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On the granites of Honkamäki and Otanmäki, Finland,

with special reference to the mineralogy of accessories

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Geologinen tutkimuslaitos • Otaniemi 1966

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ON THE GRANITES OF HONKAMÄKI AND OTANMÄKI, FINLAND

WITH SPECIAL REFERENCE TO THE MINERALOGY OF ACCESSORIES

BY

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O. LINDHOLM AND J. SIIVOLA

WITH 26 FIGURES AND 10 TABLES IN TEXT AND ONE PLATE

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ABSTRACT

The granites of Honkamäki and Otanmäki are characterized by the presence of Nb, F, Rb and rare earths as minor constituents. Using several techniques, including microprobe analyses, it was found that these minor constituents mainly form independent minerals, such as columbite, thorite, bastnäsite, etc. Furthermore, the granites contain alkalic amphibole and occasionally also aegirine.

The zircon present in the granites has been used for radiometric age determination. The value obtained, 2 050 m.y., is common for a group of Finnish galenas but before this it has not been found as the age of intrusive rocks in Finland.

Helsinki 1966. Valtioneuvoston kirjapaino

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INTRODUCTION

Within the Otanmäki region (Fig. 1) characterized by deposits of vanadium-bearing magnetite-ilmenite ores and by a complex geological structure, there occurs a gneissose granite which is fine- to medium-grained, principally aplitic, and pinkish in colour. In the south it is bordered by an arch made up predominantly of amphibolite with gabbroic portions and intrusions accompanied by lense- and strip-shaped ore bodies. Its eastern part continues northwestwards forming a large bend. In the east, another comparatively stright running amphibolite zone, roughly one kilometer wide, delimits the area inside this bend. According to Pääkkönen (1956), the area thus limited by the amphibolites consists of gneissose granite. Furthermore, most of the area in question is covered by swamp. The only known outcrops are situated in the marginal parts of the area: at the vanadium plant of the Otanmäki mine (Katajakangas), at Honkamäki, SW-corner of the area, and to the south of Pentinpuro. Outcrops are also known to the south of the church of Vuolijoki. The same granite occurs likewise as well defined veins and dykes of various thickness in the Otanmäki mine (Paarma, 1954). The granite dykes underground have been found close to the granite area in the north exclusively, and Pöschl (1964, p. 26) states that »- - - Gänge von vergneistem Granodiorit und vergneistem Granit schneiden zwar die Gefüge des »Altbestandes» diskordant, sind aber ausnahmslos den Schieferungstexturen der Umgebung Konkordant eingeschaltet, stets zusammen mit der Umgebung Kräftig durchbewegt und vergneist.»

FIG. 1. Location of the Otanmäki region.

According to Pääkkönen (1956), in the outcrop of the NW slope of Otanmäki, the gneissose granite is extraordinarily strongly crushed. At Honkamäki, the granite is less sheared, but has strongly crushed zones.

Pääkkönen (op. cit.) considers the gneissose granite to be synkinematic. He mentioned also the presence of an amphibole, most probably riebeckite, in this granite, and pointed out the high ferric iron content of the granite.

Later on a radioactive anomaly of limited size was encountered at Honkamäki. These features drew the attention of the Chief Geologist of the Otanmäki Company, Mr. H. Paarma, to this rock and he asked the first author of the present paper to investigate this gneissose granite in more detail. This investigation, presented on the following pages, was done by the authors so that Marmo was responsible for the petrology and compilation of the paper, Hytönen for the mineralogy, and Lindholm for the local geology. Kallio has done the investigation of the heavy fractions of the granite, and Hoffrén all analytical work using X-ray spectrometry, while Siivola was responsible for the micro probe work. Furthermore, the authors wish to express their gratitude to Dr. O. Kouvo, Geological Survey of Finland, for the mass-spectrometric investigation of the zircons.

THE OTANMÄKI ORE FIELD

Ilmenite-magnetite ore was discovered in 1937—38 to the south of lake Oulujärvi (Fig. 2). A mining company, Otanmäki Oy, was established in 1950 for the exploitation of this ore.

The deposit includes several ore bodies, all of which are within a zone composed of basic rocks (Fig. 2). This zone resembles the letter »L» in shape.

According to geological mapping, drilling and aerogeophysical survey, the zone, critical from the point of view of the occurrence of ore bodies, is accompanied by a granite. It is this granite which is the main subject of the present paper.

Due to the flat topography of the areas concerned and the extensive cover of swamps and low morainic or sandy hillocks, the bedrock is only seldom outcropped. The data of the airborne geophysical survey carried out at a height of 30 m to 50 m greatly facilitated the compilation of the geological map (Fig. 2). Nonetheless it is a generalized map.

The inner part of the region is composed chiefly of granite and granite gneiss with amphibolite strips, mostly parallel to the ore-bearing zone. In the south and the west of this zone the main rock is veined gneiss likewise containing some amphibolite strips. In the east, between the area shown in Fig. 2 and the Karelidic schists, a large microcline granite area occurs.

The ore-bearing formation is situated between the aforementioned veined gneisses and the complex of granite and granite gneiss with amphibolite strips. This formation is, however, discontinuous consisting of several lense-shaped intrusions along a zone some 25 km in length, and containing several ilmenite-magnetite ore bodies of varying sizes.

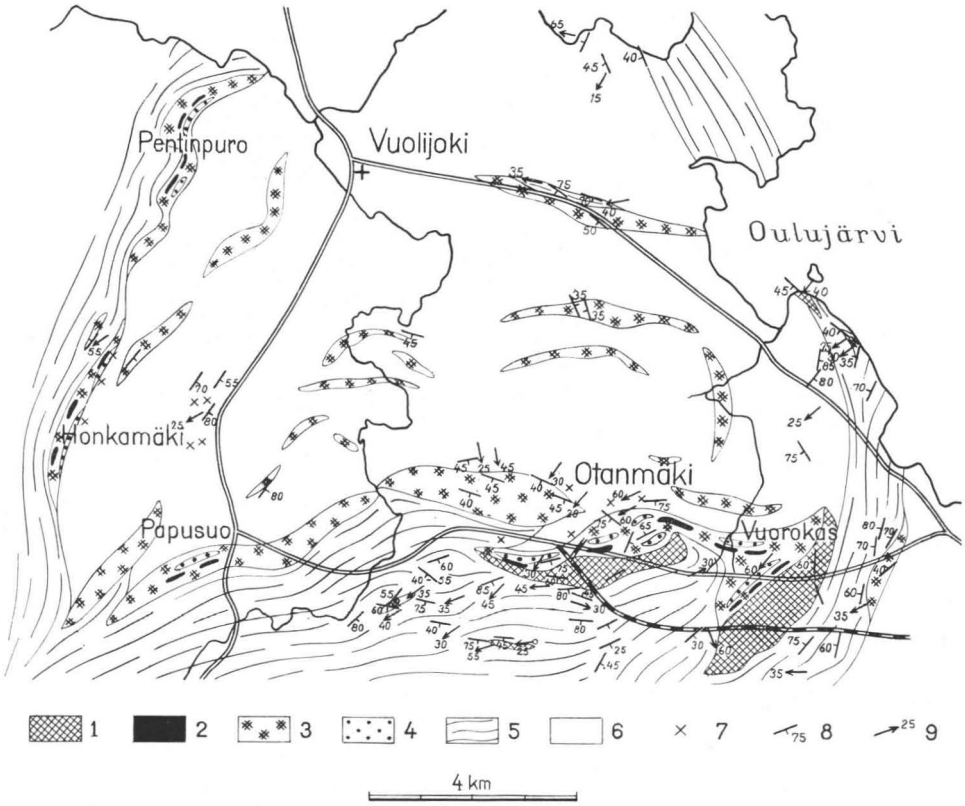


FIG. 2. Geological map of Otanmäki-area 1 = gabbro; 2 = ore bodies; 3 = amphibolite; 4 = anorthosite; 5 = gneiss; 6 = granite and granitized gneisses; 7 = outcrops examined for the present study; 8 = banding or dip of schistosity; 9 = lineation.

The mineralogical composition of the basic rocks of the area is very simple. The main constituents are hornblende and plagioclase. Pyroxene has not been met with, and uralite is occasional. The common accessories are ilmenite, sphene and pyrite. Epidote, chlorite, and sericite are irregularly present.

The amphibolite is fine-grained and distinctly schistose. Within the veined gneisses and inside the ore-bearing zone, this rock type is almost exclusive basic rock. To the south of the ore deposits of Otanmäki, there occurs a coarse-grained, ophitic gabbro. It is pale-coloured and contains more plagioclase than hornblende. Similar gabbro has been met with also to the south-east of the ore-bodies of Vuorokas (see Fig. 2).

Concerning the ore itself, it occurs in all the known places of this region in a very similar way. Fig. 3 illustrates the horizontal section of +225 m level of the mine. On the map the rock types are simplified, indicating only ore, rocks rich in feldspar and

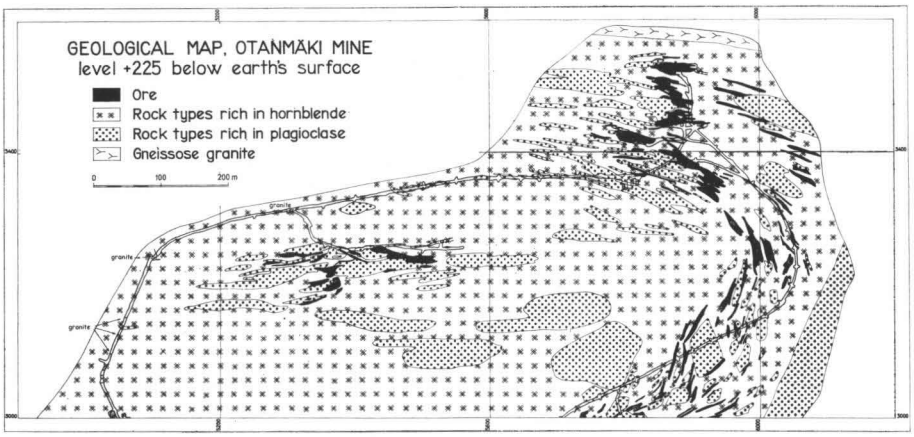


FIG. 3. Geology of the +225 level in the Otanmäki mine.

varieties rich in hornblende. The ore bodies are lense-shaped in vertical position, and the almost haphazard irregularity in the distribution of these bodies is characteristic of the whole ore field. In the mine, it seems that the ore, together with dark gabbroic and amphibolitic varieties, has brecciated the more salic types.

The composition of the ore is regular. Magnetite and ilmenite form separate grains. The former contains 0.6 % vanadium, which makes the Otanmäki mine into an important producer of this metal. Ilmenite and hornblende likewise contain some vanadium.

Both in the north and the west, the ore-bearing formation of Otanmäki terminates into the pink granite to be described in this paper. The contact between them is not exposed in any outcrop, nor has it been reached by addits or tunnels, but the northeast contact has been pierced in drillings. According to the information available, this contact is parallel to the ore-bearing zone. At the northern end of the +225 m level, there are some dykes which may originate from the aforementioned granite, and they definitely cross-cut the ore. The actual contact, however, must be at least 100 m away from these dykes, and it also cuts the strongly schistose amphibolite. The dykes consist mainly of microcline, plagioclase and quartz. In addition they contain dark green hornblende, dark brown biotite and sphene. Accessories are apatite, fluorite and zircon. The dykes are narrow, but of very irregular width. On an average they are only a few dm but sometimes they expand into clusters of up to 1 m in thickness.

It is noteworthy that there are also other kinds of dykes in the mine. They consist of strongly sericitized albitic plagioclase and quartz. Potash feldspar, chlorite, epidote and ore minerals are the minor constituents. As can be seen from the analyses of Table 2, they also contain strontium (0.07 % SrO) but no rubidium, which situation is contrary to that of the pink granite (see also p. 14). Similarly composed material forms also narrow interlayers (or concordant veins) in the amphibolite.

PETROGRAPHY OF THE HONKAMÄKI AND OTANMÄKI GRANITES

Owing to the scattered occurrence of the granite, as well as to the large areas entirely covered by drift, any continuity of the granite cannot be proved. It may be a coherent large body or composed of separated minor occurrences. Furthermore, even megascopically the granites of different outcrops are not very similar. At Honkamäki, the granite of which has been mainly investigated for the present study, the rock is pinkish and comparatively pale; at the Vanadium plant, close to the ore body at Otanmäki it is also pinkish, but dark. The granite to the SW of the ore field is also similar in appearance. In the mine itself, the granite veins and dykes are greyish or pink, aplite-looking. The rock is always medium to fine-grained, however, and the potash feldspar occurs in such a way that any age difference between this and the other salic constituents of the rock can hardly be ascertained under the microscope.

On the whole, the granite is rather inhomogeneous as far as its composition is concerned while still predominantly preserving the granitic character. This inhomogeneity can also be seen within a single outcrop. Thus, for instance, the largest outcrop investigated, at Honkamäki, contains radio-active spots (Fig. 4). There, the rock is rich in fluorite and calcite. They occur elsewhere in Otanmäki granites in much smaller amounts, with the latter often missing entirely. Fig. 5 illustrates the texture characteristic of the granite at Honkamäki. In Fig. 6, granite from a dyke in the mine is shown, the rock there being particularly rich in sphene. Fig. 7. illustrates the characteristic occurrence of fluorite in the same granite as shown in Fig. 5. Outcrops of similar pink granite have also been met with to the east of Honkamäki. There the radioactivity of the rock is distinct but much weaker in intensity than that measured at the outcrop at Honkamäki. An exception is the easternmost outcrop where the granite seems to be extensively recrystallized and where it is penetrated by numerous pegmatitic and quartz veins, not characteristic of this granite in general. The radio-

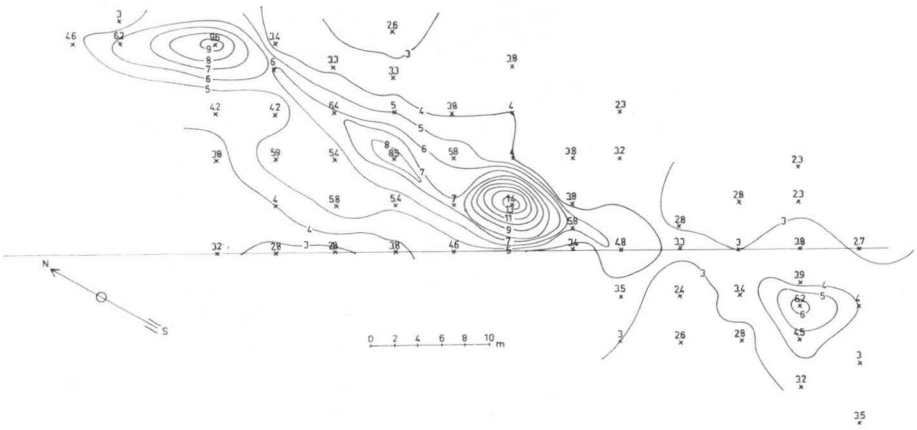


FIG. 4. Radioactivity variations on the outcrop at Honkamäki.

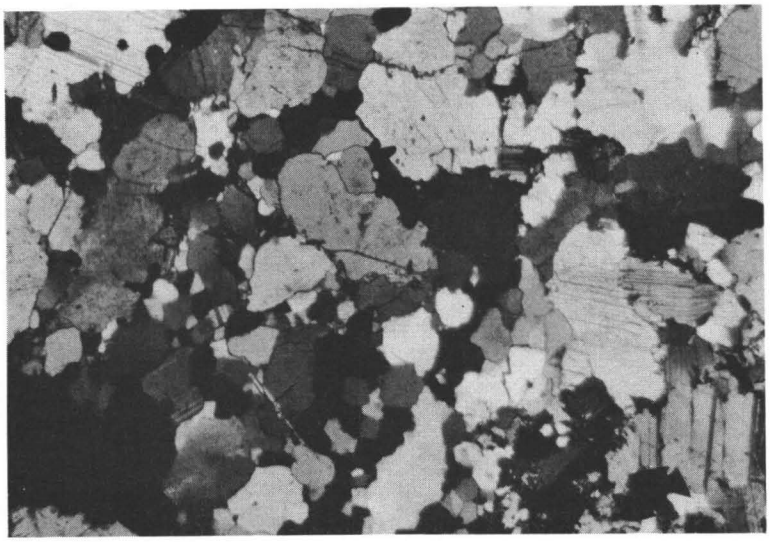


FIG. 5. Granite, Honkamäki. N+, 35x.

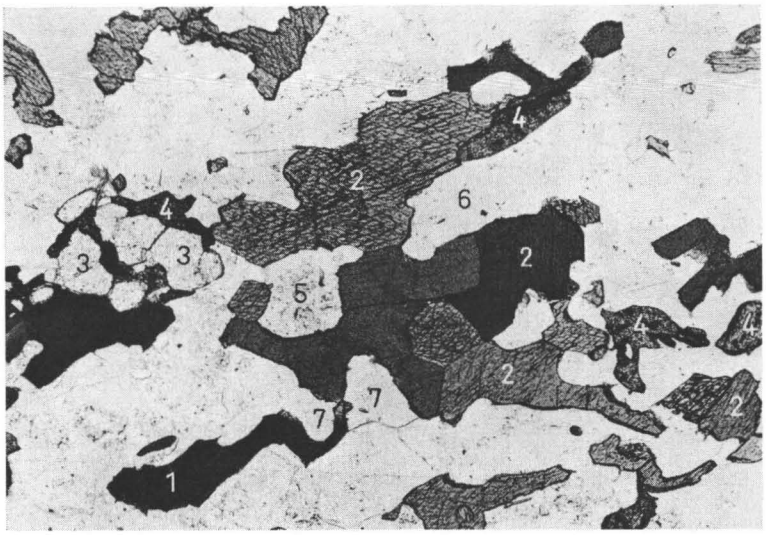


FIG. 6. Granite, Otanmäki mine, +225 level. 1 = black green chlorite; 2 = amphibole; 3 = apatite; 4 = sphene; 5 = albite; 6 = microcline; 7 = quartz. N ‖ . 45x.

activity seems to be concentrated into the veins richest in feldspar, in which some spots, only few cm^2 in size, are particularly radioactive. The zone with radioactive spots is only some 10 m in width.

It is typical of all samples sofar examined that the potash feldspar is invariably microcline of high triclinicity. This has been determined for 19 samples collected

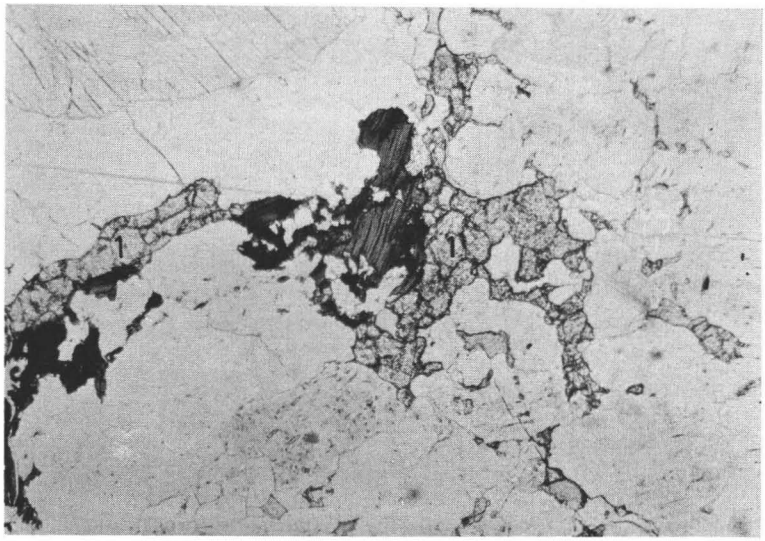


FIG. 7. Granite, Honkamäki. 1 = fluorite; dark is biotite; matrix: plagioclase, microcline and quartz. N ‖ . 55x.

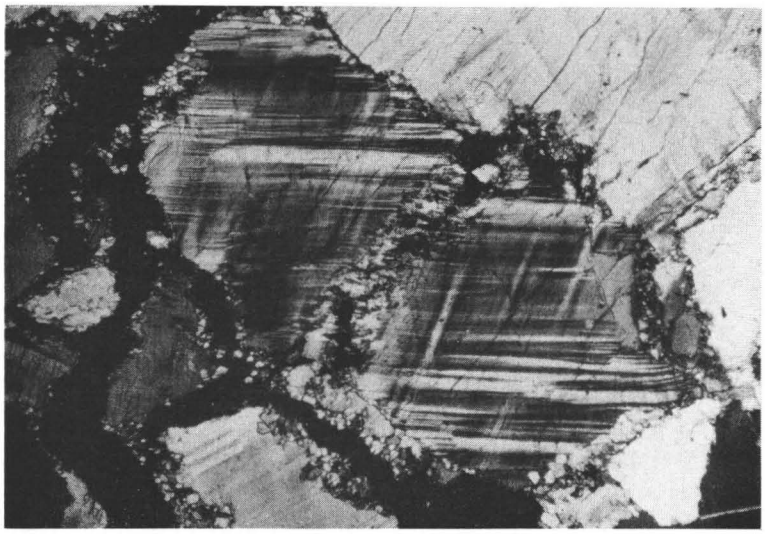


FIG. 8. Granite, Honkamäki. Microcline grain is broken and the cracks are filled with a fine-grained mixture of feldspars and quartz. N+; 50x.

around the whole granite area concerned. Two determinations yielded a triclinicity of 1.0, twelwe 0.95 four 0.90 and one 0.85.

In all the cases examined, the composition of the plagioclase is Ab_{93-95} An_{5-7}. Sometimes, the grains of microcline are broken and filled again by a very fine-grained mixture of quartz, younger microcline and albite (Fig. 8).

The mode of occurrence of the microcline, its high triclinicity and the albitic character of the plagioclase, as well as the whole micro-texture of the rock are characteristic of the so-called late-kinematic granites (e.g. Marmo, 1962).

An especially interesting variety of this granite occurs at the northern edge of the outcrops at Honkamäki. The rock there is medium-grained with distinct planar banding seen in the hand specimen and caused by alternating dark mafic and reddish felsic streaks. According to point counting on one thin-section (1690 points) the following mineral composition (weight percent) was obtained: 39 % microcline, 19 % albite, 14 % quartz, 12 % aegirine, 10 % alkali amphibole, 4 % opaque minerals, and 2 % accessories including monazite, sphene, zircon, epidote and brown mica.

Sometimes, in the microcline, there are streaks of magnetite (Fig. 9). Among the accessories, monazite forms the largest grains — approx. 0.2 mm in length.

The rock is an alkali granite whose chemical composition (see Table 2) indicates the molecular proportion of alumina as less than that of soda plus potash. This is typical of peralkaline granites (Shand, 1949) and is also portrayed by the presence of acmite ($Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$) in the norm.

Microcline of this rock is cross-hatched (tricl. 0.9) and perthitic. Albite is usually twinned and sometimes antiperthite has been observed. Both feldspars contain abundant opaque inclusions. Quartz has an undulatory extinction. The femic constituents occur usually as irregularly shaped crystal aggregates, and they are arranged into irregular bands.

The most interesting feature of this variety is the presence of aegirine (see Plate I), not earlier observed in granites of Finland. For this mineral, the following optical

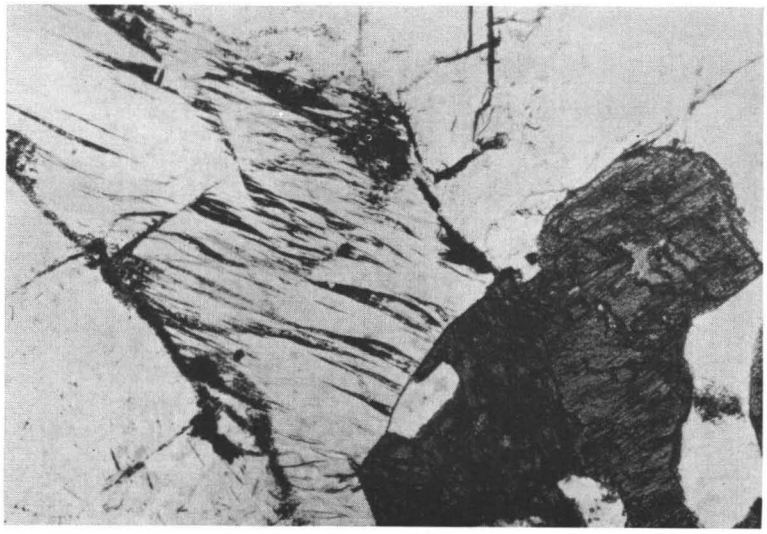


FIG. 9. Granite, Honkamäki. Microcline with strips of magnetite inside. To the right is bluish green amphibole. N ||. 72x.

properties have been recorded: $\alpha = 1.763$; $\gamma = 1.809$ (for both: ± 0.003), extinction close to parallel; elongation is negative $(\alpha \wedge c \approx 0°)$; pleochroism and absorption: α bright green $> \beta$ green $> \gamma$ greenish yellow or greenish brown. According to the diagram of Deer, Howie and Zussman (1963) the optical orientation corresponds to an aegirine with 0.72 ions of Fe^{+3} per formula unit. The refractive indices, on the other hand, indicate aegirine with 0.79 to 0.85 ions of Fe^{+3}. According to the diagram of Tröger (1959) based on Larsen (1941), the data correspond to an aegirine with 76 mol. % $NaFeSi_2O_6$, 24 mol. % $(MgFe)CaSi_2O_6$ and (73—77) mol. % $NaFeSi_2O_6$. (27—23) mol. % $(MgFe)CaSi_2O_6$, respectively.

The pleochroism of amphibole is characterized by dark or deep blue, and by almost complete absence of green. This, and the absorption, suggest that the amphibole in question is of an alkali variety. Both mentioned characteristics, as well as the anomalous interference colours, resemble those of the blue amphibole occurring as fissure infilling in the granite at the Vanadium plant (Hytönen and Heikkinen, 1966). The blue, however, is not that deep and the absorption is stronger than that of the latter. On the other hand, the refractive index α (1.708 ± 0.003) of the amphibole here in question is higher than that in the amphibole occurring in the granite at the Vanadium plant (1.696 ± 0.002). Extinction is close to parallel.

PETROCHEMISTRY OF THE HONKAMÄKI AND OTANMÄKI GRANITES

In Table 1 there are three analyses of the granite dealt with in the present paper. The sample taken from Honkamäki (1) differs markedly from the two others in that it contains much fluorite, much more than could be observed in thin sections from any other samples of the area described. This sample is, furthermore, taken from the place of highest radioactivity (see Fig. 4), probably caused by some Th-bearing mineral. In addition, the Nb_2O_5-content is unusually high for a granite. Also the zircon content is considerably higher than in any other samples investigated. These details of the chemical composition together with the comparatively much calcite, give this sample a total composition which is distinctly different from that of the other samples belonging to this granite area, and also from the granite occurring at the Vanadium plant (anal. 2). The latter is much shorter in the elements discussed above, containing, however, some alkali amphibole, probably riebeckite, and veins which are mainly composed of a sodic amphibole. Anal. 3 in Table 1 reproduced from the paper by Pääkkönen (1956) is incomplete and therefore prevents a discussion on the respective rock from this point of view. Microscopically, however, fluorite is a minor but common constituent in all the granites of the area. A common feature of those granites is also the high Fe_2O_3 and FeO, together with the remarkably low content of MgO.

In general, the Rb-content is not high, but still remarkable, and it seems to be characteristic of the granites discussed here. In contrast, it is worthwhile to point out that SrO-content is at the same time very low — according to the analyses given,

TABLE 1

Chemical composition of the Honkamäki and Otanmäki granite

	1	2	3
SiO_2	75.34	71.19	71.55
TiO_2	0.20	0.32	0.45
Al_2O_3	11.08	13.51	12.81
Fe_2O_3	1.53	1.50	2.80
FeO	1.48	1.41	0.94
MnO	0.05	0.07	0.06
MgO	0.21	0.03	0.09
CaO	1.31	0.30	0.63
Na_2O	2.99	4.66	4.60
K_2O	4.75	6.29	4.84
P_2O_5	0.03	0.09	0.05
CO_2	0.35	0.00	
H_2O+	0.55	0.32	0.50
H_2O-	0.08	0.06	0.35
F	0.25	0.01	
Nb_2O_5	0.05	0.01	
ZrO_2	0.15	0.02	
ThO_2	0.03		
SrO	0.0	0.0	
Rb_2O	0.03	0.02	
	100.46	99.81	99.67
$O = F_2$	0.11		
	100.35		99.67
		Calculated mode	Determined mode
Quartz	38.71	19.56	32.1
Albite	25.15	37.73	11.6
Anorhite	2.43	0.28	
Microcline	25.60	37.25	45.5
Biotite	2.70		9.4
Muscovite	0.87		
Riebeckite	—	2.39	
Calcite	0.80		
Fluorite	0.25		
Sphene	0.59		
Apatite		0.34	0.1
Magnetite	2.09	1.39	1.3
Ilmenite	—	0.61	
Zircon	0.27		
Rest	0.89	0.26*)	
	100.35	99.81	100.0

1. Vuolijoki, Honkamäki. Anal. P. Ojanperä

2. Vuolijoki, Otanmäki, at Vanadium Plant. Anal. P. Ojanperä

3. Vuolijoki, Otanmäki, drill hole. Anal. B. Wiik (Pääkkönen 1956, p. 22)

F. analyzed by A. Heikkinen Nb_2O_5, ZrO_2, ThO_2, SrO, Rb_2O determined X-ray-spectrographically by V. Hoffrén

*) There is a deficiency of 0.8 % Al_2O_3 in the rock indicating its peralkaline character.

0.0 %. This is especially interesting, because, in the mine itself, along with the granite veins, the albitic veins contain more than 50 % albitic plagioclase (Table 3). These veins have 0.07 % SrO and 0.0 % Rb_2O. If it is thought tentatively that granite and albitic rock have a common or similar source, then Rb_2O has been concentrated with K-feldspar, but SrO quantitatively with the albitic plagioclase. In the albitic vein from the mine, Nb_2O_5 and ZrO_2, characteristic of the granites discussed in the present paper, are likewise absent.

TABLE 2

Chemical composition of alkali granite, specimen 7—OM, Honkamäki, Vuolijoki.
Analyst: Aulis Heikkinen

	Weight per cent
SiO_2	64.48
TiO_2	1.11
Al_2O_3	12.20
Fe_2O_3	6.00
FeO	3.00
MnO	0.29
MgO	0.29
CaO	0.40
Na_2O	5.68
K_2O	5.13
P_2O_5	0.04
CO_2	0.00
Nb_2O_5	0.03
ZrO_2	0.14
SrO	0.00
Rb_2O	0.03
H_2O+	0.51
H_2O-	0.06
F	0.09
Cl	0.04
	99.52
$-O = F_2, Cl_2$	0.05
	99.47

	Weight Norm
Q	13.3
or	30.3
ab	33.9
hl	0.1
Z	0.2
Salic	77.8
ac	12.1
di	1.0
hy	3.0
mt	2.6
il	2.1
ap	0.1
fr	0.2
Femic	21.1

Nb_2O_5, ZrO_2, SrO, Rb_2O determined X-ray spectrographically by V. Hoffrén.

The variety of granite of Honkamäki, containing aegirine (Table 2) and rich in zircon, distinctly contains niobium and rubidium, but no strontium, thus also markedly differing from the albite-rich rock cutting the ore formation in the mine. It mainly differs from the main granite at Honkamäki (Table 1, column 1) or at Vanadium plant (columm 2) because of 1) enrichment in soda, the ratio K_2O:Na_2O being for the Honkamäki granite 1.58, for the granite at the Vanadium plant 1.35 and for the aegirine-bearing granite 0.9 (Table 2), and because 2) in the same order, strong impoverishment in silica has taken place, 75.34, 71.19, 64.48 resp. Concerning alumina, on the contrary, no similar trend appears, but if compared only with the adjacent Honkamäki granite (Table 1), a clear enrichment of this constituent has taken place — an observation which is of some importance, if considered in the light of some results obtained by Black (1965) for the so called »Younger granites» of Nigeria and Niger. He has found, that differentiation there has proceeded along two lines. Along the line characterized by the shortage in alumina it produced aegirine-amphibole granite and along the line with more alumina it resulted in the formation of biotite granite.

On the whole, the abundance of accessory constituents is typical of the granite varieties of the Otanmäki region discussed in this paper. This feature is not in any way common, where the Precambrian granites of Finland are concerned. Certainly this may depend also upon the fact, that very detailed granite studies have been seldom made,

TABLE 3

Albite-rich vein cutting the ore in the Otanmäki mine.

Analyst: P. Ojanperä

SiO_2	66.80
TiO_2	0.51
Al_2O_3	14.86
Fe_2O_3	1.72
FeO	0.73
MnO	0.06
MgO	1.31
CaO	5.45
Na_2O	5.92
K_2O	1.48
P_2O_5	0.20
CO_2	0.02
H_2O+	0.45
H_2O-	0.12
F	0.02
SrO	0.07
Rb_2O	0.0
ZrO_2	0.0
Nb_2O_5	0.0
	99.72
$-O = F_2$	0.01
Total	99.71

Calculated mode

Quartz	17.04 %
Albite	49.78 »
Anorthite	3.89 »
Microcline	8.90 »
Magnetite	2.32 »
Sphene	1.18 »
Apatite	0.34 »
Diopside	7.13 »
Clinozoisite	8.40 »
Calsite	0.04 »
Fluorite	0.02 »
Rest	0.67 »
Total	99.71 %

F determined by A. Heikkinen, SrO, Rb_2O, ZrO_2, Nb_2O_5 X-ray spectrometrically by V. Hoffrén.

Plagioclase (according to optics): An_5Ab_{95}.

and sufficiently complete chemical analyses are rare. Still the results obtained above seem to entitle the present authors to point out the similarity, in this sense, between the granites described here and, for instance, the Nigerian »Younger granites» — despite the fact that the composition of accessories may not be exactly similar. On the other hand, the otherwise very similar granite of Tebo, Sierra Leone (Marmo, 1966) does not contain heavy accessories as does the granite of Honkamäki, but there is a content of BaO and SrO not observed in the latter. Thus the granite of Honkamäki, with its compositional varieties, represents a granite type which is to be considered exceptional — at least among the Precambrian granites, and which has only seldom been described in the literature dealing with granite petrology. Therefore, this rock — especially its composition and distribution of accessory elements in different minerals — was examined as thoroughly as possible.

THE HEAVY ACCESSORY MINERALS OF THE HONKAMÄKI GRANITE

To be able to perform a »microchemical» study of the granite of Honkamäki, it was first necessary to separate from the rock all such constituents as could contain the accessory elements found by chemical analyses. For this purpose a sample, 25 kg in weight, was taken from the outcrop at Honkamäki at the point indicating the highest

observed radioactive anomaly. The chemical composition of this sample is shown in anal. 1 of Table 1. The sample was crushed so that three quarters of it passed through a 60 mesh sieve. The preliminary separation was carried out using superpanner and bromoform. From the fraction heavier than bromoform, magnetite (and pieces of iron) was removed using a hand magnet. The remaining heavy fraction — totalling 60 g — was split into four parts according to their specific gravity, by using Clerici solution. Each of these was then further split into two using an electromagnetic separator. In so doing the rest of the magnetite (2 g) was also removed.

The main minerals of the heavy fraction were biotite, fluorite, clino-amphibole, sphene and zircon. In addition, the following minerals were identified by the X-ray diffraction method: apatite, bastnäsite, clino-pyroxene, columbite, danalite, epidote, garnet, hematite, ilmenite, molybdenite, pyrite, and thorite. The distribution of these minerals among the different fractions is seen in Table 4.

Biotite, fluorite and amphibole are also the essential constituents of the whole rock. Also apatite, epidote, sphene and zircon could be microscopically identified in thin sections. The rest of the heavy minerals listed could be found only in the heavy fraction.

TABLE 4

The distribution of heavy minerals in different fractions of Honkamäki granite, Vuolijoki.

d	brf—3.4		3.4—3.8		3.8—4.2		>4.2	
Electromagnetic separator	non-magnetic	magnetic	non-magnetic	magnetic	non-magnetic	magnetic	non-magnetic	magnetic
The weight of fraction (g)	9	9	11	4.5	12	2	9	1.5
Nr of fraction	4f1	4f2	7f1	7f2	6f1	6f2	3f1	3f2
biotite		×						
fluorite	×							
amphibole		×						
sphene			×					
zircon I							×	
zircon II			(×)	(×)	×	(×)		
apatite	×							
bastnäsite				×				
columbite								×
danalite				×				
epidote		×						
garnet				×				
hematite								×
ilmenite								×
molybdenite							×	
pyrite							×	
pyroxene				×				
thorite					×	(×)		

The most abundant mineral in the heavy fractions is zircon, which occurs in two morphologically different forms. Zircon I, which, concentrated into the heaviest fraction ($d > 4.2$), is pale brownish in colour and forms clear well-formed crystals; zircon II, which, mainly obtained from the fraction $d = 3.8 - 4.2$, occurs as turbid, broken crystals called »altered zircon» in the following. Zircon I was cleansed for age determinations.

The zircon II, »altered zircon», occurring in the lighter fraction, may be a water-bearing variety of zircon, a so-called hydrozircon. Especially of interest here is a similar mineral extracted and investigated by Coleman and Erd (1961) from the Wind River formation, Wyoming. This hydrozircon has a specific gravity = 3.0 to 3.2, and according to their description, derives from a granite. Because zircon II has not, however, been examined more closer this comparison is here only very tentative.

In the fraction $d = 3.4 - 3.8$, a black grain (which may be an aggregate of several crystals) of bastnäsite was found. When powdered, it became colourless. The occurrence of this mineral with its $d \approx 5$ in a light fraction may depend upon the aggregate character of the grain investigated. Adams and Young (1961) have described a bastnäsite from Pikes Peak granite, Colorado, where it also occurs as impure micro-crystalline aggregates. The occurrence of bastnäsite in the granite of Honkamäki is of interest, because this mineral has been considered to belong to contact-metamorphic zones and to have formed by hydrothermal replacement. Recently Gross and Heinrich (1965) have identified this mineral as a very rare constituent in the sill-like granite bodies of Windy Point, Colorado (see also p. 24). Glass and Smalley (1945) reported it also from pegmatites. In Finland, bastnäsite has been encountered in the Korsnäs lead mine. It has also been mentioned as occurring in the western parts of the parish of Juuka, but no details are available of the latter find.

Danalite occurs as pink grains of a light shade without any visible crystal form. According to a microprobe test, from one single point of such a grain, the following semiquantitative composition, 90 % of the total, was obtained: 32 % FeO, 10 % ZnO, 8 % MnO, 35 % SiO_2, 5 % S (Geoscan cannot indicate lighter elements, such as Be). The X-ray powder pattern of the danalite is seen in Table 5.

Danalite belongs to the helvite group. According to Winchell and Winchell (1951) these minerals have been met with in gneisses, granites, pegmatites and in contact zones. Danalite has not been earlier recorded from Finland.

The garnet is andraditic, mainly dark brown in colour, and it has no visible crystal forms. In the dark brown andradite $a_0 = 11.95$Å, in the lighter coloured grains $a_0 = 11.85$Å.

Pyroxene is bright green, non pleochroic, and the optical properties are $\alpha = 1.702$, $\gamma = 1.730$, $c \wedge \gamma \approx 45°$. According to its optical properties and X-ray powder pattern (Table 5), the pyroxene belongs to the diopside-hedenbergite series. As revealed by the refractive indexes, its composition is $di_{45}he_{55}$ (Zwaan, 1954).

Molybdenite is of ordinary hexagonal 2H type.

TABLE 5

X-ray powder pattern of five minerals, Honkamäki granite, Vuolijoki. Rad. Cu, Filt. Ni, camera ø = 57.3 mm

Bastnäsite			Columbite			Danalite			Pyroxene			Amphibole		
hkl	d meas. Å	I estim.	hkl	d meas. Å	I estim.	hkl	d meas. Å	I estim.	hkl	d meas. Å	I estim.	hkl	d meas. Å	I estim.
*)	7.2	m	020	7.0	w	002	4.08	m	110	6.5	w	110	8.5	vs
002	4.9	s	130	3.65	ms	012	3.64	m	200 } 020 }	4.6	vw	111	5.0	vw
*)	3.68	vw	131	2.96	vs	112	3.35	vs				040	4.6	vw
110	3.56	vs	200	2.86	vw	022	2.89	w	$11\bar{1}$	4.4	vw		3.75	vw
*)	3.23	vw	002	2.53	m	013	2.58	s	021	3.35	vw	131	3.39	m (b)
*)	3.18	vw	201	2.49	m	222	2.37	w	220	3.23	w	310	3.14	s
112	2.86	vs	060	2.36	w	023	2.26	vw	$22\bar{1}$	3.00	vs	151	2.95	w
004	2.45	w	032	2.21	m	123	2.19	s	$31\bar{1}$	2.90	w	330	2.82	vw
300	2.05	m	132	2.07	w	004	2.05	vw	$13\bar{1}$	2.56	w	151	2.72	s
301	2.01	m	310	1.892	w	033	1.929	vs	002 } $11\bar{2}$ }	2.51	vs	061 } 002 }	2.58	ms(b)
302	1.905	m	260	1.824	w	024	1.829	m						
*)	1.748	vw	062 } 261 }	1.722	s	224	1.668	m	311	2.30	vw	$\bar{3}51$	2.35	m
222	1.667	m				015	1.604	w	112	2.22	w	112	2.29	w
304	1.555	vw	133 } 172 }	1.530	m	125	1.496	m	$33\bar{1}$ } $42\bar{1}$ }	2.12	m	$\bar{3}32$	2.18	m
224	1.432	vw				044	1.449	m				261	2.04	m (b)
306	1.281	vw	191	1.467	s	035	1.405	m	041	2.04	vw	172	1.697	w
			401	1.375	w	006	1.366	m	$40\bar{2}$	2.02	m	480	1.653	w
			+ add.	lines to		116	1.329	m	150	1.76	m		1.625	vw
			0.804			145	1.263	m	$22\bar{3}$	1.64	s	600	1.588	m
						127	1.114	m	550	1.54	w	263	1.519	m (b)
						237	1.040	w	402	1.52	w		1.448	ms
						118	1.010	w	+ add.	lines to		+ add.	lines	
						921	0.8839	vw	0.799					
						930	0.8640	w						
						10.3.1	0.7818	m						

*) lines not mentioned in the cards of ASTM 11—301 and 11—340. The lines may be caused by minute amounts of CeF_3 and LaF_3 (ASTM 8—45 and 8—461, respectively.)

Thorite occurs in almost entirely metamictic grains. The colour varies from bright yellow to black. Only the grains lightest in colour gave a faint X-ray image of thorite. The metamictic thorite grains were heated for 3 hours at 700°C, for 1 hour at 1 000°C, and for 1 hour at 1 300°C. Thereby it was observed that huttonite was crystallized at 1 000°C proving that the original mineral had been thorite.

On the distribution of accessory elements

As mentioned in connection with the petrochemical discussion of the granite of Otanmäki region (p. 13), the abundance of accessory elements in this granite is of interest. It was of still greater interest to find out, in which minerals these elements occur.

Lisitsina and others (1965) have studied some granites of the Tien Shan Russian Asia, and discussed the conditions necessary for the formation of accessory minerals instead of the respective elements becoming incorporated in lattices of the major constituents. According to this study, Nb, Ti, and P can form independent minerals only if $Nb_2O_5 > 0.007$ %, or $TiO_2 > 0.05$ %, or $P_2O_5 > 0.02$ % in the total rock. Furthermore, independent niobates cannot be formed if there is, simultaneously, more than 0.25 % TiO_2 in the rock. They also observed, that in the alaskitic granites, containing 0.15 — 0.42 % F and 0.1 — 0.3 % Nb_2O_5 (in hornblende-bearing varieties, however, only 0.004 — 0.008 % Nb_2O_5), the niobium forms its own minerals, but simultaneously it is also present in other minerals in the following way: in ilmenite 0.8 to 3.82 %, in biotite 0.003 to 0.017 %, in sphene 0.84 to 2.93 %, in zircon 0.1 to 0.3 %.

As for the lantanides, the cited authors observed that in the alaskitic veins Ce_2O_3 and Y_2O_3 form independent minerals, but are also incorporated in fluorite (0.74 %), zircon (0.84 %), biotite (0.01 to 0.023 %) and hornblende (0.0015 %).

If the granite of Honkamäki is considered from a similar point of view, one can observe, that the contents in Nb_2O_5 (0.05 %), TiO_2 (0.20 %) and P_2O_5 (0.03 %) are high enough to establish the conditions under which similar minerals are formed, the content of TiO_2 being below the limit which would prevent the formation of columbite. It was of interest to find out, how the results obtained by Lisitsina and her colleagues would fit into the granite of Honkamäki. Therefore, the various heavy fractions of the granite described above, which had been mineralogically investigated were analytically examined using the XRF-spectrography method.

The first step was to find out semiquantitatively the behaviour of the accessory elements during the separation process, that is, into which fraction (see Table 4) each of them had mainly been concentrated. In Table 6, this distribution is given, the fractions being the same as used for mineralogical purposes. The concentrations are indicated only by the magnitude, not in exact figures.

TABLE 6

Distribution of niobium and rare earths in the heavy fractions of the Honkamäki granite.

Nr of fraction	Spec. grav.	Amount analyzed (g)	% Nb_2O_5	Remarks
4f1	brf—3.4	9.0	0.x	
4f2	»	9.0	0.x	
7f1	3.4—3.8	11.0	X.0	
7f2	»	4.5	X.0	RE-max.
6f1	3.8—4.2	12.0	0.x	Th-max.
6f2	»	2.0	0.x	
3f1	<4.2	9.0	0.x	
3f2	»	1.5	X.0	Nb-max.

Niobium is mainly present in the fractions 3f2, 7f1 and 7f2, each of which contains a few percent of Nb_2O_5. It is, however, most abundant in 3f2. For this fraction both X-ray diffraction (p. 17) and the microprobe test (p. 28) gave columbite as being the only Nb-bearing mineral present.

For the fractions 7f1 and 7f2 (d = 3.4 — 3.8), the following observations of importance could be noted: 7f1 contains mainly sphene, but XRF-spectrum indicated also approx. 2 % Nb_2O_5 and very abundantly, approx. 15 % ZrO_2. In addition there are some hundredths per cent lantanides, mainly cerium, lantanum, and neodymium in resp. proportion 2: 1: 1. As will be shown later (p. 23), Nb is there as an independent mineral — possibly Ca,Y-niobate — which occurs only as inclusions in sphene. ZrO_2 is entirely bound to zircon (obs. d = 3.4 — 3.8). The fraction of 7f2, which is of the same density as 7f1, is a kind of mixed fraction (see Table 5). It contains Nb as abundantly as 7f1, but also represents the highest content (appr. 1 %) of rare earths, which are mainly represented by Ce, La, and Nd — also in proportion 2: 1: 1. This fraction has not been subjected to the microprobe tests, but possibly the problematic Ca, Y, Fe, U, Th and RE-niobo-tantalate discovered from polished section of the granite (see p. 26) could be found in this fraction. It may also be mentioned that despite the fact that tantalum has been found in this mineral (micro probe), in some places even abundantly, this element could not be observed in any of the investigated fractions using XRF. Taking into consideration the sensitivity used, one can safely say that everywhere in the examined fractions, the ratio Ta/Nb must be less than 1:10.

Surprisingly, according to XRF-spectra, zirconium is present in three fractions of different density, and in large quantities also in that fraction, which has a density as low as 3.4 — 3.8. The higher fractions contain mainly zircon. This distribution within a large range of density values may be explained as being due to the presence of »altered zircon» (see p. 18). Thorium is present along with zirconium, the maximum being in 6fl and 6f2. As mentioned above (p. 17), thorite was identified from the last-mentioned fractions (d = 3.8 — 4.2).

The electron probe analyses

The electron probe (microprobe) analyses were performed using a Geoscan EP-analyzer with two channels, made by Cambridge Instruments Ltd.

The problems set forth for this work can be divided into three: 1) distribution of Rb; 2) distribution of lantanides; 3) search for Nb-Ta (-Y)-minerals.

1. For the first problem, the original granite material (Table I, Anal. 1) was used. It contained 0.03 % Rb_2O. To be solved was whether Rb is evenly distributed in potash feldspar or mica and consequently fixed into their lattices, or whether it is concentrated into definite maxima within these (or other) minerals. For this purpose, a polished section of the original granite was prepared and coated, in vacuo, by a 50 Å thick Cu-film.

The following working constants were used: 20kV/0.1 μA; analyzed line RbLα_1. The results of this study, seen in Figs. 10 to 13, revealed that:

— Rubidium is entirely fixed into potash feldspar and into biotite. Plagioclase, amphibole and pyroxene are completely devoid of it (see Fig. 10).

— In the Rb-bearing minerals, this element is very evenly distributed (Fig. 13). Therefore one is entitled to conclude, that in these minerals rubidium is in the lattices replacing some other element, most probably potassium.

— the amount of rubidium in the biotite is somewhat higher than that fixed by potash feldspar, but usually so that the ratio

$$\frac{\text{Rb in mica}}{\text{Rb in feldspar}} \ll 2.$$

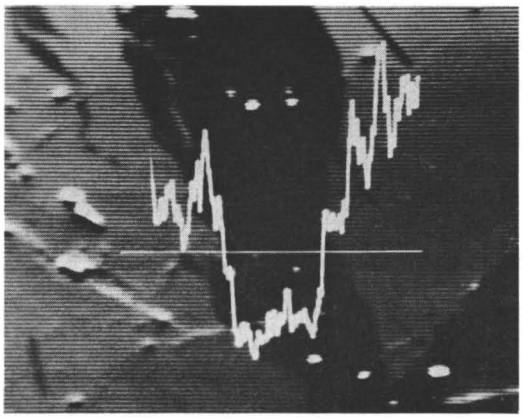


FIG. 10. Granite, Honkamäki. Pale area is microcline, dark is plagioclase. The profile (white line) indicates the Rb-intensity. The zero level is represented by plagioclase. Electron image. 300x.

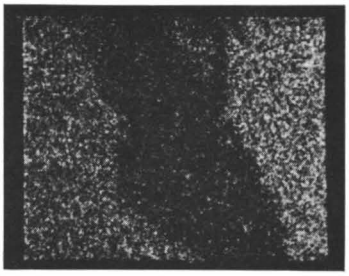


FIG. 11. Granite, Honkamäki, Central part of Fig. 10. Distribution of rubidium (white spots), X-ray image, RbLα_1. 300x.

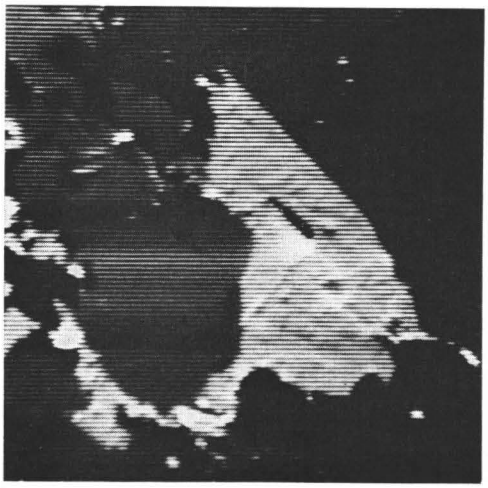


FIG. 12. Granite, Honkamäki. Pale is mica, dark microcline, and black plagioclase. Electron image. 300x.

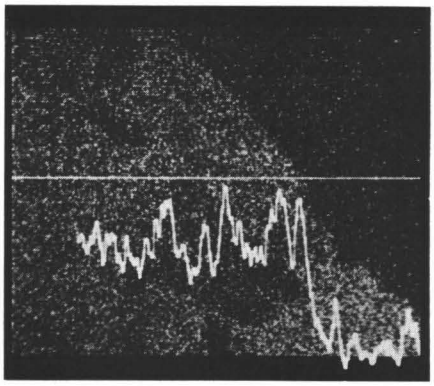


FIG. 13. Central part of Fig. 12. Profile indicating the Rb-distribution along white horizontal line. X-ray image. Rb$L\alpha_1$. 200x.

2. The non-magnetic part, of the fraction 7f1 (see Table 5), contains lantanides. Later on, however, it was found by XRF-analysis, that 7f2 contains lantanides in a tenfold amount if compared with 7f1. According to XRF-analysis, these fractions contain Ce, La, Nd, and Sm, maybe also Eu.

From the polished section used for the tracing of Rb, a very minute grain (less than 10 μ across) was found at the edge of an ilmenite grain. Qualitatively, this grainlet contained La, Ce, Nd, and traces of Sm and Eu. By a more careful examination of the polished section, from an area of 2 sq. cm, some 30—40 similar grains were found. They were rounded or elongated, metamictic (?), slightly pinkish and had taken a bad polish. On the average these grains are 40 μ across, and often occur together with biotite and sphene, but also close to amphibole, zircon or ilmenite, as is shown in Fig. 14. In a slide prepared from the concentrate of the non-magnetic fraction 7f1, this mineral occurs as inclusions in sphene.

In Fig. 14, there is a hexagonal grain of fluorite (central part of the image). To the right there is a grain of amphibole, and between these two, as well as in the fissures of amphibole, there is material, which is pink under the microscope. The electron probe analysis of this gave the following results:

— La, Ce, and Nd always occur together, and exclusively within the above-mentioned pinkish grains. These elements are entirely absent in fluorite and amphibole (Fig. 15).

— Fe and Mg are typical only of amphibole; Al and Si also of surrounding feldspars.

— In addition to fluorite Ca also follows the lantanide-bearing pinkish grains.

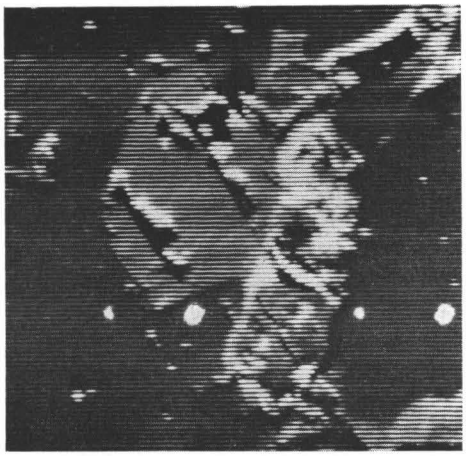


FIG. 14. Granite, Honkamäki. Polished section 8 801. Material containing rare earths between fluorite (hexagonal) and amphibole. Electron image. 270x.

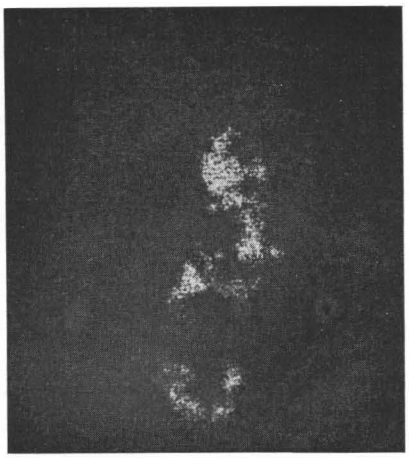


FIG. 15. Area from Fig. 14. Distribution of cerium. X-ray image, $CeL\alpha_1$. 270x.

— According to the intensity measurements, the ratio of Ce: La: Nd equals 2.5: 1: 1. Thus cerium is present in an amount slightly exceeding that of La and Nd together.

— The pink mineral does not contain any P or Si. Therefore, if remembering that the Geoscan does not detect elements lighter than sodium, the mineral may be a fluoride, fluorcarbonate (carbonate or oxyde).

The semiquantitative composition of this mineral is given in Table 7, and the distribution of cerium and calcium in Fig. 16 to 18.

It should also be mentioned that, in the examined areas, no other rare earths except traces of Sm have been detected.

This mineral is probably the same as that identified by X-ray diffraction method (see p. 18) as bastnäsite ($CeFCO_3$).

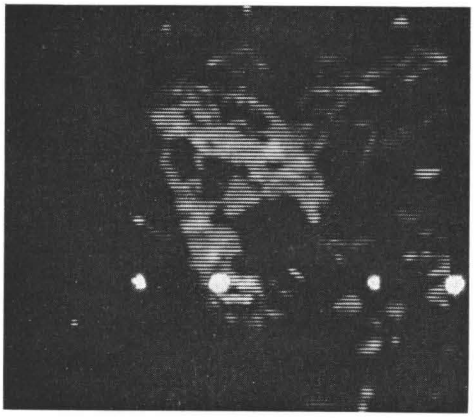


FIG. 16. Electron image of the mineral rich in rare earths. 390x.

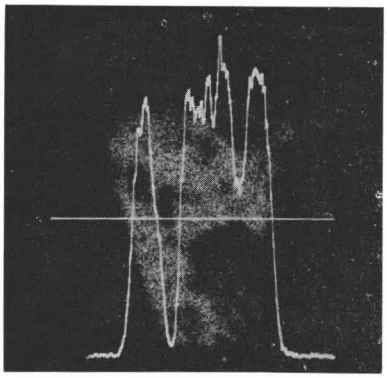


FIG. 17. The same area as seen in Fig. 16. Distribution of cerium and a profile across the rare-earths mineral. X-ray image, CeLα_1. 390x.

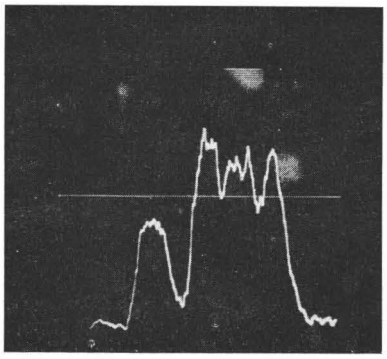


FIG. 18. The same area as seen in Figs. 16 and 17. Distribution of calcium. Compare with Fig. 17 to see how clearly Ca and Ce follow each other. X-ray image. CaKα. 390x.

TABLE 7

Semiquantitative composition of the pink mineral (three different grains).

	I	II	III
Ce	22 %	27 %	23 %
La	9 »	12 »	8 »
Nd	9 »	11 »	17 »
Ca	6 »	6 »	6 »
Total	46 %	56 %	54 %

Standard: synthetic CeF_3 (with 1 % La) and fluorite. The lines analyzed: CeLα_1, LaLα_1, NdLα_1, and CaKα
The constants used: 20 kV/0.1 μA; PHA $4.75 + 0.50$ V

3. According to the XRF-analyses, Nb was concentrated into fractions 7f1, 7f2 and 3f2. The Y-content was known (XRF) to be very low, and Ta was in any case less than a tenth of the Nb-content, thus almost negligible.

When analysing the appropriate minerals with Geoscan, the Mn-columbite examined by Vorma and Hoffrén (1965) was taken as standard ($Nb_2O_5 = 37.65$ %, $Ta_2O_5 = 43.45$ %, FeO = 1.73 %; MnO = 14.50 %). Results:

— In the sphene, there are very small inclusions in which there are Nb- and Y-maxima, Ti is about a half of that in sphene, the amount of Ca being the same in both. This suggests the presence of some Nb-Y-Ca mineral (perhaps one of the fergusonite-samarskite series).

— In fraction 7f1 (d = 3.4 — 3.9) grains of the altered zircon mentioned on p. 18, were found.

— Figures 19 to 24 illustrate an aggregate, approx. 70μ in diameter, found in the polished section of granite. This may be either a completely metamictic mineral or an aggregate of microcrystalline material, in which each point represents a separate mineral causing very different analytical values within extremely

minute areas as is seen in Figs. 19 and 20. The aggregate contains Nb, Ta, Y, U, Ce, La, Nd, Ca, Fe, (Mn), Ti and Si. The distribution of these elements is seen in Fig. 20. Ta and U (Figs 21 and 22) occupy fields which can be delimited, but this cannot be done for Nb, Ca and Ti (Figs. 23, 24). Furthermore, the lantanides as well as Fe and Y occur together with the minimum values for Ta' The distribution of Nb and Ta within the area of the aggregate is shown in Table 8.

FIG. 19. Granite, Honkamäki. Polished section. A grain containing niobium and tantalum. Electron image. 470x.

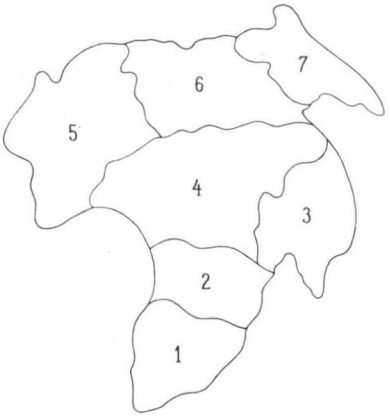


FIG. 20. The same grain as seen in Fig. 19. Distribution of different elements within this grain:
1 = Nb—Ln—Y—Fe—Ti; 2 = Nb—Ta—U—Ca—Si; 3 = Nb—Ca; 4 = Nb—Ln—Y—Fe—Ti; 5 = Nb—Ta—Ti—Ca—U; 6 = Nb—Ti—Ca—Ta—U; 7 = Nb—Ti—Ca—Ln.

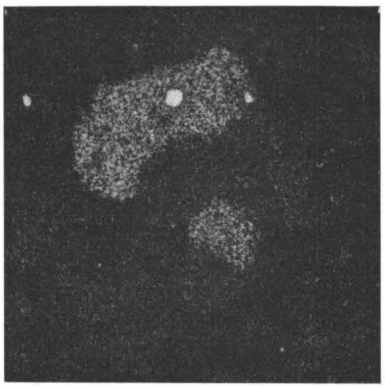


FIG. 21. The same grain as seen in Fig. 19. The distribution of tantalum. Observe the sharp contours of the areas enriched in Ta. X-ray image. Ta$L\alpha_1$, 470x.

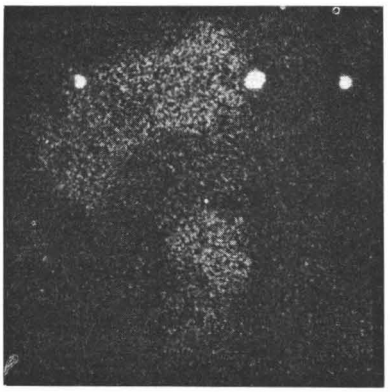


FIG. 22. The same grain as seen in Fig. 19. The distribution of uranium distinctly follows that of tantalum. (Compare Fig. 21). X-ray image. U$M\alpha_1$ (II). 470x.

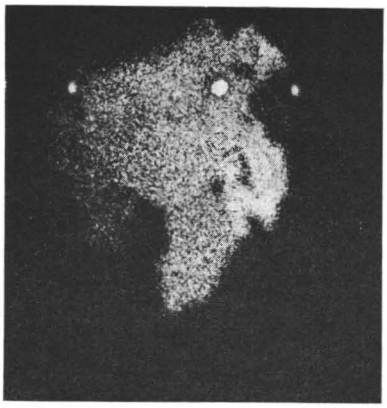
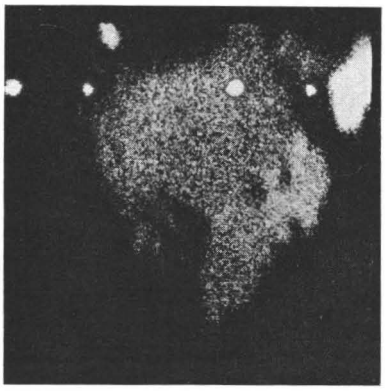


FIG. 23. The same grain as seen in Fig. 19. The distribution of niobium, which is very different from that of Ta (Fig. 21) and of U (Fig. 22). X-ray image. $NbL\alpha_1$. 470x.



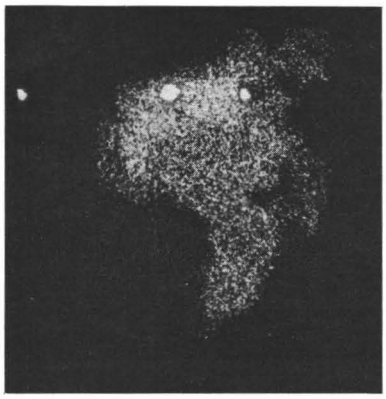


FIG. 24. The same grain as seen in Fig. 19. The distribution of calcium (left) and titanium (right). The former follows both Nb and Ta (Figs. 21 and 23), the latter mainly Ta (Fig. 21). X-ray image. $CaK\alpha$, and $TiK\alpha$. 470x.

TABLE 8

Distribution of Nb and Ta within the areas illustrated in Fig. 20 (areas 1 to 5) and in some single points of the figure area.

	1	2	3	4	5	single points				
Nb_2O_5 %	21	17	33	25	19	19	57	26	34	35
Ta_2O_5 %	2	8	3	2	8	8	3	8	26	7

This aggregate resembles very closely the grains of »radioactive columbite» of Verity examined by Heinrich (1962), which, according to him, are likewise complexely intergrown aggregates of different minerals, and especially submicroscopic mixtures of nonradioactive columbite and uranoan pyrochlore. In the case of the Honkamäki aggregate areas 5 and 6 of Fig. 20 may likewise be uranoan pyrochlore with approx. 2 % U_3O_8, but the rest of the grain consists of still more complex minerals.

— The composition of columbite was determined using the fraction 3f2 with the grain size — 60 mesh, from which a few grains were picked out under the binocular microscope. These grains were fixed onto a glass slide using Aquadag colloidal graphite and then analyzed with Geoscan. This method was succesfully used in the present work, and also, for instance, for identification of danalite, as well as for examination of lantanide-bearing grains. The results for columbite are given in Table 9.

TABLE 9

Semiquantitative analyses of columbite grains.

	1	2	3
Nb_2O_5	56	70	61
Ta_2O_5	2	2	2
FeO	16	20	18
MnO	2	3	2
Y_2O_3	2	1	2
TiO_2	1	1	1
CaO	×	×	none
Total	79	97	86

ON THE AGE OF THE GRANITE OF HONKAMÄKI

As was mentioned on p. 18, at least two morphologically different zircons were separated from the Honkamäki granite. One of them, zircon I, divided into two fractions by size, was analyzed by Dr. Olavi Kouvo at the laboratory for mass spectrometric analyses at the Geological Survey of Finland. Both the analytical and the age data of these zircon fractions are given in Table 10. These data are also plotted in a concordia diagram, Fig. 25. The two fractions (both the coarser and the finer than 0.075 mm) show a striking similarity pointing to an age of 2 050 m.y. The discordia curves are drawn for samples that are 1 900 m.y. and 2 050 m.y. old according to the data presented by Wasserburg (1963), whereby the diffusion took place under such conditions that D/a^2 increased linearly in proportion to the amount of radiation damage. The numerical data show an age range from 1905 to 2 025 m.y., and the concordia plot indicates a slight diffusion of lead, both points still remaining on the discordia curve of 2 050 m.y.

It is of interest to examine how this age obtained for the Honkamäki granite fits into the general picture so far obtained of the zircon ages of Finland.

Comparison of the zircon ages of the Karelidic and Svecofennidic orogenic belts shows that plutonic rocks associated with both belts crystallized at about the same time, 1 900 m.y. ago. The age data also strengthen the conclusion that rocks in the pre-Karelidic basement complex crystallized earlier, 2 800 m.y. ago. The most recent review concerning that problem including the mantled gneiss domes has been written by Kouvo and Tilton (1966, in press).

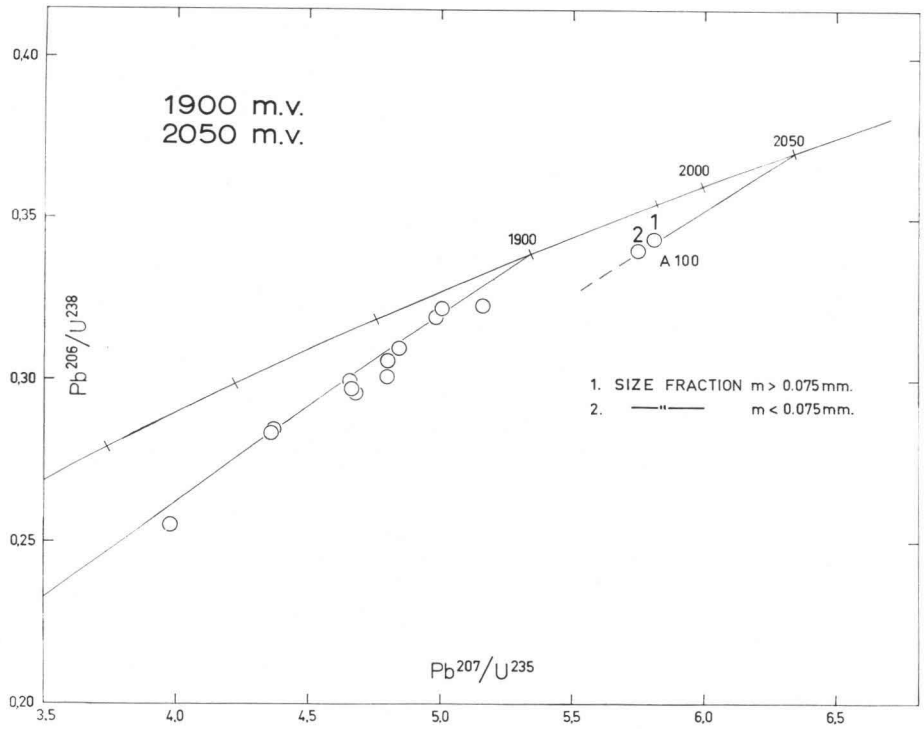


FIG. 25. Concordia diagram indicating also the position of zircon ages for the granite of Otanmäki (1 and 2). According to Dr. Olavi Kouvo.

TABLE 10

Age data for zircon from the microcline granite of Honkamäki, Vuolijoki

Fraction	U (ug/g)	Pb^{206} (rad.) (ug/g)	Isotopic abundance relative to Pb^{206}				Age in millions of years		
			Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}	U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}
m>0.075 mm	498	147	0.021	100	12.55	14.87	1 920	1 975	2 025
m<0.075 mm	501	146	0.014	100	12.44	14.83	1 905	1 965	2 025

Several common lead ages on galenas from the Finnish Precambrian (Kouvo 1958, Kouvo and Kulp 1961 and Kouvo, personal communication) show distinct groups as follows: 1 570 m.y. (rapakivi galenas), 1 850 m.y. (Svecofennian galenas), 2 100 m.y. (Karelidic galenas) and several older ages up to 3 000 m.y. connected with the pre-Karelidic basement rocks.

The nearest sulfide deposits to Otanmäki (Vihanti and Pyhäsalmi) show an average common lead age of 2 075 m.y. and 2 030 m.y. respectively.

Figure 25 indicates also a tight group of 1 900 m.y. zircons along the diffusion curve drawn for minerals that are 1 900 m.y. old. This group includes zircons from

both formations, Karelidic and Svecofennidic. The Otanmäki zircon is distinctly older than those. The nearly concordant age group of Otanmäki zircon gives support to the conclusion that the 2 050 m.y. age is near to the real age of that mineral.

In order to get a closer approximation for the disturbance of the Pb-U systems of this zircon, two cogenetic fractions were analyzed. Unfortunately, a sufficient difference in radioactivity was not found. However, one of the observable facts is that with the aid of this cogenetic pair of zircons one can find out that the points for both fractions really fall on the 2 050 m.y. diffusion curve.

The minimum age could be explained by presuming an episodic loss of lead, or a more complex event. In this case the points should lie in the field bounded by a chord connecting 1 900 m.y. and 2 800 m.y. on concordia and by the continuous diffusion curves for 2 800 and 1 900 m.y. old samples supposing that the real age is 2 800 m.y. (pre-Karelidic basement complex). This case has been discussed more thoroughly by Kouvo and Tilton (1966, in press). The results give, however, more support to the slight continuous diffusion as stated above.

The radiometric age data on zircon from Otanmäki granite do not agree with the earlier age data obtained for minerals from the Finnish Precambrian. It is interesting enough that the age is quite near to those obtained for the Karelidic galenas. Future age determinations will show if a plutonic event can be found which took place 2 050 m.y. ago.

The morphologic studies on the zircon crystals show a maximum length-frequency at 40—60 μ and maximum elongation-frequency at 1.4—1.6 (Fig. 26).

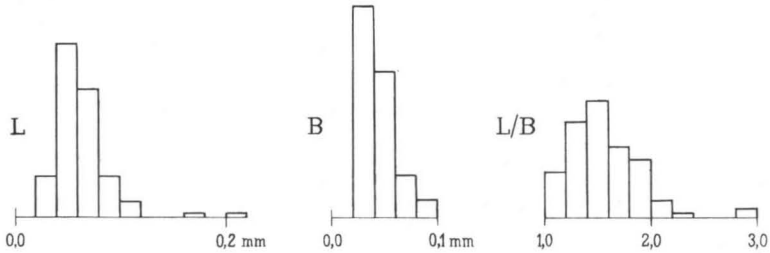


FIG. 26. Zircon size frequency histograms. 100 grains of »zircon I». Honkamäki granite, Vuolijoki.

CONCLUSIONS

The present study of the granites of Otanmäki, and in particular those of Honkamäki, revealed many interesting features which have bearings on granites in general.

Due to the scarcity and discontinuity of outcrops, the geological setting of the granite remained obscure. Its intrusive character can only be resumed. There is also some evidence in favour of the latekinematic character of the granite in question, and also indications that the emplacement of granite took place later than that of the adjacent ilmenite-magnetite ore-bodies. Furthermore, there are dykes and veins cross-cutting the ore-bearing formation, which are mainly composed of albitic plagioclase, and which behave in the mine very much in the same way as the granitc veins. Whether these two salic rocks also have a genetical relationship cannot be deduced from the field observations. It is, however, of interest, that according to the available chemical analyses (p. 14), Sr has been mainly enriched into the albitic rock, where Rb is absent but Rb is well represented in the granite.

Some hints as to whether or not the granite could originate from the same sources as the ore-forming material, can possibly be obtained from the fact that sphene and magnetite occur in both rock types. As far as the sphene of granite is concerned, it is chemically different from that occurring in the ore formation. A conspicuously high content of vanadium (0.6 %) is characteristic of the magnetite of the latter. The magnetite of the granite, on the contrary, contains less than 0.1 % of this element. Consequently, these two constituents do not give any support to the idea about a common source. It may also be mentioned that the lantanides present in granite (p. 21), are completely absent in the ore.

The mineralogical composition of the granite of Honkamäki is such that it suggests intrusion under hydrothermal conditions for the origin of this rock. This could also explain the inhomogeneity of the rock, which is probably due partly to discontinuous crystallization from the hydrothermal solutions and, in particular, to varying concentrations within the solutions under the prolonged duration of crystallization of the material involved.

In a sense the ages obtained for zircon of this rock (p. 28), approx. 2 050 m.y. are at variance with the latekinematic character of this granite. Unfortunately, there are no K-Ar or Rb-Sr ages available, but, on the other hand, for all the basement here involved, these ages are expected to be 1 800—1 900 m.y., as has been found everywhere in the Svecofennidic and Karelidic formations of Finland. For the galena-ages, on the contrary, the Svecofennidic ore bodies (earlier taken as older than Karelidic)

give ages of some 1 900 m.y., but those within the Karelidic zone give 2 050 m.y. which have not been found so far among the intrusive rocks. Thus the granite of Honkamäki is the first observed representative of an intrusion belonging to this age group. For the time being, this observation can be taken only as such, and one should refrain from expressing any conclusions along these lines until further facts and observations are available.

The chemical composition of the granite here under consideration is characterized by the presence of minor constituents not usually taken as belonging to the primary composition of a granite — that is, of a granite magma. Thus many authors have supposed that if in a granite, minerals such as apatite or sphene are present, they are products of »hybridization». On the other hand, granites of indisputable magmatic origin (e.g. the Younger granites of Nigeria) contain chracteristically such elements. It would be of interest to tackle this dispute and first of all try to find out why such opinions exist. This is not, however, the proper place for such a discussion. Maybe it is due to the fact that most of the granites studied are devoid of such accessory elements, and that examined rocks have been taken as magmatic without a critical review of the available arguments; or, it may be also due to the fact that such constituents as Rb, Sr, Nb, La etc. are seldom included in analyses of granites.

For the granites of Otanmäki, such constituents are present in all available analyses, and especially Nb_2O_5, ZrO_2, Rb_2O and lantanides, as well as fluorine, but unevenly distributed. As far as P_2O_5, TiO_2, ZrO_2 and F are concerned, they all form their own minerals entirely according to expectations. A hidden position in other minerals, in particular in sphene, has been proposed for Nb_2O_5 and lantanides. The present study indicates, however, that also these elements tend to form their own minerals — a finding which was possible here only because a modern technique could be applied to the study. This is an especially interesting result, because according to the earlier expectations (p. 20) the contents of the above mentioned elements in the granites in question are sufficient for these elements to occur as independent minerals. It appears that a careful examination of minerals — including accessories — may be of considerable importance for the granite problem in general. If the presence of such elements is characteristic of a restricted group of granites only, this finding is significant, and even more should it turn out that these elements do not always form own minerals. Consequently, the present study is challenging the petrologists to cope with new details and problems before proceeding with developing and theorizing the granite problems.

REFERENCES

ADAMS, JOHN W. and YOUNG, EDWARD J. (1961) Accessory bastnäsite in the Pikes Peak granite, Colorado. U.S. Geol. Surv. Prof. Paper 424—C, p. 292.

BLACK, RUSSELL (1965) Sur la signification pétrogénétique de la découverte d'anorthosites associées aux complexes annulaires subvolcaniques du Niger. C.R. Acad. Sci. Paris, t. 260, p. 5 829.

COLEMAN, R. G. and ERD, R. C. (1961) Hydrozircon from the Wind River formation, Wyoming. U.S. Geol. Surv. Prof. Paper 424—C, p. 297.

DEER, W. A., HOWIE, R. A. and ZUSSMAN, J. (1963) Rock forming minerals. Vol. 2. Chain silicates. London.

GINZBURG, A. I., editor, (1963) New data on rare element mineralogy. Consultants Bureau, New York.

GLASS, J. J. and SMALLEY, R. G. (1945) Bastnäsite. Amer. Mineral., vol. 30, p. 601.

GROSS, E. B. and HEINRICH, E. Wm. (1965) Petrology and mineralogy of the Mount Rosa area, El Paso and Teller Counties, Colorado. I: The granites. Amer. Mineral., vol. 50, p. 1 273.

HEINRICH, E. Wm. (1962) Radioactive columbite. Amer. Mineral., vol. 47, p. 1 363.

HYTÖNEN, K. and HEIKKINEN, A. (1966) Alkali amphibole of Otanmäki, Finland. Bull. Comm. géol. Finlande 222 (in press).

KOUVO, OLAVI (1958) Radioactive age of some Finnish pre-Cambrian minerals. Bull. Comm. géol. Finlande 182.

KOUVO, O. and KULP, J. LAURENCE (1961) Isotopic composition of Finnish galenas. Ann. N.Y. Acad. Sci., vol. 91, art. 2, p. 476.

KOUVO, O. and TILTON, G. R. (1966) Mineral ages from the Finnish Precambrian. J. Geol., vol. 74, (in press).

LARSEN, E. S. (1941) Alkalic rocks of Iron Hill, Gunnison County, Colorado, U.S. Geol. Surv., Prof. Paper 197—A.

LISITSINA, G. A. *et al* (1965):

Лисицина, Г. А. Богданова, В. И., Варшал, Г. И., Сиротинина, Н. А.: О некоторых геохимических особенностях образования акцессорных минералов в гранитах Чаркасарского массива в Кураминском хребте Тянь-Шаня. Геохимия 1965, 5, p. 602.

MARMO, VLADI (1962) On granites. Bull. Comm. géol. Finlande 201.

—»— (1966) Monzonitic hornblende granite NW of Tebo, Sierra Leone. Bull. Comm. géol. Finlande 222 (in press).

PAARMA, HEIKKI (1954) The ilmenite-magnetite ore deposit of Otanmäki. *In* The mines and quarries of Finland (ed. by E. Aurola). Geotekn. julk. 58, p. 36.

PÄÄKKÖNEN, VEIKKO (1956) Otanmäki, the ilmenite-magnetite ore field in Finland. Bull. Comm. géol. Finlande 171.

PÖSCHL, ARTUR (1964) Die Titanomagnetit-Lagerstätte Otanmäki in Finnland; Stoffbestand, Bau und Entstehungsgeschichte. Inaug. Dissert. Ludwig-Maximilians-Universität, München.

SHAND, S. J. (1949) Eruptive rocks. New York.

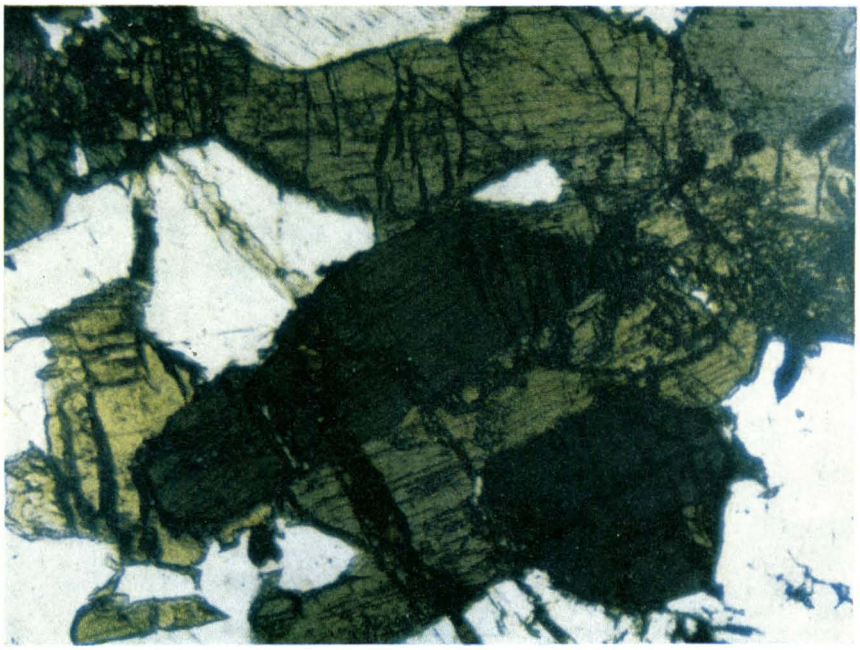
TRÖGER, E. E. (1959) Optische Bestimmung der gesteinsbildenden Minerale. Teil I. Bestimmungstabellen. 3. Aufl. Stuttgart.

VORMA, ATSO and HOFFRÉN, VÄINÖ (1965) On adelpholite and its relation to the minerals of the yttrotantalite-samarskite series. Bull. Comm. géol. Finlande 218, p. 201.

WASSERBURG, G. J. (1963) Diffusion processes in Pb—U systems. J. Geophys. Research, vol. 68, p. 4 823.

WINCHELL, A. N. and WINCHELL, H (1951) Elements of optical mineralogy, Pt. II, Description of minerals. New York—London.

ZWAAN, P. C., 1954, On the determination of pyroxenes by X-ray powder diagrams. Leidse Geol. Mededel., vol. 19, p. 167.



Granite, Honkamäki, N ||. Magn. 130x.