

# A SPECIALIZED TOPAZ-BEARING RAPAKIVI GRANITE AND ASSOCIATED MINERALIZED GREISEN IN THE AHVENISTO COMPLEX, SE FINLAND

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The Ahvenisto rapakivi complex is a satellite northwest of the large Wiborg rapakivi batholith in Southeastern Finland. The rapakivi rocks are surrounded by rapakivi-age gabbros, anorthosites, monzodiorites and diabases. The complex consists of a highly evolved suite of several texturally, mineralogically and geochemically different rapakivi types. They are anorogenic and their age is 1640–1630 Ma.

The youngest phases of the rapakivi suite are even-grained, topaz-bearing and geochemically specialized tin granites. They also show the characteristics of A-type granites. Earlier known rapakivi granites in Finland of the same type have been described from Eurajoki and Kymi.

These specialized Kuusisuo granites are highly evolved microcline-albite granites, which are modified by many (auto)metasomatic and late/postmagmatic alteration reactions. They have high Si, F, Li, Rb, Sn, Nb, Th and U, and low/extremely low Ti, Fe, Mg, Ca, P, Zr, Ba, Sr and La. They intrude earlier phases of rapakivi granites as a small cupola, which in its upper parts is altered to topaz-bearing rapakivi and mineralized topaz-greisen. Mineralized greisen veins occur in the surrounding rapakivi granites. The uneconomic mineralizations contain SnO and sulphides of Cu, Zn and As.

Key words: granites, rapakivi, topaz, greisen, chemical composition, tin, Proterozoic, Kuusisuo, Heinola, Finland.

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## Introduction

Rapakivi granites and associated diabase dykes, gabbros and anorthosites form a belt from the Ukraine over Fennoscandia, Greenland and Labrador to the central and southwestern parts of the United States. They are anorogenic and 1750–1400 Ma old (e.g. Emslie 1978, Anderson 1983). In Finland there are four large rapakivi batholiths, the Wiborg, Åland, Vehmaa and

Laitila batholiths, and several smaller, at times polyphase satellites, e.g. the Suomenniemi and Ahvenisto batholiths and the Eurajoki stock (Fig. 1).

The latest phases of the rapakivi granites in Finland have for a long time been known as potential tin granites. Uneconomic mineralizations of Sn, Be, W, Pb and Zn have earlier been described from the topaz-bearing, latest intrusive phases in Eurajoki in W Finland and in Kymi in

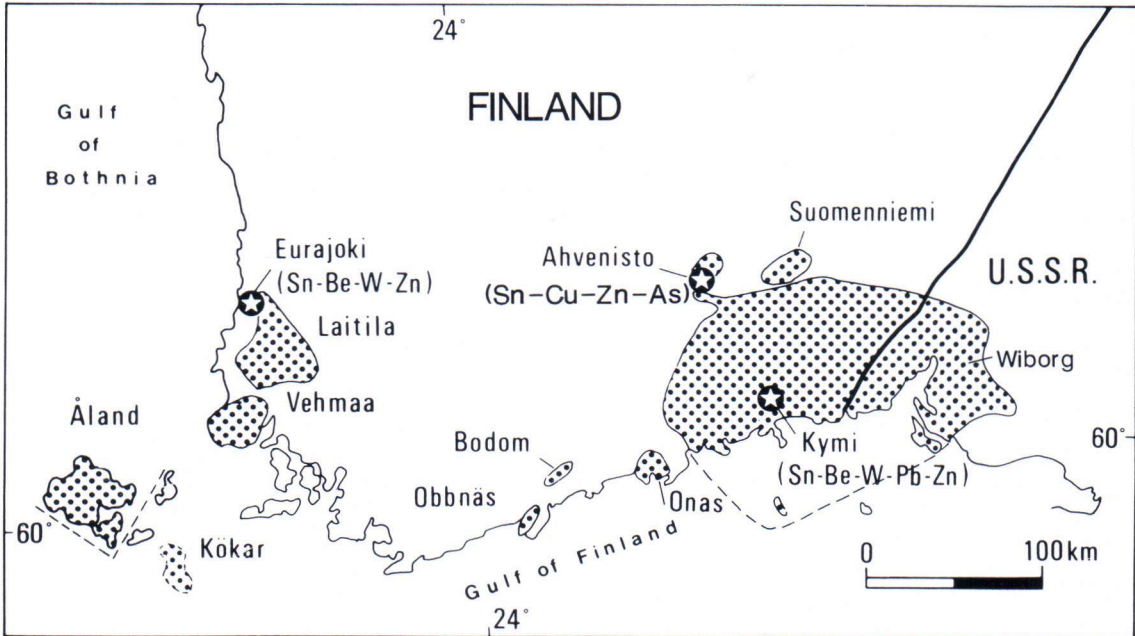


Fig. 1. The rapakivi granites in southern Finland and associated mineralizations (Nurmi & Haapala 1986, modified).

the Wiborg batholith (Haapala 1974, 1977a, 1977b, 1988) (Fig. 1). Mineralized greisen veins occur in the Åland batholith (Bergman 1981).

In 1978 Rautaruukki Oy, a steel and mining company, started prospecting for tin in the surroundings of the rapakivi areas. Geochemistry of the heavy-mineral fraction of till was used in the reconnaissance phase of this exploration. A distinct Sn anomaly was found in the southern parts of the Ahvenisto area and between this complex and the Wiborg batholith (Mattila and Peuraniemi 1980, Peuraniemi et al. 1984).

Further investigations in the Kuusisuo area in the southern part of the Ahvenisto rapakivi complex including detailed mapping, percussion drilling and diamond drilling, revealed greisen veins in the outcrops and mineralized greisen bodies associated with a previously unknown, topaz-bearing type of rapakivi in the drill holes (Edén 1980, 1987, Mattila 1983, 1985, Peuraniemi et al. 1984).

This paper describes the most evolved rapaki-

vi types in the Ahvenisto area. They consist of a topaz-bearing granite and its topaz-free parts, together called the Kuusisuo granites, and associated greisen. The slightly less evolved Mannila granites are also described. The older types of biotite rapakivi granite in the surroundings are only briefly discussed.

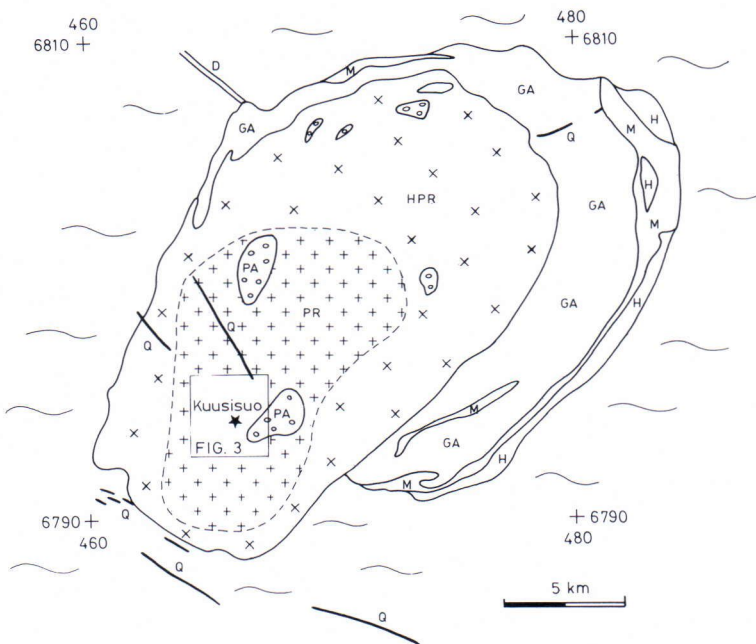
About 200 chemical analyses were made on XRF and AAS at Rautaruukki Oy in Raahe. Some micro-probe analyses were made with a JEOL JSM-35 instrument at the University of Oulu.

### The Ahvenisto Rapakivi complex

The entire Ahvenisto complex, including the basic members, has been described by Savolahti (1956). The biotite rapakivi granites occupy an area of about 240 km<sup>2</sup> and are in north and east surrounded by a horse-shoe shaped body of gabbro, anorthosite, (quartz)monzodiorite, dia-



Fig. 2. Geological map of the Ahvenisto complex (modified from Savolahti 1956, Johansson 1984). PR = porphyritic biotite rapakivi, HPR = hornblende-bearing porphyritic biotite rapakivi, PA = porphyry aplite, H = hornblende rapakivi, GA = gabbro-anortosite, M = (quartz)monzodiorite, Q = quartz porphyry, D = diabase.



base and a narrow body of hornblende rapakivi along the easternmost border (Fig. 2). The basic rocks are slightly older than the rapakivi granites, because the latter cut and brecciate the former (Savolahti 1956, Johansson 1984). A swarm of diabase dykes of approximately the same age as the rapakivi granites runs in a WNW direction from the complex (Laitakari 1987).

The rapakivi granites in the Ahvenisto complex are coeval with the main phases of the Wiborg batholith, and their age is 1640–1630 Ma. The latest phases may, however, be of approximately the same age as the Kymi cupola, which has been described as the youngest intrusion phase in the Wiborg batholith (Vaasjoki 1977, Vaasjoki et al. 1989). The Ahvenisto rapakivi complex is thought to be connected with the main batholith at a shallow depth. Laurén (1968, 1970) has interpreted gravity data as if beneath Ahvenisto there is a 18 km deep »root» of the otherwise 5–10 km thick, laccolith-like Wiborg batholith. According to the newest in-

terpretations of geophysical data, the Ahvenisto batholith is a cupola »standing up» above the sheet-formed Wiborg batholith (Elo and Tuomi 1989).

According to Savolahti (1956) a partly porphyritic biotite rapakivi forms the main part of the Ahvenisto complex. In the present author's opinion most of the rapakivi complex is porphyritic biotite rapakivi. The rock has angular, or sometimes rounded, megacrysts (1–3 × 3–6 cm) of K-feldspar in a coarse- to medium-grained matrix of K-feldspar, quartz, plagioclase and biotite-chlorite. The typical rapakivi texture, rounded megacrysts of K-feldspar with a mantle of plagioclase, is totally absent. At the borders of the complex abundant hornblende and sometimes even fayalite occur. Fluorite and in smaller amounts zircon, apatite and opaques are typical accessories. Sericite, chlorite and muscovite are common alteration products.

The biotite rapakivi consists of several intrusions or subphases. The inner parts of the com-

plex, at least in the south, are built up of geochemically more evolved phases. They are slightly finer grained, some are even-grained, and none contain hornblende (Edén 1980, 1987).

Small bodies of porphyry aplite occur in many places in the complex (Fig. 2). Mineralogically these rocks are identical with the porphyritic biotite rapakivi. The K-feldspar megacrysts are, however, both smaller and less abundant and occur in a fine- to medium-grained groundmass. Rounded quartz inclusions, myrmekite and graphic textures are common. The contacts with the porphyritic rapakivi can be either sharp, without chilled margins, or fully gradational.

The chemical composition of the porphyry aplites exhibits the same range of composition as the different types of porphyritic biotite rapakivi. Each porphyritic rapakivi phase seems to have its own chemically similar porphyry aplite. This has not, however, been exactly verified. Most porphyry aplites are horizontal or vertical sheet-like intrusions, probably formed during block movements.

Quartz porphyry dykes of varying length and width occur both inside and outside the rapakivi complex, but not in the area with the youngest rapakivi phases. Some aplites, and more seldom pegmatites, also occur.

The youngest intrusive phases, which occur in the southern part of the rapakivi complex, in Kuusisuo and its surroundings, are described below.

### **The Kuusisuo and Mannila granites**

This paper focusses on the small Kuusisuo area and its surroundings in the southern part of the Ahvenisto rapakivi complex (Fig. 2, 3). Here, unlike in the bulk of the complex, outcrops are very few. The granites are mostly late phases of biotite rapakivi and porphyry aplites and in many outcrops there occur greisen veins 0.5–10 cm wide.

In the NW part of the study area there are

some geochemically quite strongly evolved rapakivi granites, here called the Mannila granites. They include a wide variety of textural types but geographically they are restricted to a small area or to inferred fracture/ fault zones. They are either fine-grained and even-grained, medium-grained with a few phenocrysts of K-feldspar and quartz, or even coarse-grained and porphyritic. Mirolitic cavities and pegmatic bodies occur commonly, especially in the fine-grained type, and all types have some secondary topaz. The fine-grained types are younger than the porphyritic ones.

Several drill holes penetrated rock types previously unknown in the Ahvenisto complex. They consist of an even- and medium-grained rapakivi granite, which in its upper parts is topaz-bearing (Fig. 3, 4). In the uppermost parts it is altered to greisen and mineralized. These Kuusisuo granites represent the youngest intrusive phase in Ahvenisto, and may thus be of approximately the same age as the Yymi cupola. The Mannila granites are both chemically and spatially closely related to the Kuusisuo granites.

The full size of the Kuusisuo granites and their lower parts is not known, but the area penetrated by the drill holes is only about 100 × 100 m. The distribution of the greisen veins observed in outcrops and drill holes suggests that they form a long and narrow ridge or several bulges along the same axis in a NNE-SSW direction (Fig. 3). It is also uncertain, whether the granitic parts ever reach the surface. The greisenized upper part does so in two drillholes (R 4 and R 7) (Fig. 3, 4).

### *Petrography of the granites and greisens*

The coarse, porphyritic type of the Mannila granites cannot easily be distinguished macroscopically from the porphyritic biotite rapakivi. It is reddish and has white or glassy quartz. Certain identification is only achieved through chemical analysis.

All Mannila granites are quite strongly altered. The K-feldspar is strongly pigmented and altered



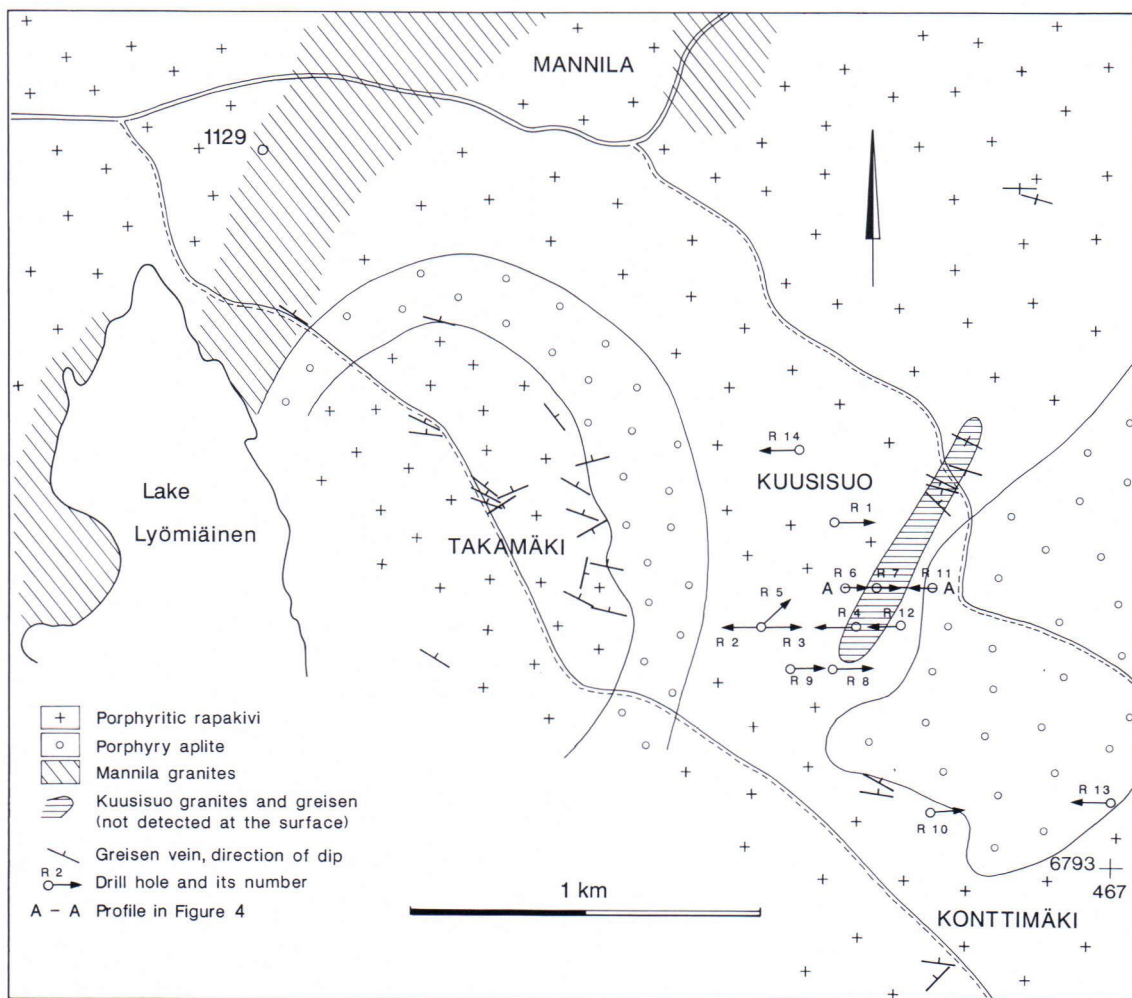


Fig. 3. Geological map of the Kuusisuo area.

to plagioclase, muscovite, chlorite and quartz. The plagioclase is either fresh and secondary albite or altered to sericite-muscovite. Chlorite and fluorite are also common alteration products. Some topaz is always found in thin sections and partly it seems to be primary. Zircon is absent.

The topaz-bearing Kuusisuo rapakivi granite and the topaz-free type, here called medium-grained rapakivi, are even-grained and medium-grained. In fact it is one and the same granite, which in its upper parts has undergone au-

tometasomatic and subsolidus reactions and become topaz-bearing. The medium-grained type has been found only in one drill hole (R 12), while the topaz-rapakivi is found in four holes (R 6, R 7, R 11 and R 12).

The Kuusisuo granites are reddish and their grain size is 1–2 mm. The main minerals are quartz, K-feldspar and plagioclase (Table 1). In the topaz-rapakivi topaz and biotite-chlorite also occur in amounts of about 5 % each. Instead it has 10 % less K-feldspar than the medium-

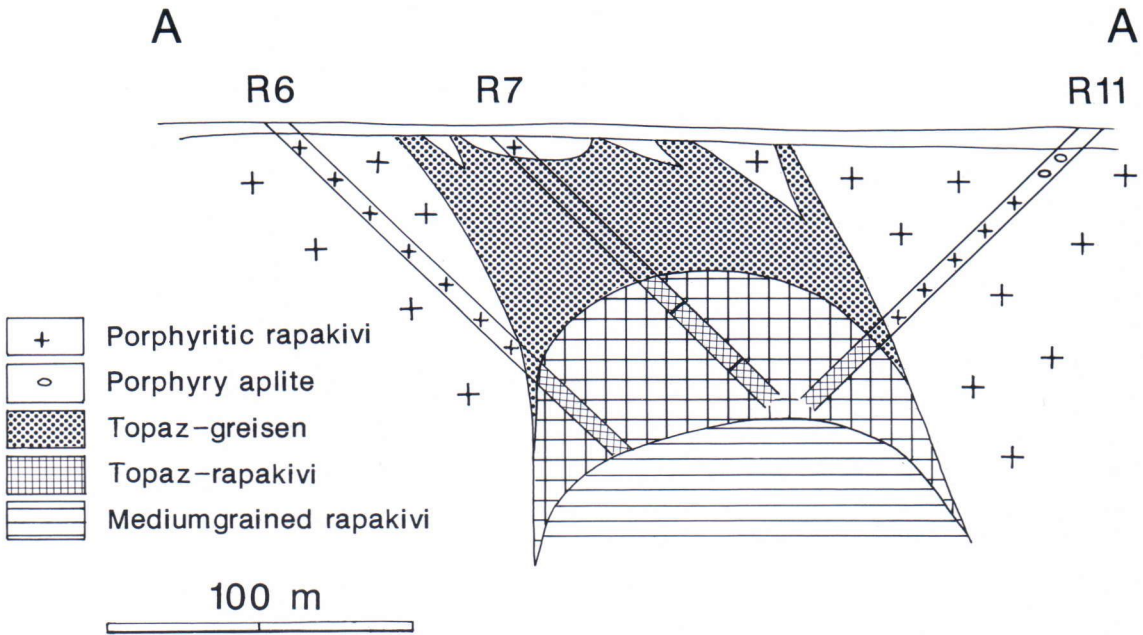


Fig. 4. Profile from three drill holes through the Kuusisuo granites and the topaz-greisen.

grained rapakivi. The medium-grained type contains very little mica, and most of it is muscovite. The topaz-rapakivi has 1.5 % fluorite, or twice as much as the medium-grained rapakivi. Both types have more plagioclase than rapakivi normally has.

Typical accessories are cassiterite and sulphides. In the topaz-rapakivi monazite is also frequently occurring. Zircon is almost totally ab-

sent. The topaz-bearing phases in Eurajoki and Kymi also have bastnaesite, ilmenite, columbite and thorite as typical accessories (Haapala 1974, 1988).

Both types of the Kuusisuo granites typically contain coarse-grained aggregates of quartz, feldspar, micas and varying amounts of fluorite, chalcopryrite, cassiterite, sphalerite, pyrite and arsenopyrite.

Quartz and plagioclase are subhedral-anhedral, while the K-feldspar fills the space between them. In places quartz grains up to 5 mm occur. The plagioclase is mostly clear albite, some is slightly altered to sericite. The K-feldspar in the medium-grained rapakivi is strongly pigmented and is often replaced by albitic plagioclase, but also by quartz and muscovite. Through the pigment perthite and less commonly, the cross-hatched twins of microcline can be observed. In the topaz-rapakivi the K-feldspar is more strongly altered and replaced by muscovite-chlorite, plagioclase, quartz, topaz and fluorite. Partly as a re-

Table 1. The modal composition of the Kuusisuo granites. Arithmetic mean and variation. (800 points)

	Topaz-bearing (6)	Mediumgrained (3)
K-feldspar	24.5 (18.6—34.4)	34.0 (27.5—39.2)
Quartz	33.9 (28.2—41.3)	34.2 (23.7—43.2)
Plagioclase	27.8 (21.0—31.3)	28.8 (25.5—34.0)
Biotite + chlorite	5.0 (0.8—7.5)	0.1 (0.0—0.3)
Muscovite	1.7 (0.2—5.0)	1.6 (1.2—2.3)
Topaz	5.0 (2.4—6.8)	0.0
Fluorite	1.5 (0.2—4.9)	0.7 (0.3—1.0)
Accessories	0.6 (0.5—0.6)	0.6 (0.5—0.7)
	100.0	100.0



sult of these alterations, there are more micas and less K-feldspar in the topaz-rapakivi than in the medium-grained rapakivi.

Topaz is partly primary and partly it replaces quartz and feldspars. It has a grain size of 0.02—2 mm. The smaller grains often occur in aggregates. Some topaz is altered to muscovite along fractures.

There are three types of mica. They are normal biotite or protolithionite, muscovite and green chlorite. Muscovite and chlorite usually occur as ragged intergrowths.

In an A-P-Q-diagram the granites would plot in the field of »normal granite» (Streckeisen 1967), when all plagioclase is counted as P. The fact, that a great part of the plagioclase is albite, with  $An < 5$ , should move the granites to the fields of syenogranite or alkali feldspar granite. As they hold less than 10 % dark minerals, they could also be called alaskites.

The rapakivi granites at Kuusisuo are greisenized in different ways and to varying degrees. Greisen veins occur in the outcrops and in almost all drill holes. Larger greisen bodies are penetrated in some drill holes.

In drill holes R 4 and R 7 a greisen body is penetrated for tens of meters. In hole R 6 it is about 10 m thick (Fig. 4). Topaz is typical for this greisen, and accordingly it is called topaz-greisen. This greisen is usually grey, medium-grained and homogenous; only seldom coarse-grained aggregates are observed. The topaz-greisen seems to change gradually downwards to topaz-rapakivi. This gradation is well displayed in drill hole R 7.

Quartz makes up about 50 % of the topaz-greisen, micas about 30 % and topaz about 15 %. Feldspars are almost totally absent. Topaz occurs both as aggregates of small grains and as bigger individual grains. The micas are the same as in the topaz-rapakivi, i.e. biotite or protolithionite and intergrown muscovite and chlorite. Accessory minerals are fluorite, monazite, cassiterite, chalcopyrite, sphalerite, pyrite, xeno-

time and arsenopyrite. The coarse-grained aggregates are enriched in ore minerals.

In the middle of hole R 3 and in the lower end of hole R 4 there is a 10—30 m thick rock type called sericite-greisen. Preserved relic textures show, that it is an alteration product of a porphyritic rapakivi. It has megacrysts (1—4 cm) of altered K-feldspar in a finer, heterogenous mass of sericite, fluorite, quartz, K-feldspar, chlorite and opaques. Monazite is a typical accessory, others are e.g. cassiterite and carbonate. Topaz is absent in this greisen type.

In the outcrops greisen veins 1—10 cm in width are found. In the drill holes there are also much thicker veins. Towards the outer regions of the investigated area, there are only thin streaks of greisen and quartz veins.

The greisen veins are dark grey and they usually have a seam of quartz in the middle. Sometimes there is also e.g. chalcopyrite or arsenopyrite in the seam. Mineralogically the veins consist of varying amounts of quartz in a fine-grained mass of sericite, muscovite, chlorite, fluorite and ore minerals. Topaz is commonly absent, although the veins look like topaz-greisen. In a few veins some topaz does occur, indicating stronger alteration and a closer similarity to the topaz-greisen.

#### *Geochemical characteristics*

Table 2 gives the chemical composition of the rapakivi granites in the Kuusisuo area. Rapakivi granites differ chemically from normal granites. At Kuusisuo, the difference is even more pronounced, due to magmatic differentiation and fractional crystallization. The K/Rb ratio in Table 2 is a distinct feature of the fractionation. While this ratio is over 160 for normal granites, the granites at Kuusisuo have much smaller ratios. The ratio of 59 for topaz-rapakivi is according to Groves and McCarthy's (1978) classification a sign of strong fractionation.

Geochemically specialized granites or tin-granites are associated with ores or mineralizations

Table 2. Chemical composition of the rocks in the Kuusisuo area given as arithmetic means.

	Porphyritic (44)	Mannila granites (10)	Medium-grained (4)	Topaz-rapakivi (26)	Topaz-greisen (47)
SiO <sub>2</sub> (%)	72.79	76.20	75.38	73.98	71.96
TiO <sub>2</sub>	0.24	0.09	0.014	0.017	0.019
Al <sub>2</sub> O <sub>3</sub>	13.35	12.37	13.60	14.03	14.37
Fe <sub>2</sub> O <sub>3</sub>	1.24	0.76	0.25	0.83	1.87
FeO*	1.40	0.88	0.27	1.04	3.67
MnO	0.04	0.02	0.01	0.04	0.14
MgO	0.17	0.04	0.00	0.01	0.01
CaO	1.02	0.59	0.65	0.70	0.96
Na <sub>2</sub> O	2.58	2.91	3.72	2.82	1.09
K <sub>2</sub> O	6.06	5.39	5.39	4.88	2.93
P <sub>2</sub> O <sub>5</sub>	0.06	0.02	0.02	0.01	0.01
Cu (ppm)	36	22	80	260	478
Zn	70	50	16	470	852
Sn	12	10	10	40	185
U	7	8	8	10	15
Th	62	63	42	40	28
Nb	35	39	72	80	82
Zr	327	180	78	70	66
Ba	391	160	75	70	43
Sr	65	35	20	20	27
La	78	63	12	20	< 10
Ce	209	180	92	100	82
Li	74(16)	64(8)	28	210	852
F	6772(36)	3950(8)	6000	14270	33080
Rb	404(25)	419(9)	455(2)	740(21)	1080(37)
K/Rb	126(25)	104(9)	92(2)	59(21)	
Mg/Li	15	12	< 1	< 1	< 1
Na/K	0.38	0.48	0.63	0.53	0.35
A/CNK	0.95—	0.99—	1.02—	1.07—	
	1.29	1.18	1.05	1.55	

\* Calculated from Fe according to Le Maitre (1982)

of e.g. Sn, W, Zn, Cu, Be and Li and have common geochemical characteristics distinguishing them from other granites (see Tischendorf 1977; Taylor 1979). The Kuusisuo granites exhibit many of these characteristics.

Compared with »normal» granites, the granites at Kuusisuo have high contents of SiO<sub>2</sub>, K<sub>2</sub>O, F, Rb, Li, Sn, Nb, U and Th. The contents still increase towards the youngest differentiates. Zr and Ce are high in the porphyritic rapakivi and the porphyry aplites, but are depleted in the late Mannila and Kuusisuo granites.

The granites are depleted in TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, FeO, MgO, CaO, MnO, P<sub>2</sub>O<sub>5</sub>, La, Ba and Sr. TiO<sub>2</sub>, MgO, Zr, La, Ba and Sr are extremely

low in the youngest phases. The ratios of K/Rb, Mg/Li and Na/K are also low. The latest phases, the Kuusisuo granites, thus have the geochemical features of tin-granites (cf. Tischendorf 1977).

There are two geochemically different and geographically separated porphyry aplites (not given in Table 2) in the Kuusisuo area (Fig. 3). The one in E-SE is geochemically identical with the porphyritic rapakivi, while the other one at Takamäki in W is geochemically less evolved.

The Mannila rapakivi granites fall geochemically between the porphyritic biotite rapakivi and the Kuusisuo granites with respect to most elements. But they have very low TiO<sub>2</sub>, MgO, CaO and P<sub>2</sub>O<sub>5</sub>, resembling the Kuusisuo granites in



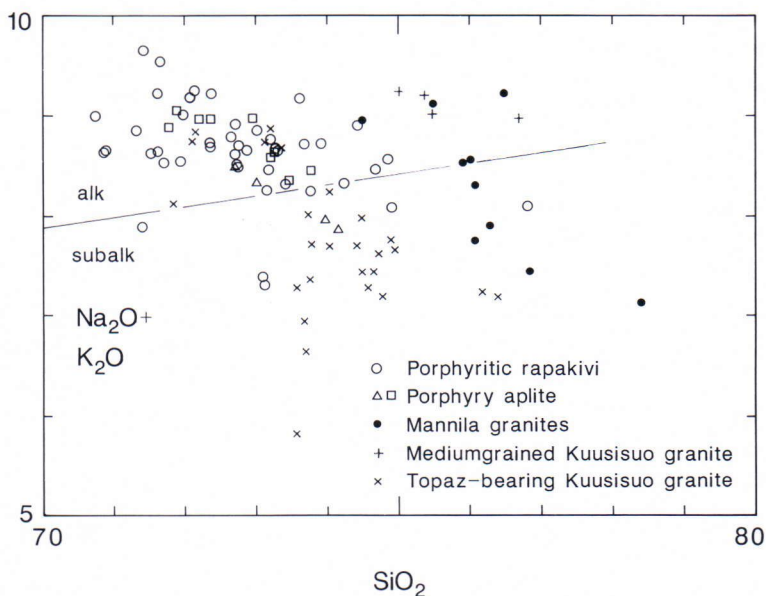


Fig. 5. Alkalies vs silica of the granites in the Kuusisuo area. The alkalic/subalkalic boundary from Miyashiro (1978).

this respect. On the other hand they have even lower contents than the porphyritic types of the otherwise high F and Li, resembling the so called precursors of tin granites (Tischendorf 1977).

Compared with the topaz-bearing rapakivi the topaz-greisen has lower  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , Ba, K/Rb and Na/K.  $\text{Fe}_2\text{O}_3$ , FeO, MnO, Sn, Li and F are much higher and S, Cu, Zn, U and Rb higher in the greisen. Most of these changes have started with the change from the medium-grained to the topaz-bearing type. The greisen veins show changes in the same elements but to a smaller extent, taking into account that the altered rock in this case is porphyritic rapakivi.

The topaz-greisen and the greisen veins have increased, in places highly increased, amounts of Sn, Cu, Zn, As, W, Bi, Li, F and Rb.

The rapakivi granites in the Kuusisuo area are subalkaline with distinct alkaline affinities (Fig. 5). The Na/K ratio is low overall, but increases in the youngest phases (Fig. 6). The granites have variable A/CNK values, but the youngest topaz-granites are distinctly peraluminous, having values  $> 1.1$ , while the medium-grained type and the Mannila granites usually have values  $< 1.1$

(Fig. 7). The wide variation is partly due to the alteration reactions, which have changed the contents of Ca, Na and K.

The granites, especially the latest phases, show A-type characteristics. Besides the characteristics already mentioned, the granites at Kuusisuo have e.g. high  $\text{SiO}_2$ ,  $\text{Na}_2\text{O} + \text{K}_2\text{O}$ , Fe/Mg, F, Zr, Nb and Sn, and low CaO, Ba and Sr (for a definition of A-type granites see Loiselle and Wones 1979, Collins et al. 1982, White and Chappell 1983). They also have corundum in their norms.

The abundances of  $\text{SiO}_2$ , Rb, Ta and Y show that the granites in Ahvenisto are within plate (WP) granites according to the classification introduced by Pearce et al. (1984).

## Discussion and conclusions

The evolutionary trend; porphyritic rapakivi and porphyry aplite — Mannila granites — medium-grained rapakivi — topaz-bearing rapakivi — topaz-greisen, is clearly evident from the geochemical composition. Particularly beautifully it appears in a Rb-K/Rb diagram and in the

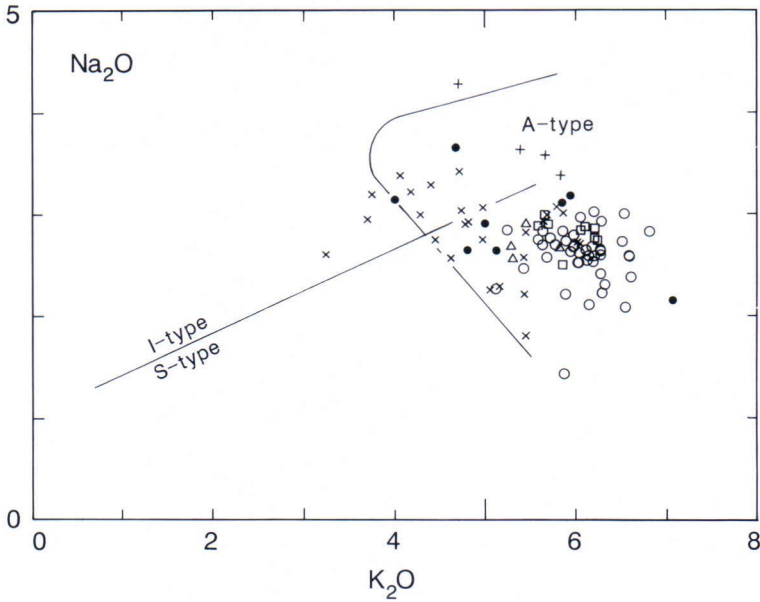


Fig. 6. Na<sub>2</sub>O-K<sub>2</sub>O diagram of the granites in the Kuusisuo area. I-S line and A curve based on White & Chappell (1983). Symbols as in Fig. 5.

trace element diagrams of Ba-Rb-Sr and Ti-Zr (Fig. 8, 9 and 10).

The evolution can be seen as a gradual change in chemical composition. Some oxides and

elements show a distinct gap between different granite types, while others are overlapping. Besides the evolution from type to type, there is also fractionation within the different phases.

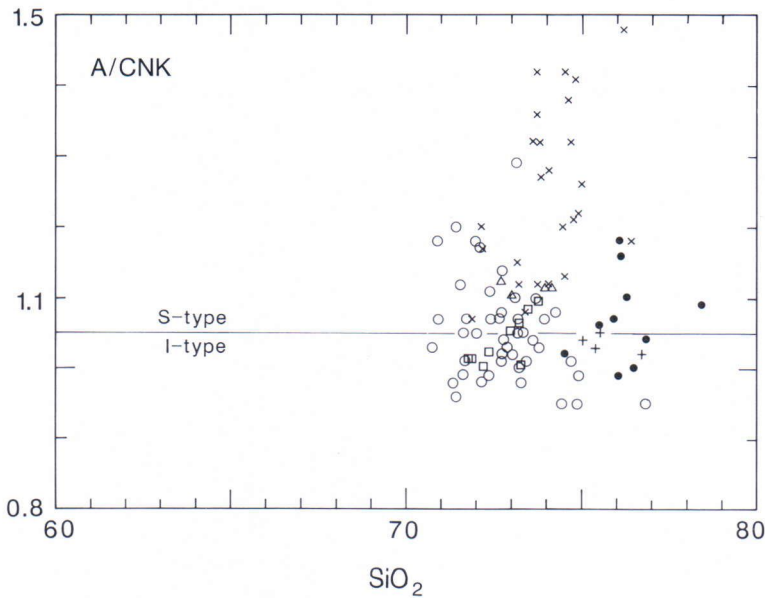


Fig. 7. Alumina saturation-silica diagram of the granites in the Kuusisuo area. I-S line after White & Chappell (1983). Symbols as in Fig. 5.



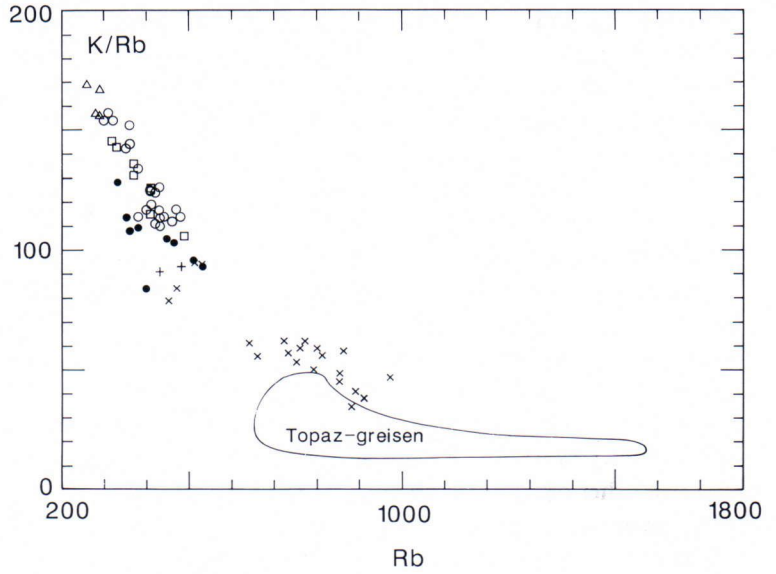


Fig. 8. Rb-K/Rb diagram showing the fractionation of the granites in the Kuusisuo area. Symbols as in Fig. 5.

(Auto)metasomatic and postmagmatic alteration reactions have worked in the same direction, narrowing the possible gaps in composition. This may explain why the Manila granites overlap the

Kuusisuo granites in some diagrams. They have been altered by the same fluids, and thus the Manila granites also have minor topaz, some of which, however, seems to be primary.

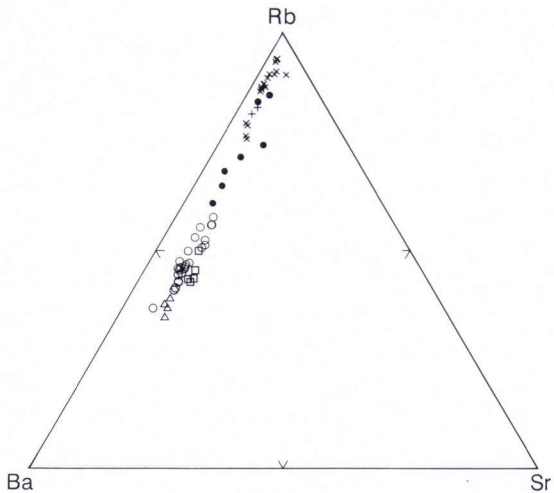


Fig. 9. Rb-Ba-Sr diagram showing the trends of the granites in the Kuusisuo area. Symbols as in Fig. 5.

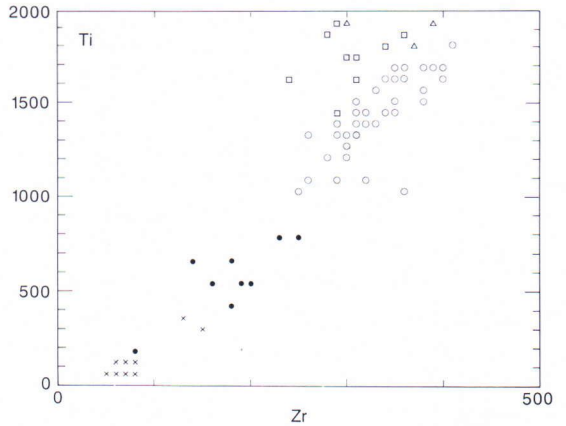


Fig. 10. Ti-Zr diagram showing the trends of the granites in the Kuusisuo area. Symbols as in Fig. 5.

The Mannila granites are thought to be early crystallized parts or subphases of the same magma that formed the Kuusisuo granites. The coarse-grained, porphyritic type has intruded first along fractures in the porphyritic biotite rapakivi. The fine-even-grained type also occurs as dykes in the coarse-grained type, and must be younger. There are, however, no chilled borders between them. They have to a great extent intruded along the same channels. The even-grained type has abundant miarolitic cavities and pegmatitic bodies, indicating the separation of an aqueous phase. The medium-grained type with some phenocrysts could be a mingling product of the two other ones, because locally it has diffuse fragments of the porphyritic type or clusters of K-feldspar phenocrysts. This granite type makes up most of the Mannila granites.

The Kuusisuo granites are on the whole geochemically much more evolved than the Mannila granites. They have lower Ti-, Fe- and Mg-oxides, Li, Zr, Ba, Sr and La, and higher CaO, Na<sub>2</sub>O, Nb, F and Rb than the older phases have (Table 2, Fig.11). The Fe-oxides, Li, Cu and Zn increase abruptly from the medium-grained granite to the topaz-rapakivi and -greisen. Na increases in the Mannila and the medium-grained granites, but decreases strongly in the topaz-bearing phases. SiO<sub>2</sub> changes in the same way, but very moderately. K<sub>2</sub>O decreases continuously.

The Kuusisuo stock reached an impermeable roof, which is shown by a relatively thin pegmatite of Stockscheider type at the contact with the older porphyritic rapakivi types. Water- and volatile-rich rest-solutions, also enriched in F, Li, Rb, Nb and metals, were trapped under this roof, altering the already crystallized granite to topaz-rapakivi and -greisen. In some places the solutions were isolated in pockets and are now seen as the coarse-grained aggregates of quartz, feldspars, micas, fluorite, topaz and ore minerals. Now and then the fluid pressure rose so high, that it caused fractures in the overlying rocks. The solutions entered the fractures and caused alteration — the greisen veins — in the surrounding

rapakivi. The fractures were sealed and the process started again. This was repeated a few times, producing several generations of greisen veins (cf. Plimer 1987).

The chemical compositions and the diagrams show that the Kuusisuo granites in drill hole R 12 are less fractionated than in holes R 4, R 6 and R 7, where they reach their highest elevation. The Mannila granites reach the surface and resemble very much the granites in hole R 12. They are thought to represent a block later uplifted relative to the Kuusisuo block.

The fractionation is reflected by the K/Rb ratios, which are: Mannila granites 106, topaz-rapakivi in hole R 12 88, in R 6 59 and in R 7 45. The topaz-greisen has a K/Rb ratio of 23. Of the Mannila granites, the aplitic one in outcrop -1129 (Fig. 3) has the most evolved chemical composition. In many of the diagrams it lies in the same area as the Kuusisuo granites.

A profile of the penetrated parts of the granites in Kuusisuo is drawn in Figure 4. The drill holes go down to 80—100 m vertical depth. The contacts between the different rock types are all gradual and diffuse. Greisenized zones also occur in the topaz-rapakivi and vice versa. The greisen in drill hole R 7 is much more altered and mineralized than in hole R 4, the uppermost parts of which are eroded away.

The greisens with the strongest alteration that occur in the uppermost 2/3 of drill hole R 7 and in the center of hole R 4 have Li 0.1—0.2 %, Rb >0.1 %, F 2.5—5 % and occasionally high Zn, Cu and Sn. In the upper part of R 4 there are also high values of Ag (four analyses 8—13 ppm), As (600—1200 ppm) and W (500—800 ppm). A greisen body in the topaz-rapakivi in R 6 has Cu 0.5 %, Zn 0.3 % and As 0.5 %. None of the greisens are sufficiently enriched to be of economic interest.

The highest metal contents have been found in the greisen veins. One vein in Takamäki has Fe 18 %, Cu 1.2 %, Bi 0.2 %, Sn 0.04 % and Pb 0.03%, while another one has As 1.4 % and Sn 0.04 %. The highest Sn-contents are in drill



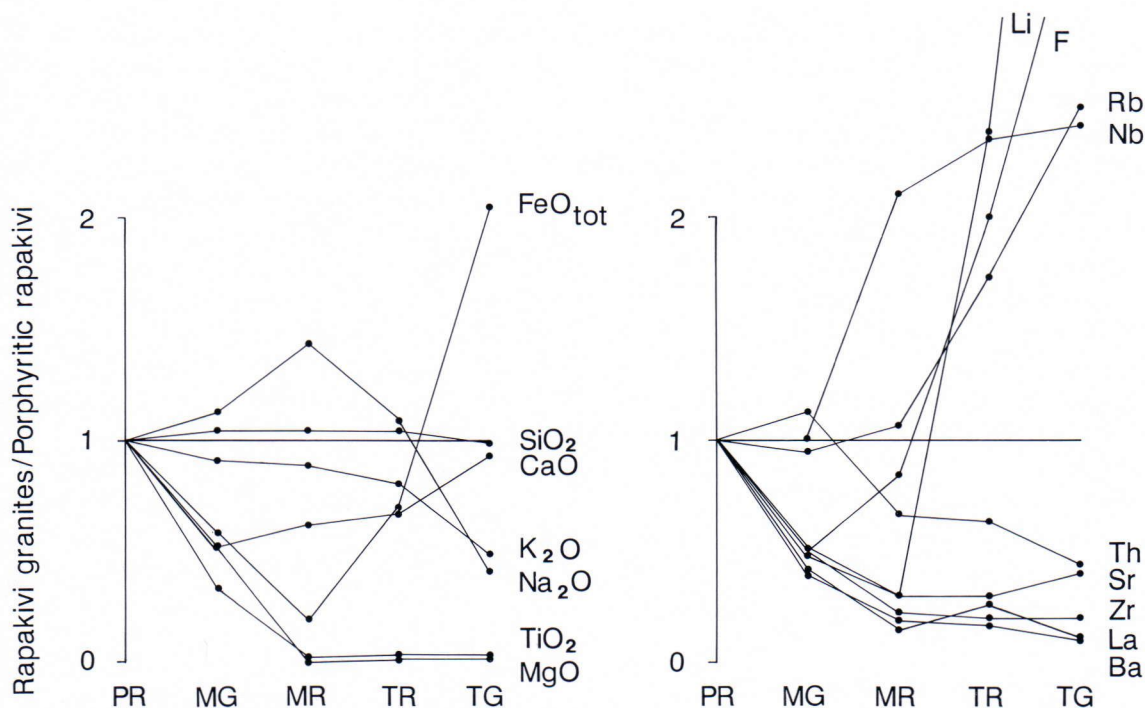


Fig. 11. The trends of some oxides and elements in the evolution of the rapakivi granites in the Kuusisuo area normalized against the porphyritic rapakivi. PR=porphyritic rapakivi, MG=Mannila granites, MR=medium-grained rapakivi, TR=topaz-rapakivi, TG=topaz-greisen.

hole R 10, while R 5, R 8 and R 9 has high Cu and Sn in some of their veins. The greisen veins in hole R 14 have high Zn (0.1–0.7 %).

There is no evident zonation of ore minerals in the greisen veins. Only in drill holes R 12, R 13 and especially in R 14 Zn is much more abundant than Cu. This indicate that the veins are far away from the source (cf. Strong 1988). Otherwise the veins have varying amounts and ratios of Sn, Cu, Zn, As, W and Bi. This probably depends on the several generations of greisen veins and on the block movements that seem to have taken place in the Kuusisuo area.

The rapakivi granites at Kuusisuo are of the same type and show the same characteristics and evolution as the Eurajoki and Kymi rapakivi granites described by Haapala (1977a, 1977b, 1988). One slight difference is the absence of Be-minerals in the greisens at Kuusisuo. The evolu-

tion at Kuusisuo is also much the same as in the models of mineralizations associated with granites, worked out by e.g. Pollard and Taylor (1986), Plimer (1987) and Strong (1988).

The rock association in the Kuusisuo area is the result of (at least) two different processes. The evolution trend: porphyritic rapakivi and porphyry aplites — Mannila granites — medium-grained rapakivi — topaz-bearing rapakivi — topaz-greisen, is evident from field observations and from the geochemical compositions (Table 2, Fig. 11). In particular the steady decrease of the Ti- and Mg-oxides and the trace elements Zr, Ba, Sr and La in this series, is consistent with a primary magmatic differentiation trend. This primary trend is well shown by the diagram of the immobile elements Ti and Zr (Fig. 10).

The element distribution in the late stage Kuusisuo granites suggests that the primary trend is

overprinted by late/post-magmatic processes (Fig. 11). F, Rb and Nb increase rapidly, beginning in the Mannila granites. Li, Fe, Cu and Zn increase even more steeply in the phases younger than the Mannila granites. These changes are due to the crystallization of the latest rest-solutions and perhaps also to the influx of new solutions from outside. The solutions also cause the strong alteration reactions.

Li, F and Fe are enriched in the dark mica (protholithionite), F also in the topaz and in the fluorite together with Ca. Fe, Cu and Zn increase because of the growing amounts of ore minerals. Nb can be incorporated in the mica and in casiterite (e.g. Haapala 1988).

The medium-grained granite has very small amounts of dark mica-chlorite, which also explains the very low abundances of Li, Fe, Ti and Mg. The slight increase of Mg and Ti in the topaz-*rapakivi* reflects the higher content of dark mica and chlorite.

Rb is concentrated in the latest rest-solutions as a result of magmatic differentiation and fractional crystallization. The amount of Rb in K-feldspar and micas can rise to much higher values in the late stage differentiates (Heier and Billings 1970). This explains the high Rb in the latest phases although the total amount of K-feldspar is less.

The unusual composition of the late magmatic phases has also had its own effect on the mineralogical and chemical composition. The magma forming these late stage granites was rich in volatiles, especially water and F, which lowered both the viscosity and crystallization temperature of the magma and produced granites, that contain microcline and albitic plagioclase (Manning 1982). In Figure 11 this mineralogical composition is reflected as a decrease in Ca and increase in Na. The most obvious indications of the high F-content of the magma are the fluorite, topaz and F-rich mica, which characterize these rocks.

In the latest phases Na decreases, however, due to the breakdown of the plagioclase in the greisenizing processes. Ca increases because the

amount of fluorite grows in the latest phases. K also decreases when the feldspars are destroyed.

The numerous alteration reactions; albitization, silicification, muscovitization, chloritization and topazization, show that the Mannila granites have also been affected by the same type of alteration that have produced the topaz-*rapakivi* and -*greisen*. In the Mannila area there was no elevation in the roof of the granite, where hydrothermal solutions could have concentrated in greater amounts. The Kuusisuo granites situated at fractures enabling the additional influx of solutions from outside.

According to Plimer (1987) the first subsolidus metasomatic event in the described type of granites is that of K-feldspathization. This is usually overprinted by intense albitization in the apical parts of the granite. These albite-rich metasomatites commonly contain Li and F minerals, e.g. protolithionite, topaz, fluorite and abundant quartz. This albitized granite also undergoes greisenization in the apical parts. The greisens are tabular, stockwork or sheeted bodies. This process replaces feldspars with quartz, muscovite, Li-micas, F-minerals and ore minerals. The petrology and mineral assemblages suggest that these types of processes also have been acting at Kuusisuo.

The overlying rocks have been hydrofractured by the greisenizing fluids. The greisen veins have a scatter of orientations and abundances, but in different directions. The large size, the unusual abundance and the mineralization of the greisen veins in the outcrops at Takamäki and near drill hole R 10 in Konttimäki, might indicate other cusps like Kuusisuo.

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