61	58.81	60.42	29.14	3
.028	1.45	59.17	60.62	29.27	.025	1.18	52.23	53.41	25.81	
—	—	—	—	—	—	—	—	—	—	
.026	1.40	61.09	62.49	30.19	.024	1.29	61.39	62.68	30.30	4
.025	1.36	61.89	63.25	30.57	.023	1.27	63.44	64.71	31.30	
—	—	—	—	—	—	—	—	—	—	4 c 2)
—	—	—	—	—	—	—	—	—	—	4 m 2)
.029	1.69	65.34	67.03	32.34	.031	1.73	63.50	65.23	31.46	5
—	—	—	—	—	.030	1.69	64.44	66.13	31.90	
.028	1.54	62.79	64.33	31.06	—	—	—	—	—	5 c
.036	1.73	54.28	56.01	26.96	—	—	—	—	—	5 m
.022	1.25	64.77	66.02	31.94	.028	1.60	64.04	65.64	31.68	6
.022	1.31	66.03	67.34	32.57	—	—	—	—	—	
—	—	—	—	—	.034	1.78	59.57	61.35	29.56	6 c
—	—	—	—	—	.042	2.11	56.77	58.88	28.28	6 m
—	—	—	—	—	—	—	—	—	—	7
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
.024	1.29	61.45	62.74	30.33	.026	1.32	57.49	58.81	28.41	11
.032	1.71	59.89	61.60	29.69	.022	1.16	60.12	61.28	29.65	
.024	1.21	57.23	58.44	28.25	—	—	—	—	—	
.026	1.48	64.07	65.55	31.66	.035	2.04	65.85	67.89	32.69	12
.027	1.49	62.90	64.39	31.10	.028	1.40	56.44	57.84	27.92	
—	—	—	—	—	—	—	—	—	—	12 ac 3)
—	—	—	—	—	—	—	—	—	—	12 im 3)
.023	1.23	61.20	62.43	30.19	—	—	—	—	—	13
.022	1.22	63.37	64.59	31.25	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
.023	1.36	66.28	67.64	32.71	.025	1.33	59.02	60.35	29.16	14
—	—	—	—	—	.018	.90	55.50	56.40	27.32	
.029	1.56	60.14	61.70	29.77	—	—	—	—	—	14 c
.042	2.04	54.30	56.34	27.06	—	—	—	—	—	14 m
.027	1.46	61.98	63.44	30.64	.025	1.36	62.02	63.38	30.63	15
.024	1.35	62.56	63.91	30.89	—	—	—	—	—	
—	—	—	—	—	.025	1.39	62.29	63.68	30.77	15 c
—	—	—	—	—	.031	1.58	57.80	59.38	28.64	15 m
.026	1.46	64.20	65.66	31.72	.023	1.25	60.52	61.77	29.87	16
.027	1.48	62.60	64.08	30.95	.024	1.35	62.45	63.80	30.84	
—	—	—	—	—	—	—	—	—	—	16 c
—	—	—	—	—	—	—	—	—	—	16 m
.031	1.77	64.62	66.39	32.02	.028	1.61	64.53	66.14	31.93	17
.029	1.65	62.92	64.57	31.15	.025	1.45	64.79	66.24	32.01	
—	—	—	—	—	—	—	—	—	—	
.027	1.56	64.99	66.55	32.14	.015	.56	40.81	41.37	20.06	18
.029	1.50	59.28	60.78	29.33	.027	1.29	54.03	55.32	26.71	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	18 c
—	—	—	—	—	—	—	—	—	—	18 m
—	—	—	—	—	.024	1.31	61.93	63.24	30.57	19
—	—	—	—	—	.021	1.18	62.59	63.77	30.86	
—	—	—	—	—	—	—	—	—	—	
.023	1.27	61.26	62.53	30.23	—	—	—	—	—	19 c
.027	1.47	61.78	63.25	30.55	—	—	—	—	—	19 m
.031	1.65	60.32	61.97	29.88	—	—	—	—	—	19 c
.040	2.11	59.43	61.54	29.58	—	—	—	—	—	19 m

(Table 5. Cont.)

Sample No.	D > 4.2					3.5 < D < 4.2				
	Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2	Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2
20	.022	1.29	64.54	65.83	31.84	—	—	—	—	—
	.021	1.25	65.90	67.15	32.49	—	—	—	—	—
20 c	—	—	—	—	—	.029	1.61	63.41	65.02	31.38
20 m	—	—	—	—	—	.068	3.34	55.55	58.89	28.04
20 c	—	—	—	—	—	.022	1.25	64.39	65.64	31.75
20 m	—	—	—	—	—	.051	2.83	62.99	65.82	31.52
21	.021	1.24	66.26	67.50	32.66	.022	1.25	62.94	64.19	31.05
	.021	1.24	66.28	67.52	32.67	.025	1.35	59.93	61.28	29.61
	—	—	—	—	—	—	—	—	—	—
21 c	—	—	—	—	—	.023	1.29	63.49	64.78	31.33
21 m	—	—	—	—	—	.028	1.39	55.91	57.30	27.66
22	.024	1.25	58.42	59.67	28.84	.032	1.77	63.28	65.05	31.36
	.024	1.26	57.81	59.07	28.55	.025	1.46	64.60	66.06	31.92
	—	—	—	—	—	.026	1.49	64.52	66.01	31.89
23	.023	1.32	65.70	67.02	32.41	.025	1.39	63.63	65.02	31.42
	.022	1.27	64.45	65.72	31.79	.022	1.26	64.44	65.70	31.78
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	.023	1.30	63.74	65.04	31.45
	—	—	—	—	—	.030	1.60	60.39	61.99	29.90
	—	—	—	—	—	.039	1.86	54.38	56.24	27.05
24 c	.023	1.35	66.05	67.40	32.59	—	—	—	—	—
24 m	.029	1.62	64.22	65.84	31.78	—	—	—	—	—
25	.025	1.41	64.45	65.86	31.83	.024	1.37	65.19	66.56	32.18
	.024	1.33	63.67	65.00	31.43	—	—	—	—	—
	.024	1.39	64.33	65.72	31.77	—	—	—	—	—
25 c	—	—	—	—	—	.031	1.75	64.52	66.27	31.96
25 m	—	—	—	—	—	.022	1.26	64.68	65.94	31.90
26	.026	1.48	64.05	65.53	31.65	.028	1.55	62.81	64.36	31.07
	.024	1.36	63.67	65.03	31.44	.024	1.36	62.25	63.61	30.74
26 c	—	—	—	—	—	.066	3.20	55.22	58.42	27.84
26 m	—	—	—	—	—	.031	1.75	62.88	64.63	31.16
27	.024	1.43	67.41	68.84	33.28	.027	1.54	63.39	64.93	31.35
	.027	1.58	66.50	68.08	32.88	.023	1.13	55.34	56.47	27.31
27 c	—	—	—	—	—	.035	1.70	54.04	55.74	26.84
27 m	—	—	—	—	—	.031	1.49	54.87	56.36	27.18
29	.025	1.38	62.41	63.79	30.83	.022	1.12	56.21	57.33	27.73
	.025	1.38	62.39	63.77	30.82	—	—	—	—	—
29 c	—	—	—	—	—	.018	.90	54.68	55.58	26.92
29 m	—	—	—	—	—	.029	1.47	56.66	58.13	28.05
31	.020	1.15	64.91	66.06	31.98	.024	1.37	63.54	64.91	31.37
	.023	1.35	65.52	66.87	32.33	.028	1.42	56.59	58.01	28.00
	.026	1.53	66.22	67.75	32.73	—	—	—	—	—
31 c	—	—	—	—	—	.024	1.34	63.00	64.34	31.10
31 m	—	—	—	—	—	.033	1.81	61.42	63.23	30.47
33	.023	1.35	67.07	68.42	33.09	.019	1.09	65.10	66.19	32.06
	.026	1.48	64.10	65.58	31.68	.023	1.40	67.21	68.61	33.17
34	.023	1.20	59.09	60.29	29.16	.021	1.15	61.88	63.03	30.50
	.024	1.27	60.19	61.46	29.71	.021	1.29	62.94	64.23	31.06
34 c	—	—	—	—	—	—	—	—	—	—
34 m	—	—	—	—	—	—	—	—	—	—
35	—	—	—	—	—	.020	1.16	65.00	66.16	32.03
	—	—	—	—	—	.024	1.16	53.20	54.36	26.27
	—	—	—	—	—	.018	1.00	61.50	62.50	30.27
	—	—	—	—	—	.028	1.39	55.99	57.38	27.70
36	—	—	—	—	—	.021	1.21	65.17	66.38	32.12
	—	—	—	—	—	.022	1.14	58.98	60.12	29.09
	—	—	—	—	—	.021	.97	52.27	53.24	25.76
37	.031	1.83	66.75	68.58	33.07	.030	1.68	64.36	66.04	31.86
	.030	1.75	66.11	67.86	32.74	.030	1.76	66.49	68.25	32.92

3.3 < D < 3.5					2.8 < D < 3.3					Sample No.
Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2	Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2	
.026	1.46	64.07	65.53	31.66	.027	1.46	59.94	61.40	29.64	20
.026	1.46	63.98	65.44	31.61	.024	1.32	61.96	63.28	30.59	
—	—	—	—	—	—	—	—	—	—	20 c
—	—	—	—	—	—	—	—	—	—	20 m
—	—	—	—	—	—	—	—	—	—	20 c
—	—	—	—	—	—	—	—	—	—	20 m
.034	1.86	61.73	63.59	30.63	.024	1.32	62.94	64.26	31.07	21
.028	1.55	62.98	64.53	31.15	.031	1.68	61.14	62.82	30.29	
.028	1.47	59.50	60.97	29.43	.034	1.83	60.69	62.52	30.12	
—	—	—	—	—	—	—	—	—	—	21 c
—	—	—	—	—	—	—	—	—	—	21 m
.029	1.59	62.06	63.65	30.72	.030	1.56	59.27	60.83	29.35	22
.026	1.37	60.19	61.56	29.74	.021	1.13	60.33	61.46	29.74	
—	—	—	—	—	—	—	—	—	—	
.027	1.58	66.35	67.93	32.80	.025	1.13	50.07	51.20	24.74	23
.029	1.21	47.51	48.72	23.51	.030	1.30	48.81	50.11	24.17	
.025	1.21	55.68	56.89	27.50	—	—	—	—	—	
.032	1.31	45.86	47.17	22.74	—	—	—	—	—	
.033	1.84	62.72	64.56	31.11	.026	1.40	61.75	63.15	30.51	24
.024	1.37	63.55	64.92	31.38	.022	1.19	61.52	62.71	30.34	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	24 c
—	—	—	—	—	—	—	—	—	—	24 m
.022	1.20	61.31	62.51	30.24	.024	1.45	66.77	68.22	32.97	25
.021	1.03	55.75	56.78	27.48	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	.017	1.02	65.13	66.15	32.05	25 c
—	—	—	—	—	.028	1.66	65.82	67.48	32.57	25 m
.022	1.24	63.37	64.61	31.25	.028	1.56	62.80	64.36	31.07	26
—	—	—	—	—	.023	1.31	62.88	64.19	31.04	
.022	1.16	60.60	61.76	29.88	—	—	—	—	—	26 c
.038	2.09	62.38	64.47	31.01	—	—	—	—	—	26 m
.025	1.38	62.80	64.18	31.02	—	—	—	—	—	27
.030	1.26	46.69	47.95	23.13	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	27 c
—	—	—	—	—	—	—	—	—	—	27 m
.025	1.43	64.86	66.29	32.04	.030	1.68	62.07	63.75	30.75	29
.031	1.36	49.50	50.86	24.52	—	—	—	—	—	
—	—	—	—	—	.038	2.05	60.64	62.69	30.15	29 c
—	—	—	—	—	.042	2.37	63.59	65.96	31.68	29 m
.022	1.18	60.89	62.07	30.03	.021	1.00	52.40	53.40	25.84	31
.026	1.37	59.15	60.52	29.23	—	—	—	—	—	
.026	1.24	53.58	54.82	26.48	—	—	—	—	—	
—	—	—	—	—	.023	1.14	55.53	56.67	27.40	31 c
—	—	—	—	—	.034	1.73	56.98	58.71	28.28	31 m
.027	1.50	62.84	64.34	31.07	.028	1.44	57.27	58.71	28.34	33
.030	1.62	62.16	63.78	30.77	.031	1.62	59.55	61.17	29.50	
.024	1.40	65.84	67.24	32.50	.050	2.20	50.12	52.32	25.07	34
.026	1.50	65.33	66.83	32.28	—	—	—	—	—	
—	—	—	—	—	.027	1.49	62.11	63.60	30.71	34 c
—	—	—	—	—	.035	1.72	55.18	56.90	27.40	34 m
.023	1.30	62.67	63.97	30.93	—	—	—	—	—	35
.022	1.31	66.01	67.32	32.56	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	36
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
.025	1.36	60.94	62.30	30.10	.022	1.15	57.83	58.98	28.53	37
.026	1.42	60.87	62.29	30.09	.033	1.67	56.81	58.48	28.18	

(Table 5. Cont.)

Sample No.	D > 4.2					3.5 < D < 4.2				
	Hf/Zr	HfO$_2$	ZrO$_2$	HfO$_2$+ ZrO$_2$	SiO$_2$	Hf/Zr	HfO$_2$	ZrO$_2$	HfO$_2$+ ZrO$_2$	SiO$_2$
38	.022	1.30	64.78	66.08	31.96	.024	1.37	64.67	66.04	31.93
	.020	1.18	64.83	66.01	31.95	.042	2.05	54.73	56.78	27.27
	—	—	—	—	—	—	—	—	—	—
39	.017	.92	61.79	62.71	30.39	.022	1.23	63.48	64.71	31.31
	.014	.78	61.89	62.67	30.40	.025	1.39	63.50	64.89	31.36
40	—	—	—	—	—	.025	1.29	58.05	59.34	28.67
	—	—	—	—	—	.027	1.55	65.05	66.60	32.16
	—	—	—	—	—	.023	1.36	66.94	68.30	33.03
	—	—	—	—	—	.023	1.37	66.78	68.15	32.95
41	.014	.80	61.73	62.53	30.33	.026	1.48	63.93	65.41	31.60
	.022	1.25	64.60	65.85	31.86	.031	1.71	63.16	64.87	31.29
	.022	1.25	64.21	65.46	31.67	.024	1.38	65.42	66.80	32.29
48	—	—	—	—	—	.047	1.89	45.57	47.46	22.76
	—	—	—	—	—	.030	1.73	63.97	65.70	31.69
48 c	—	—	—	—	—	.034	1.40	46.18	47.58	22.92
48 m	—	—	—	—	—	.088	2.42	31.20	33.62	15.90
48 c	—	—	—	—	—	.063	2.65	47.91	50.56	24.12
48 m	—	—	—	—	—	.041	1.82	50.38	52.20	25.09
49	.023	1.36	66.12	67.48	32.63	.028	1.66	66.15	67.81	32.73
	.023	1.37	66.78	68.15	32.95	.023	1.35	67.23	68.58	33.17
	.035	1.99	65.32	67.31	32.42	—	—	—	—	—
49 c	—	—	—	—	—	—	—	—	—	—
49 m	—	—	—	—	—	—	—	—	—	—
49 c	—	—	—	—	—	—	—	—	—	—
49 m	—	—	—	—	—	—	—	—	—	—
51	.021	1.16	63.81	64.97	31.45	.033	1.88	64.84	66.72	32.15
	.022	1.27	66.44	67.71	32.76	.024	1.36	63.54	64.90	31.37
51 c	—	—	—	—	—	—	—	—	—	—
51 m	—	—	—	—	—	—	—	—	—	—

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[1]) The figures for the Hf/Zr ratios are truncated, not rounded.

[2]) c = analysis from the core of a zircon crystal, m = analysis from the marginal part of the zircon crystal.

[3]) ac = allotriomorphic older core, im = idiomorphic marginal part. The analyses are from the zircon crystal illustrated in Fig. 7 a. These data are not plotted on the diagrams of Figs. 21, 22, and 27.

were weighted according to their areal distribution, the result would be about the same. This is just slightly smaller than the Hf/Zr ratio in the rock samples in Table 3.

- No clear difference in the Hf/Zr ratio between different rapakivi groups can be found even though the ratio in rock samples showed small but distinct differences (Table 3). Biotite rapakivis and Väkkärä granite tend to have in their zircons a slightly higher Hf/Zr ratio than in the other rock groups.
- The diagrams show a small but clear increase in the Hf/Zr ratio with decreasing density (from histogram a to d). The density fraction D > 4.2 is enriched in the unzoned homogeneous zircon crystals, the lighter fractions in the finely-zoned zircon. It seems that in the finely-zoned zircon the primary Hf/Zr ratio is higher than in the homogeneous one.

Fig. 22 collects the zircon data of samples from the group of normal Laitila rapakivi into the four histograms a—d. These reveal:

- The two uppermost histograms (a and b) correspond to the density fractions where most of the zircon is enriched. They show that the over-all Hf/Zr ratio in zircon is

3.3 < D < 3.5					2.8 < D < 3.3					Sample No.
Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2	Hf/Zr	HfO_2	ZrO_2	HfO_2+ZrO_2	SiO_2	
.024	1.36	63.90	65.26	31.54	.024	1.31	62.04	63.35	30.63	38
.027	1.58	66.38	67.96	32.82	.038	1.66	48.91	50.57	24.32	
—	—	—	—	—	.026	1.36	58.74	60.10	29.03	
.024	1.29	60.15	61.44	29.70	—	—	—	—	—	39
.025	1.39	63.81	65.20	31.51	—	—	—	—	—	
.023	1.26	62.02	63.28	30.60	—	—	—	—	—	40
.023	1.27	62.00	63.27	30.60	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
.029	1.52	58.40	59.92	28.91	.027	1.46	60.91	62.37	30.12	41
.026	1.38	60.63	62.01	29.96	.027	1.56	64.66	66.22	31.98	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	.044	1.85	47.04	48.89	23.47	48
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	48 c
—	—	—	—	—	—	—	—	—	—	48 m
—	—	—	—	—	—	—	—	—	—	48 c
—	—	—	—	—	—	—	—	—	—	48 m
—	—	—	—	—	.025	1.45	64.33	65.78	31.78	49
—	—	—	—	—	.029	1.64	63.74	65.38	31.55	
—	—	—	—	—	—	—	—	—	—	
.023	1.20	59.08	60.28	29.15	—	—	—	—	—	49 c
.025	1.45	65.19	66.64	32.20	—	—	—	—	—	49 m
.025	1.32	60.38	61.70	29.82	—	—	—	—	—	49 c
.046	2.50	61.29	63.79	30.60	—	—	—	—	—	49 m
.021	1.01	53.04	54.05	26.15	.027	1.46	60.77	62.23	30.05	51
.027	1.46	61.33	62.79	30.32	—	—	—	—	—	
—	—	—	—	—	.030	1.63	62.10	63.73	30.75	51 c
—	—	—	—	—	.038	2.20	65.18	67.38	32.41	51 m

about 0.023, which is slightly smaller than the ratio — 0.025 — in the corresponding rocks samples in Table 3.

- The contact varieties and the granite-porphyritic varieties, which are possibly marginal varieties, too, have slightly smaller Hf/Zr ratios than the normal rapakivi.
- The marginal parts of the zircon crystals seem to have somewhat higher Hf/Zr ratios than the central parts.
- There is a small but clear increase in the Hf/Zr ratio with decreasing density.

The data from zircons of the Ytö granite and related rocks are collected in the four histograms of Fig. 23. These histograms show:

- The over-all Hf/Zr ratio of the two heaviest density fractions is about 0.023—0.024, i.e., considerably smaller than in the corresponding rock smaples (0.029) in Table 3. This indicates that the hafnium and zirconium have fractionated between zircon and other rock-forming minerals.
- The zircon from the autoliths in the marginal coarse-grained granites has the smallest Hf/Zr ratio. In zircons contained in the small-grained central granites, the ratio is somewhat higher, and in the zircons contained in the marginal coarse-grained granites, the highest.
- A marked increase in the Hf/Zr ratio with decreasing density is to be seen.

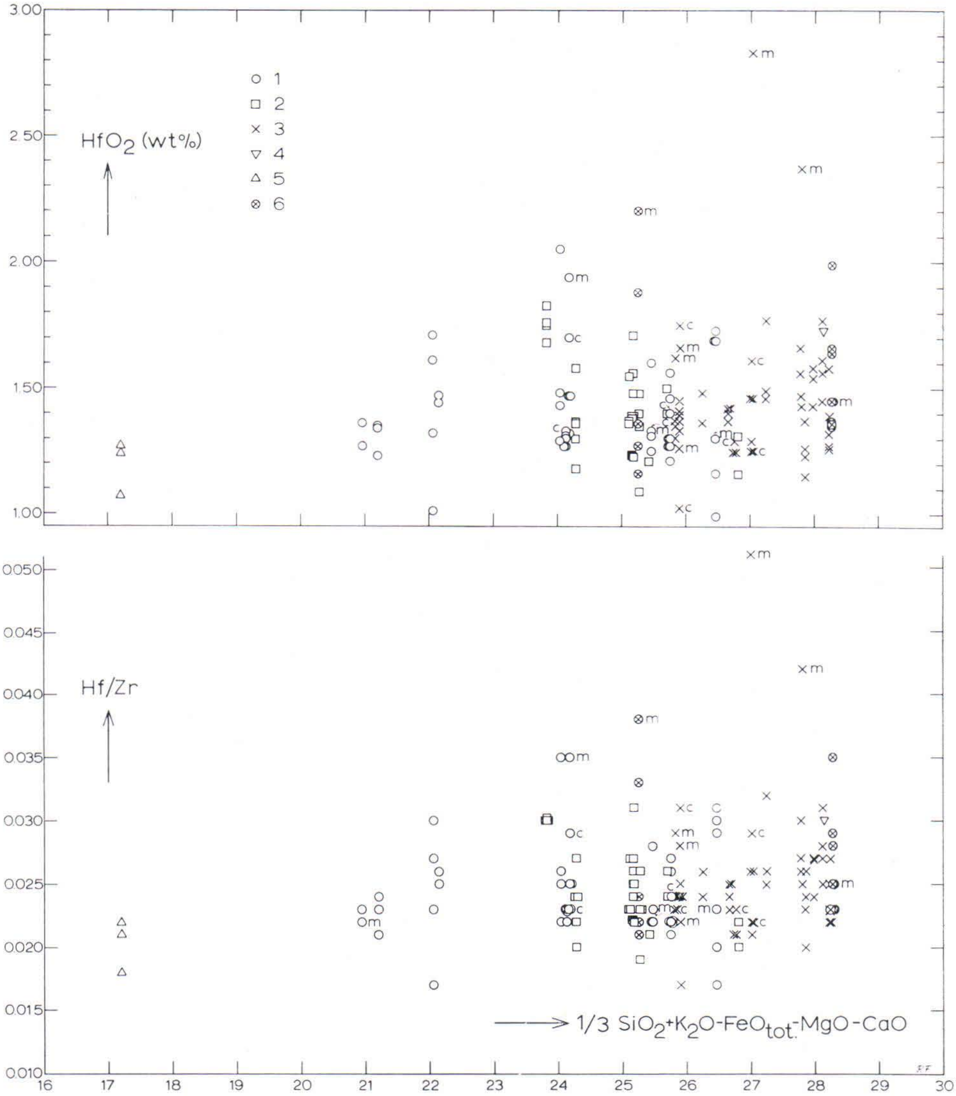

Fig. 20. Hafnium content and Hf/Zr ratio in zircon plotted against the composition of the rock. 1 = normal Laitila rapakivis, 2 = Ytö granite and related rocks, 3 = various biotite rapakivis, 4 = Väkkärä granite, 5 = Tarkki granite, 6 = rapakivitic dike rocks. Only analyses with $HfO_2 + ZrO_2 + SiO_2$ exceeding 96 wt. % (Table 5) are included in the diagram. *c* = analysis from the core, and *m* = from the marginal part of zircon grain.

The zircon data of the Lellainen-type biotite rapakivis are illustrated in the four histograms of Fig. 24. These reveal:

— The uppermost diagrams show an over-all Hf/Zr ratio of about 0.025—0.026, i.e., considerably smaller than in the corresponding rock samples (0.033) from Table 3. This again is an indication that some fractionation of Hf and Zr between zircon and other rock-forming minerals has taken place.

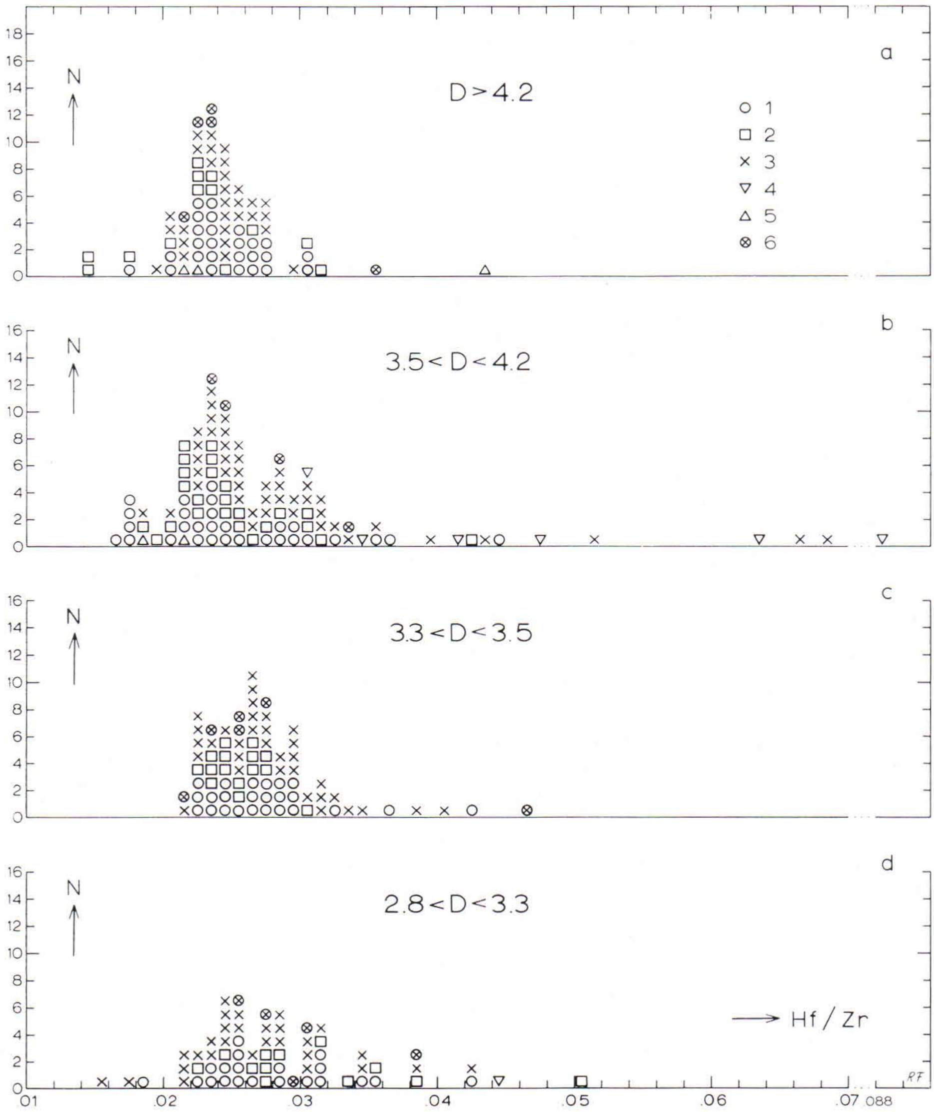

Fig. 21. Histograms illustrating the Hf/Zr ratio in zircon contained in chemically analyzed rapakivi samples from the Laitila massif. N = number of analyses, 1 = group of normal Laitila rapakivi, 2 = Ytö granite and related rocks, 3 = various biotite rapakivis, 4 = Väkkärä granite, 5 = Tarkki granite, 6 = rapakivitic dike rocks.

- On an average, the marginal parts of the zircons show higher Hf/Zr ratios than the cores do.
- An increase in the Hf/Zr ratio with decreasing density can be postulated, even though this is not clear.

The Hf/Zr data of zircon from other biotite rapakivis than the Lellainen-type are illustrated in Fig. 25. These samples form such an inhomogeneous group that no clear trends can be seen except concerning the spotted granites. These show a clear increase in the Hf/Zr ratio

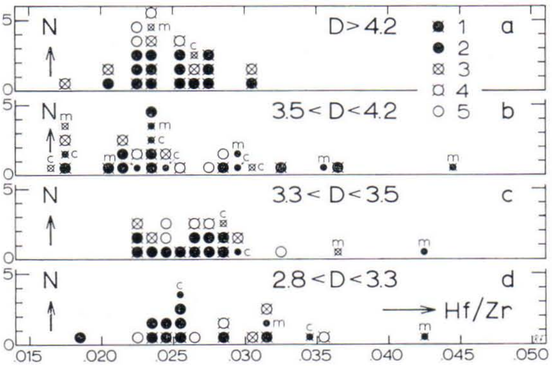

Fig. 22. Histograms illustrating the Hf/Zr ratio in zircon contained in normal Laitila rapakivis. N = number of analyses, 1 = normal rapakivi, 2 = granite-porphyritic variety, 3 = contact variety, 4 = a coarse rapakivi grading into the normal rapakivi, 5 = Kokemäki granite. *c* and *m* as in Fig. 20.

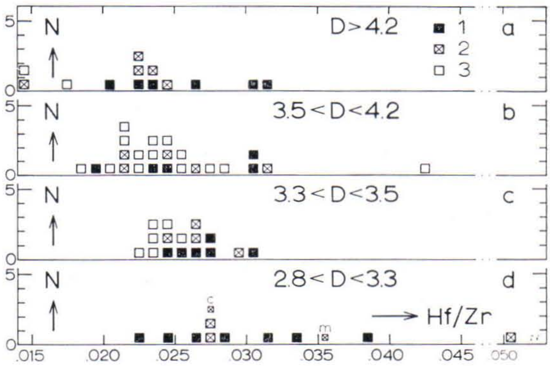

Fig. 23. Histograms illustrating the Hf/Zr ratio in zircon contained in Ytö granite and related rocks. N = number of analyses, 1 = marginal Ytö granite and Suutila granite, 2 = central Ytö granite and Katinhäntä aplite, 3 = autoliths in the marginal Ytö granite and Suutila granite. *c* and *m* as in Fig. 20.

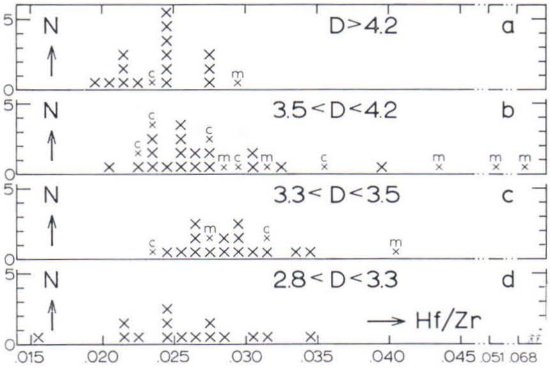

Fig. 24. Histograms illustrating the Hf/Zr ratio in zircon contained in the Lellainen-type biotite rapakivi. N = number of analyses. *c* and *m* as in Fig. 20.

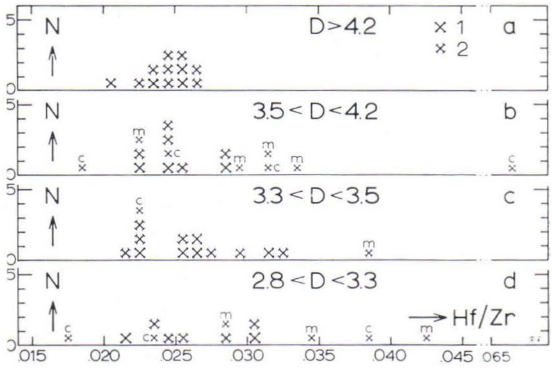

Fig. 25. Histograms illustrating the Hf/Zr ratio in zircon contained in various biotite rapakivis excluding the Lellainen-type rapakivi. N = number of analyses, 1 = spotted granites, 2 = Nos. 23, 25, and 26 in Table 2. *c* and *m* as in Fig. 20.

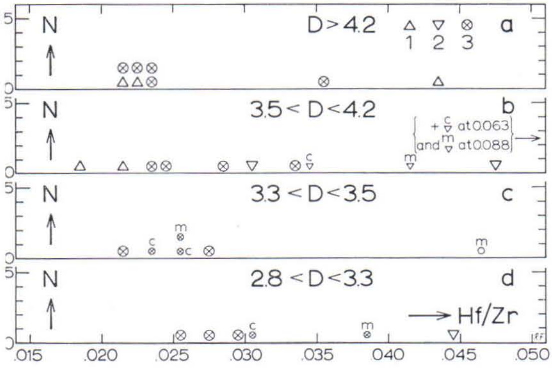

Fig. 26. Histograms illustrating the Hf/Zr ratio in zircon contained in 1 = Tarkki granite, 2 = Väkkärä granite, 3 = rapakivitic dike rocks. N = number of analyses. *c* and *m* as in Fig. 20.

with decreasing density. It can also be seen that the cores have lower Hf/Zr ratios than the marginal parts.

The data from the Eurajoki complex and rapakivitic dike rocks are collected in Fig. 26. The samples studied are, it is true, very few. With respect to the Eurajoki complex, the histograms indicate that the zircon in the Tarkki granite, which is the older hornblende-bearing marginal granite of the complex, has a lower Hf/Zr ratio than the zircon in the younger, central Väkkärä granite. The histograms also show the same feature as the other histograms do, viz., that the cores of zircon crystals have lower Hf/Zr ratios than the marginal parts.

$HfO_2 + ZrO_2$ vs. SiO_2

All the analysis data are plotted on the sixteen $HfO_2 + ZrO_2$ vs. SiO_2 diagrams of Figs. 27—30. On each diagram, the »$HfO_2 + ZrO_2 + SiO_2 = 100$»-curve is drawn to allow for easy estimation of the amount of deviation of the sum of oxides from 100 per cent. Also each diagram is fitted with constant Hf/Zr = 0.01 and 0.04 lines. These diagrams allow for the following conclusions:

- In all the diagrams with $D > 4.2$, most of the analytic points fall closer to the »sum of oxides = 100»-curve than in the lighter fractions. In these, the center of gravity of the analytic points gradually shifts off from the »sum of oxides = 100»-curve. This indicates again the growing degree of alteration of zircon with falling density. This feature is pronounced in the normal Laitila rapakivi (Fig. 27), and in the marginal granites of the Ytö and Katinhäntä-Suutila complexes (Fig. 28).
- Many of the diagrams show a small but clear increase in the Hf/Zr ratio in zircon with a decrease in the sum of oxides. This is already noticeable in the a-diagrams, i.e., among the zircons in the heaviest fraction, indicating that this fraction contains quite an abundance of somewhat altered zircon grains. The increase in the Hf/Zr ratio with a decreasing sum of oxides is to be seen in, e.g., normal rapakivis (Fig. 27) and in biotite rapakivis (Fig. 29).

DISCUSSION

The enrichment of zircon in the more basic rapakivi varieties points to an early crystallization of zircon in rapakivi. A small part of the zircon is possibly intratelluric. The occurrence of old allotriomorphic cores proves that, prior to the emplacement of the rapakivi, the melt contained zircon grains. These escaped total resorption when the rapakivi magma was produced. On the other hand, the data support the belief that the zircon continued to crystallize throughout most of the interval of magmatic differentiation (cf., Gottfried and Waring 1964).

The amount of normative zircon compared with modal zircon (Table 4) leads to the conclusion that most of zirconium and hafnium are included in zircon. Possibly only a very small fraction of them is to be found in such minerals as plagioclase, potassium feldspar and biotite. Ytö granite and related rocks may be exceptions in this respect. Departing from this, in certain granitic rocks, such as, e.g., in southern Bulgaria, described by Ivanov *et al.* (1977), only some 50 per cent of the zirconium is claimed to be included in zircon, while some 20—25 per cent is to be found in plagioclase, 6—12 in

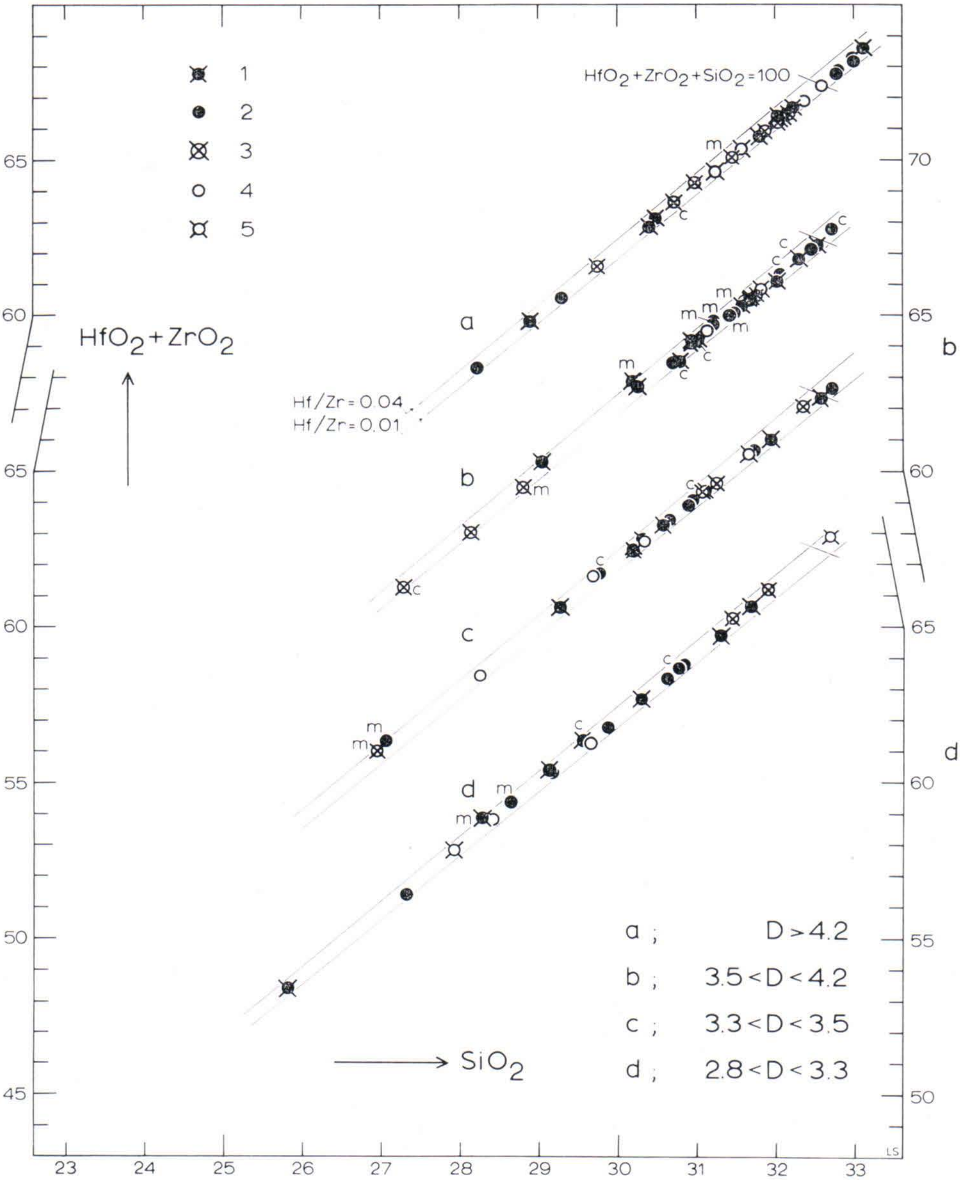

Fig. 27. $HfO_2 + ZrO_2$ (wt. %) vs. SiO_2 (wt. %) diagrams of zircons contained in normal Laitila rapakivis. 1 = normal rapakivi, 2 = granite-porphyritic variety, 3 = contact variety, 4 = a coarse rapakivi variety grading into the normal rapakivi, 5 = Kokemäki granite. *c* and *m* as in Fig. 20.

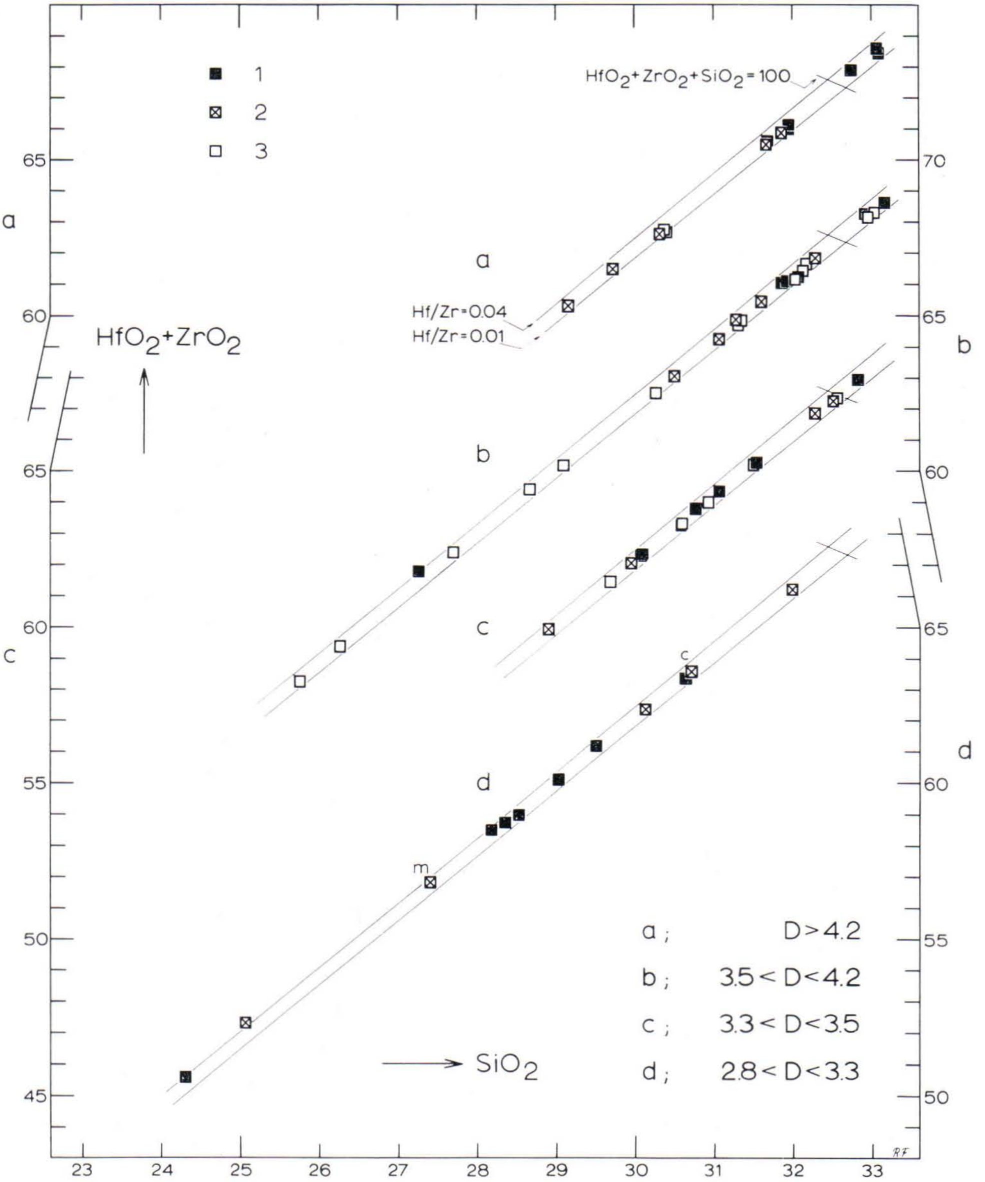

Fig. 28. $HfO_2 + ZrO_2$ (wt. %) vs. SiO_2 (wt. %) diagrams of zircons contained in Ytö granite and related rocks. 1 = marginal Ytö granite and Suutila granite, 2 = central Ytö granite and Katinhäntä aplite, 3 = autoliths in the marginal Ytö granite and Suutila granite. *c* and *m* as in Fig. 20.

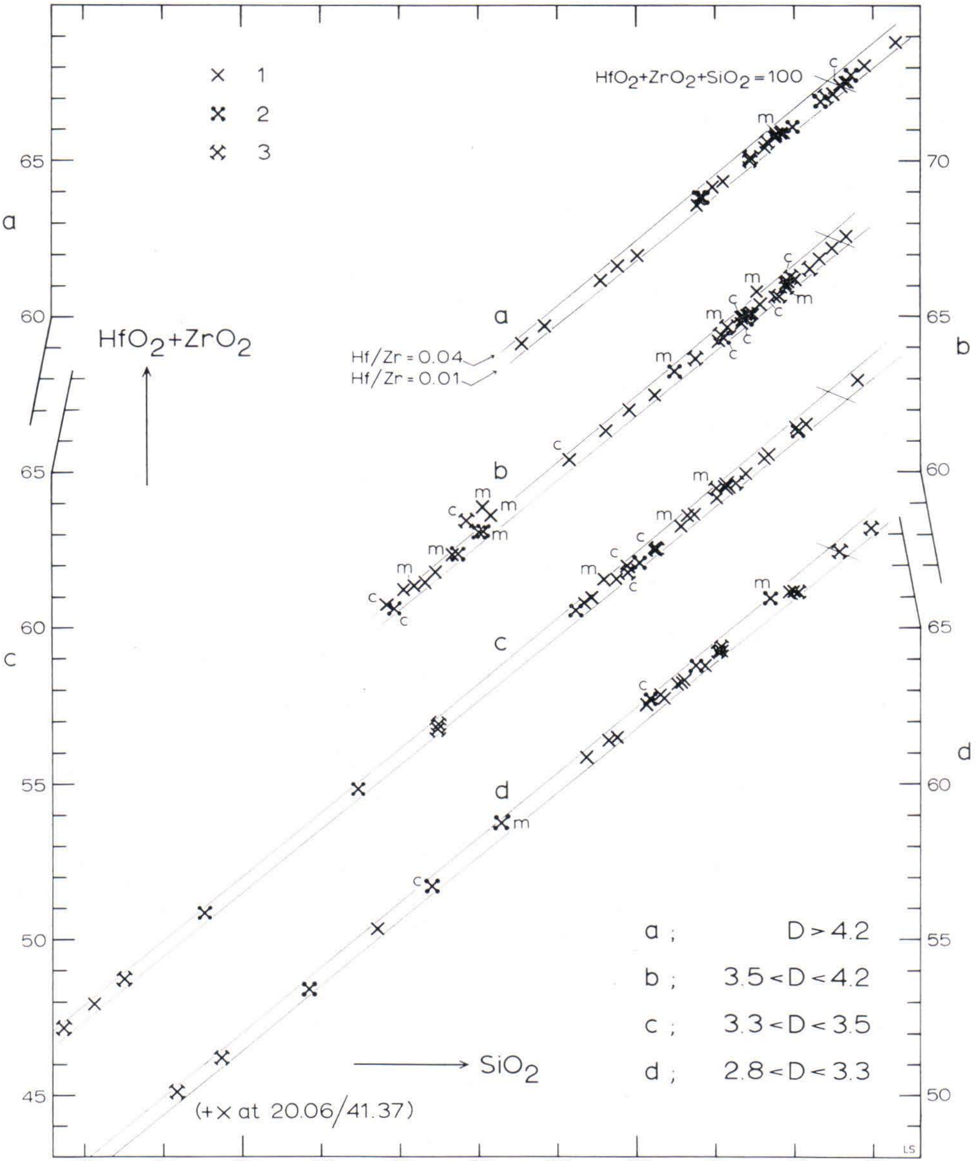

Fig. 29. $HfO_2 + ZrO_2$ (wt. %) vs. SiO_2 (wt. %) diagrams of zircons contained in various biotite rapakivis. 1 = Lellainen-type biotite rapakivi, 2 = spotted granites, 3 = other biotite rapakivis. *c* and *m* as in Fig. 20.

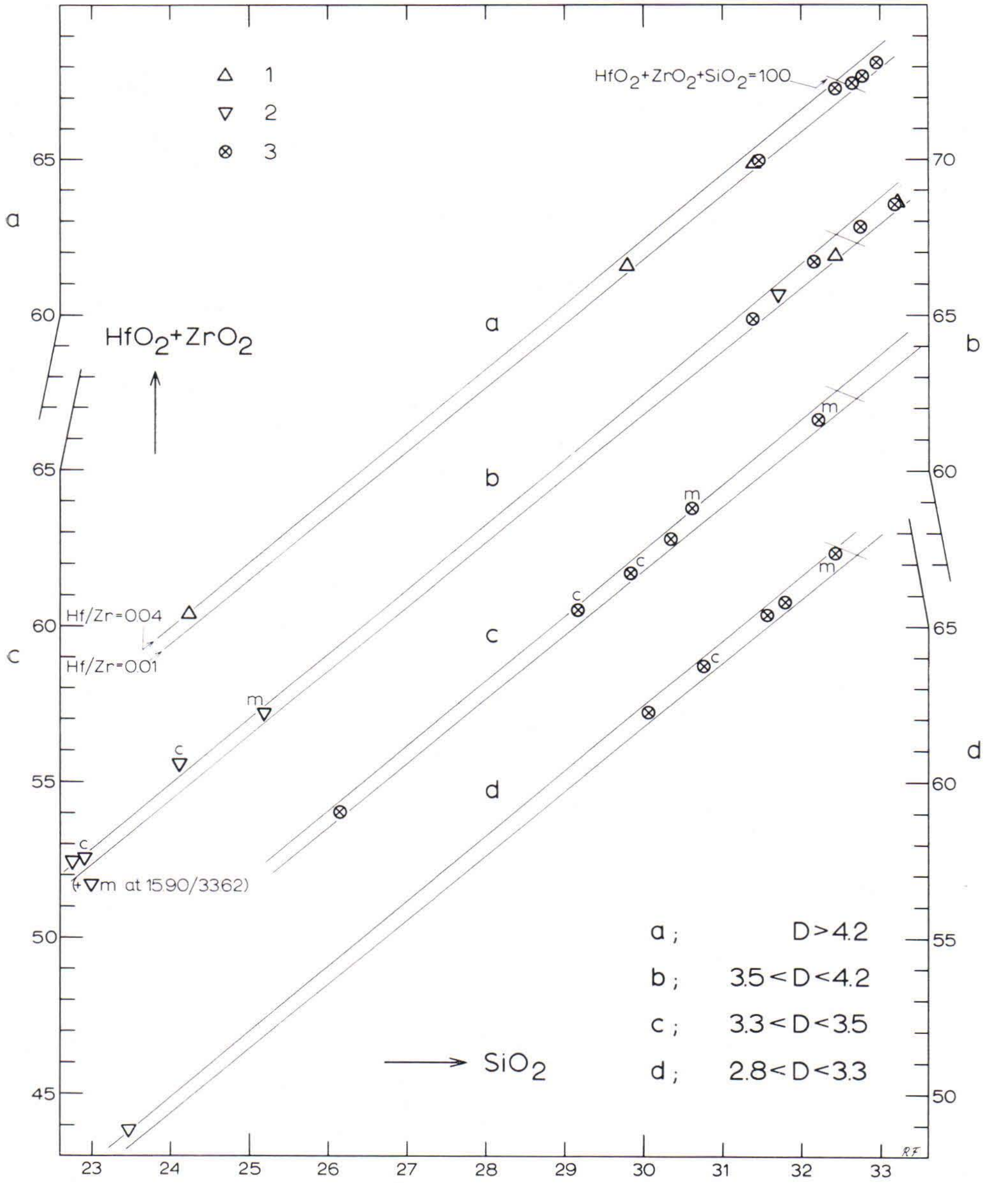

Fig. 30. $HfO_2 + ZrO_2$ (wt. %) vs. SiO_2 (wt. %) diagrams of zircons contained in 1 = Tarkki granite, 2 = Väkkärä granite, 3 = rapakivitic dike rocks. *c* and *m* as in Fig. 20.

potassium feldspar, and 3—7 in biotite. The authors cited also claimed that the Hf/Zr ratio in the average rock samples is considerable smaller than in the zircons contained in the same rocks.

Shevaleevskii *et al.* (1960) claimed that in both calc-alkalic and alkalic rocks, saturated and oversaturated by silica, the Hf/Zr ratio in zircon is related mainly to the content of dark minerals. The more basic hafnium is preferably concentrated in the dark minerals, and thus the Hf/Zr ratio would increase from gabbro to leucocratic granites and syenites.

In the Laitila rapakivi, the Hf/Zr ratio in zircon is about 0.023 (Table 5 and Fig. 21 a), i.e., slightly lower than the ratio in the rock samples (Table 3 and Fig. 2). This indicates that possibly slight fractionation of the zirconium and hafnium between the zircon and other minerals has taken place in the Laitila rapakivi.

The normal Laitila rapakivi is by far the most common variety of rapakivi in the Laitila massif. A rough estimate suggests that more than 90 per cent of the area of the massif is occupied by this variety. Remembering that the variation in the Hf/Zr ratio from one variety to another is small in rapakivi, the Hf/Zr ratio in the zircon of the normal rapakivi (0.023) or in the rock itself (0.025) can be taken as representative of the whole massif. These ratios are in agreement with that given by Fleischer (1955) for the whole earth's crust (0.02). For the sake of comparison, it might be noted that Gottfried and Waring (1964) reported the weighted average Hf/Zr ratio for the southern California batholith as 0.023, the gabbros having a Hf/Zr ratio of 0.020 and the ratios of the granites ranging from 0.027 to 0.040.

The zircon data from the Laitila massif are also in accord with the comparative study published by Kresten (1970) on Hf/Zr ratios (converted from Zr/Hf) in zircons from different rocks. As for plutonic rocks and pegmatites, Kresten pointed out that they have a quite constant Hf/Zr ratio (0.022). He also pointed out that the Hf/Zr ratio is directly proportional to the acidity and indirectly proportional to the alkalinity of the rock, and that the ratio is clearly affected by pneumatolytic-hydrothermal and metasomatic solutions. Prior to this, similar conclusions were derived by Lyakhovich and Shevaleevskii (1962) in their comprehensive study on zircon in granites from different petrographic provinces of the USSR.

The data in Table 5 and Figs. 20 and 21 show that there is a small but clear increase in the Hf/Zr ratio in zircon with increasing differentiation of rapakivi. It has been shown in many papers that the amount of hafnium in zircon and the Hf/Zr ratio in it vary in a systematic manner as differentiation of the magma progresses. Examples of this have been described by, among others, Kosterin *et al.* (1958), Shevaleevskii *et al.* (1960), Kosterin *et al.* (1960), Lyakhovick and Shevaleevskii (1962), Gottfried and Waring (1964), Larsen and Effimof (1973), and Klemic *et al.* (1973). For example, Gottfried and Waring (1964) studied the zircons of the rock samples from the southern California batholith. The hafnium content and the Hf/Zr ratio indicate a progressive enrichment of hafnium in relation to zirconium from the mafic to the more siliceous rocks. In addition, the authors cited showed that, within the rocks of a single stock, hafnium and the Hf/Zr ratio are highest in the zircon of the finest mesh size. This represents the youngest generation of zircon, which is richest in hafnium. In contrast to this, Gulson (1970) could find no correlation between the Hf/Zr ratio and grain size in zircons from the Yeoval diorite complex, N.S.W., Australia. The zoned zircons from the same rock samples, however, show a regular trend of variation in the zones from hafnium-poor core to hafnium-rich rim.

The Hf/Zr ratios are lower in zircons from the contact zone of the Laitila rapakivi than in those from more slowly cooled inner parts of the massif. Also the Hf/Zr ratios in zircons from autoliths in the marginal Ytö granite and the ones in the Suutila granite are lower than the ratios in the zircons contained in the central, small-grained granites. The latter has in turn lower Hf/Zr ratios than the coarse marginal granites. In the study cited on the zircons from the Yeoval diorite complex, Gulson showed that the Hf/Zr ratios in zircons from samples from the chilled granite margins were very much lower than in zircons from the other granites. Gulson suggested that these were the result of the rapid crystallization of the rock. The present authors suggest that the increase in the Hf/Zr ratio away from intrusive contacts would also reflect differentiation during cooling of the rapakivi.

In the previous chapters, it has been demonstrated: 1) rapakivi zircons of the lighter density fractions have, on an average, slightly higher Hf/Zr ratios than those in the heavier fractions (Figs. 21—26); 2) the fine zoning in rapakivi zircon is more common in the zircons contained in the lighter density fractions; 3) when compositional differences between the marginal parts and the core parts of zircon are detected, the marginal parts have mostly higher Hf/Zr ratios than the central parts. Moreover, the lighter the density fraction in question, the more the sum $HfO_2 + ZrO_2 + SiO_2$ usually deviates from 100 per cent (Figs. 27—30).

Vaasjoki (1977) demonstrated that in rapakivi zircon fractions, the uranium and common lead content were considerably higher in the lighter density fractions than in the heavy ones. He also attributed the metamictization in rapakivi zircon to the high uranium content. Three of the samples in Vaasjoki's Table 6 (*op. cit.*) are the same as the ones studied for zircon in the present work, viz., Nos. A 608, A 689, and A 690, which correspond to the present Nos. 6, 3 and 33, respectively. With respect to these three samples, Vaasjoki reported:

Sample No.	238U (ppm)	Total lead (ppm)	Fraction Density/mesh size
3	335.2	92.63	+ 4.2
	900.4	209.51	3.8 — 4.0
6	214.3	66.94	+ 4.2/100 — 200
	298.5	191.06	4.0 — 4.2/— 200 1)
	617.2	174.64	4.0 — 4.2/+ 100 2)
33	307.9	125.25	+ 4.2/— 150
	1 124.9	235.14	3.8 — 4.0/— 150

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1) Passes through the 200-mesh sieve.
2) Does not pass through the 100-mesh sieve.

It can be concluded that the homogeneous unzoned zircon crystals or the central parts of the zircon crystals that are finely zoned in their margins crystallized under quite stationary conditions, leading to equilibrium. A few of these zircons were nucleated on the old allotriomorphic zircon grains, which either escaped total resorption when the rapakivi magma was generated, or then may also be true xenocrysts. The finely zoned margins and zircon crystals finely zoned throughout then crystallized, probably under conditions of sudden changes in pressure. It is highly improbable that in a granite massif as large as the Laitila massif, any sudden changes either in temperature or in the composition of the magma could take place, leading to the fine zoning in zircon. In H_2O-pressure, when an epizonal granite is in question, sudden changes are highly likely owing to the possibility of water excaping from the system. The zircon crystallized under these conditions also became richer in uranium, common lead and hafnium than the zircon that crystallized earlier. Even though the uranium was not analyzed during the present study, there are grounds for concluding that the zircons with higher Hf/Zr ratios are also richer in uranium and common lead than the zircons with average ratios. This is also in accord with the observation that the rapakivi zircons with higher Hf/Zr ratios are metamictically more altered than those with lower ones.

The few analyses in Table 5 with the Hf/Zr ratio more than about 0.04 draw attention because in most of them the sum $ZrO_2 + HfO_2 + SiO_2$ deviates considerably from 100 per cent. As pointed out earlier, these zircons come mostly from fractions of lighter density, in which the crystal form of zircon is in many cases poorly developed. The grains are often turbid and the alteration of the minerals far advanced. These zircons can be correlated with the cyrtolite, malacon, etc., varieties of zircon, reported by Fleischer (1955, Table 5) to have higher Hf/Zr ratios than the averages discussed in the foregoing. Most of the analyses on cyrtolite, etc., indicated a large deviation in their sum of oxides from 100 per cent. Attention should also be called to the study of Lipova and Mayeva (1971) concerning the relation of the Hf/Zr ratio in zircon to the crystal morphology. They pointed out that the ratio is not correlated with the metamict state of zircon, although there is a tendency for the hafnium content to increase from the crystalline zircon to the metamict zircon. No strict quantitative relation could be found. On the other hand, the ratio was fairly clearly correlated with the morphology. Almost all the specimens with an Hf/Zr ratio of more than 0.05 were crystals with an imperfect shape or spherulites, which consisted of separate blocks. A major feature of all the crystals rich in Hf was their splitting in various directions. All these zircons were termed cyrtolites, malacons or naegites. The analyses indicated a large deficiency in the sum of zirconium and hafnium as compared with their amounts in the ideal zircon formula. These behaved in this respect identically with the cyrtolites, etc., of Fleischer (1955) and the metamict zircons in the present paper.

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