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Excursion A2

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**Matti Vaasjoki and Tapani Rämö**

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Cover: Wiborgite
University of Helsinki, Mineralogical Museum, Helsinki

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# THE FINNISH RAPAKIVI GRANITES: A REVIEW OF FACTS AND FANCIES WITH AN EMPHASIS ON THE WIBORG BATHOLITH

## DEFINITIONS AND NOMENCLATURE

For some centuries, geoscientists working in southern Finland have recognized large granitic bodies disrupting the patterns of the surrounding rock types (Fig. 1). Even before any geological investigations, the local people had noticed their conspicuous pattern of weathering and called the rocks "rapakivi", which literally means crumbly rock or stone. The name was noted by Urban Hjärne in 1694, and a few decades later another Nordic naturalist, Daniel Tilas, described from the Laitila area the occurrence of crystals now known to be the result of the weathering. As these could be picked up in fields, he called them "fältspat" - the first recorded use of the word feldspar.

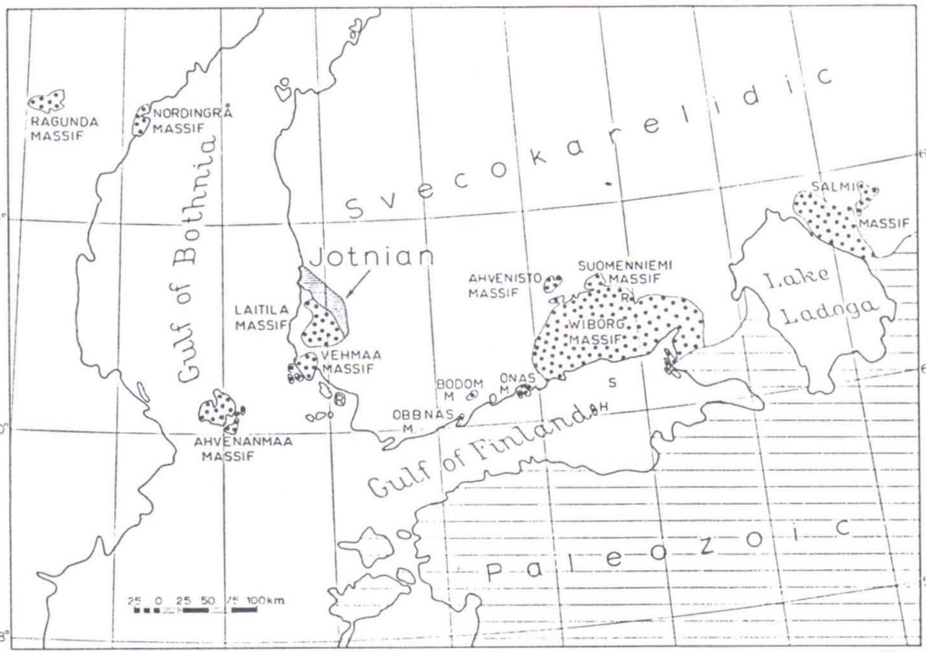

Fig. 1. The location of the rapakivi type rocks in the Fennoscandian Shield. H. Hogland; S, Someri; R, Ruoholampi; Ö, Östersundom. From Vorma (1976).

One of the founding fathers of modern Finnish geology, J.J. Sederholm (1891), defined the term "rapakivi texture" from the Wiborg area. According to him it involves the following elements:

- alkali feldspar crystals of ovoidal shape,
- mantling of the ovoids by oligoclase-andesine shells, usually 1-3 mm thick, although some ovoids remain unmantled
- the ubiquitous occurrence of two generations of alkali feldspar and quartz.

When the abundance of mantled ovoids in a rock exceeds that of unmantled ones, the typical rapakivi (or wiborgitic) texture results. When the unmantled ovoids predominate, the texture is called pyterlitic. However, all rapakivi batholiths also contain even-grained varieties. In these the diagnostic feature is usually euhedral (or drop) quartz.

After Sederholm, the Wiborg rapakivi complex was studied by by several authors but most extensively by Wahl (1925, 1936 and 1947) and Hackman (1934), and since the 1950s it has been mapped at a scale of 1:100,000 by the Geological Survey (Simonen, 1987). As a result, several different types of rock belonging to the rapakivi suite have now been recognized. Names commonly used for these rocks are:

Wiborgite: The typical rapakivi, i.e., hornblende granite in which K-feldspar phenocrysts are ovoidal in shape and mantled with plagioclase. This variety forms almost 80% of the Finnish part of the Wiborg rapakivi complex.

Pyterlite: A porphyritic biotite granite in which the K-feldspar phenocrysts are ovoidal in shape but not mantled with plagioclase. It usually grades over into wiborgite.

Porphyritic rapakivi: a biotite granite with angular phenocrysts.

Tirilite: a fayalite-bearing, even-grained darkish hornblende granite of medium coarseness.

Even-grained rapakivi: usually biotite granites found within the rapakivi batholiths.

As well as these rocks, there are porphyry aplite, granite porphyry, quartz porphyry, pegmatite and aplite dykes and even-grained topaz-bearing granites with associated greisen formation.

Note that the above nomenclature derives from the Wiborg complex and is strictly applicable only in that region. The main rock type of the Laitila batholith in western Finland, although texturally a pyterlite, is mineralogically a hornblende granite and geochemically more like a wiborgite.

## CONTACT RELATIONSHIPS AND CONTACT PHENOMENA

In southern Finland, the rapakivi granites cross-cut the 2.0-1.8 Ga old Svecofennian, which comprise metasediments and metavolcanics intruded by igneous rocks, deformed and migmatized during the Svecokarelian orogeny 1.9-1.8 Ga ago. When visible, the contact characteristics of the rapakivi granites vary considerably: sometimes the contact is sharp, but in places the size of the feldspar ovoids decreases towards the contact, and occasionally even-grained contact varieties occur. In some outcrops, the rapakivi granites brecciate the country rocks. Thus the rapakivi granites are post-tectonic in respect to the Svecokarelian orogeny.

The migmatitic country rocks display mineral assemblages of low-pressure amphibolite facies, and thus their mineralogy resembles that of the contact metamorphic hornblende-hornfels facies. Only rarely are mineral assemblages of the pyroxene-hornfels facies representing an innermost contact zone observed. The occurrence of hypersthene in these rocks indicates metamorphic temperatures in excess of 700°C, which led Vorma (1972) to contend that the Wiborg rapakivi complex was emplaced at temperatures of about 800°C.

Vorma (1972) studied orthoclase-microcline inversion in the Svecofennian rocks surrounding the Wiborg complex, and found a thermometamorphic aureole around it. Measured perpendicular to the contact surface, the aureole is <5 km wide in the NE corner of the complex, and it is slightly narrower in the west . Around the Onas, Mäntyharju and Suomenniemi satellite bodies the aureole is only a few hundred metres wide, but between the Wiborg and Mäntyharju complexes there is an extensive area characterized by orthoclase, suggestive of a rapakivi granite intrusion at depth (Fig. 2).

The contact metamorphic aureole defined by orthoclase-microcline inversion indicates an age relationship between the Wiborg batholith and the Mäntyharju and Suomenniemi satellite bodies: the orthoclase zone caused by the Wiborg complex passes through the Suomenniemi intrusion, but forms a continuous rim around the Mäntyharju batholith (Vorma 1972). Thus Suomenniemi would have been the first body to intrude the Svecofennian formations, but Wiborg and Mäntyharju are more or less coeval.

The internal age relationships of the Wiborg complex can be deduced to some extent from the contact relationships. In the Lappeenranta area, tirilite grades into the Lappee granite, which is clearly brecciated by wiborgite; elsewhere quartz porphyry dykes exhibit chilled margins against wiborgite. These observations and other considerations led Vorma (1971) to suggest that the intrusive sequence was 1) the tirilite and its associates, 2) the wiborgite and the pyterlite, 3) the Jaala-Iitti dyke (a porphyritic hornblende granite dyke cutting both earlier rapakivi granites and Svecofennian country rocks on the northwestern flank of the complex) and 4) the porphyry dykes.

## GEOCHEMISTRY

Paul Niggli (1923) was probably the first to define a rapakivi magma type. He distinguished calc-alkaline, sodic and potassic magma series, and divided the last one into many magma groups, the rapakivi magma type belonging to the granitosyenitic group. The rapakivi magma type was characterized by the following set of Niggli values: $si \approx 380$, $al \approx 40$, $fm \approx 18$, $c \approx 9$, $alk \approx 33$, $k \approx 0.50$ and $mg \approx 0.27$. Accordingly, the rapakivis are silicic magmas rich in $K_2O$ and low in MgO.

Sahama (1945) studied the trace element contents of the rapakivi granites. According to him, the rapakivis are highly enriched in fluorine, zirconium, hafnium, barium, rubidium and lead and slightly enriched tantalum and REE. Lithium and cesium are less abundant than in granites in general.

Vorma (1976) discussed the results of 225 chemical analyses representing all rapakivi occurrences in eastern Fennoscandia. The three major batholiths he considered in detail were the Wiborg, Laitila and Salmi (USSR) complexes. Comparing them, he found that:

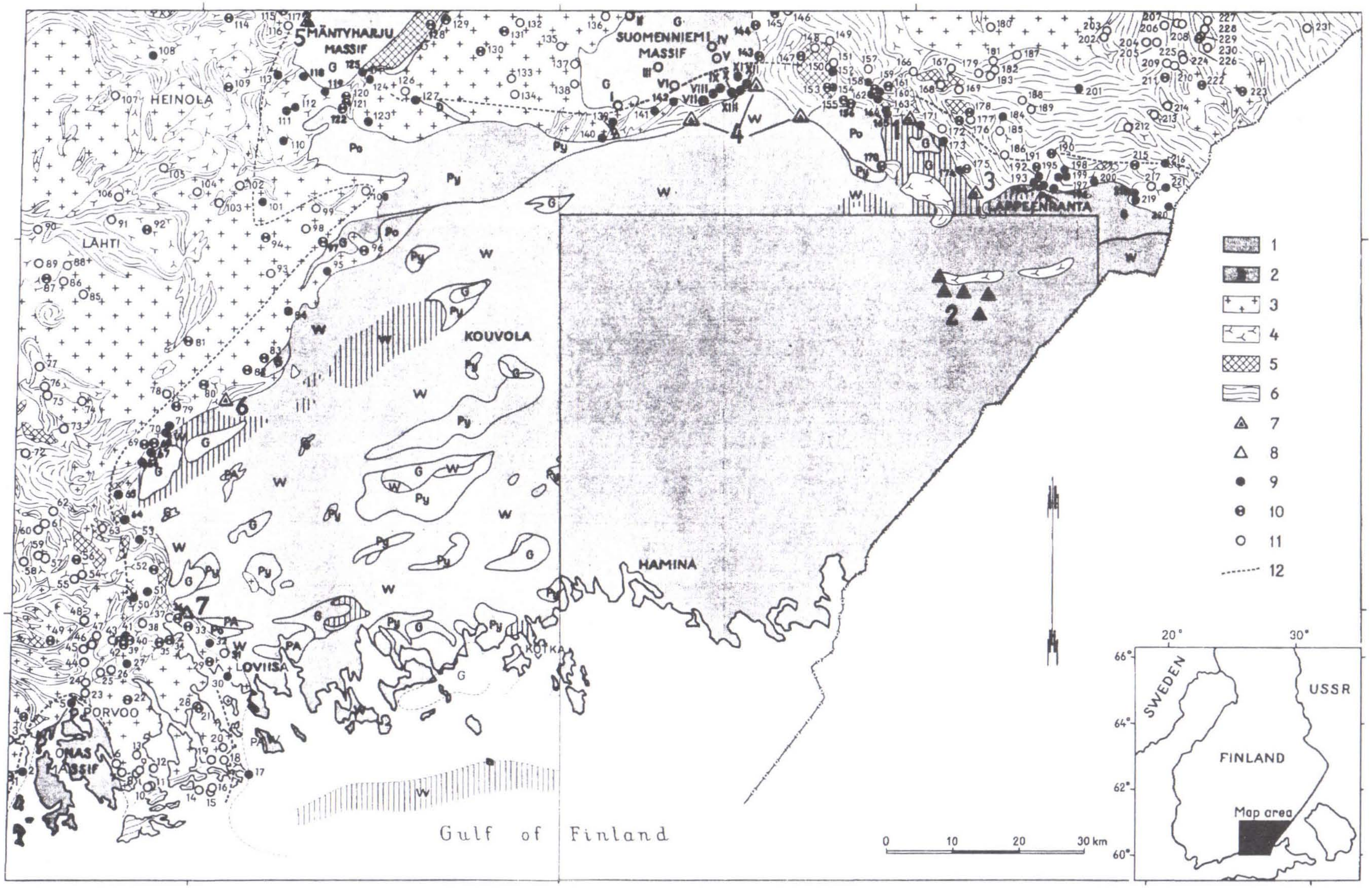

Fig. 2. The Orthoclase aureole around the Wiborg batholith and its satellite bodies. From Vorma (1972).

- the Wiborg batholith is considerably richer in CaO, slightly richer in $TiO_2$ and somewhat poorer in $Al_2O_3$ than the smaller Laitila and Salmi complexes;
- the Wiborg batholith is more differentiated than the other two;
- differentiation took a different course in the three areas: in the Wiborg batholith, $K_2O$ seems to increase with increasing $SiO_2$, and in the Salmi batholith, there is a marked decrease in $K_2O$ with increasing $SiO_2$. The Laitila batholith is intermediate between the other two;
- the Wiborg and Laitila batholiths have similar fm curves, but the Salmi complex has slightly higher fm values than the Wiborg area. At low si values, the Laitila rocks show higher fm values than the Wiborg and Salmi rapakivis, but with increasing si, the fm in the Laitila area decreases more rapidly; with si values higher than 350 it shows considerably lower fm values than the other two batholiths (Fig. 3).

When comparing the results from the three rapakivi batholiths with earlier findings, Vorma (1976) concluded that Niggli's rapakivi magma type was inaccurate in the two most characteristic points: the correct k value was higher and the mg value much lower than the values proposed earlier, and thus the rapakivi granites were even more extreme in their chemical composition than was previously thought. In the current nomenclature, rapakivi granites belong to the A-type (Nurmi and Haapala, 1986).

Vorma (1976) also called attention to the work of Wahl (1925), who had proposed separate wiborgite and pyterlite magmas. On the Ab-Or-Qu diagrams the Wiborg batholith exhibits two distinct maxima, a feature which is lacking from either the Laitila or the Salmi complexes. Vorma concluded that the compositional gap within the Wiborg batholith may indicate two magma types, but that it might also be due to inadequate sampling. Another alternative was that the rapakivi magma was either strongly differentiated or the rapakivitic melt was never thoroughly homogenized.

An important difference between the three rapakivi complexes discussed by Vorma (1976) is the high CaO and $Na_2O$ abundances in the Wiborg batholith as compared with the Laitila and Salmi batholiths, which may explain the common occurrence of wiborgite texture in the Wiborg batholith and its rarity and incomplete development in the rocks of the other batholiths. Apart from the CaO content, the general chemical composition of the Laitila batholith is closer to the wiborgites of the Wiborg batholith than to the pyterlitic varieties (Fig. 4), which is why Vorma (1976) maintained that the nomenclature used in the Wiborg area should not be applied elsewhere.

Although few up-to-date trace element data are available on the Wiborg batholith, Vorma (1976) has reported extensively on the trace element variations within the Laitila complex. He noted that the average phosphorus content of the rapakivi granites in that region are considerably lower (0.074%) than those reported by Sahama (1945), who had based his work on the Wiborg batholith.

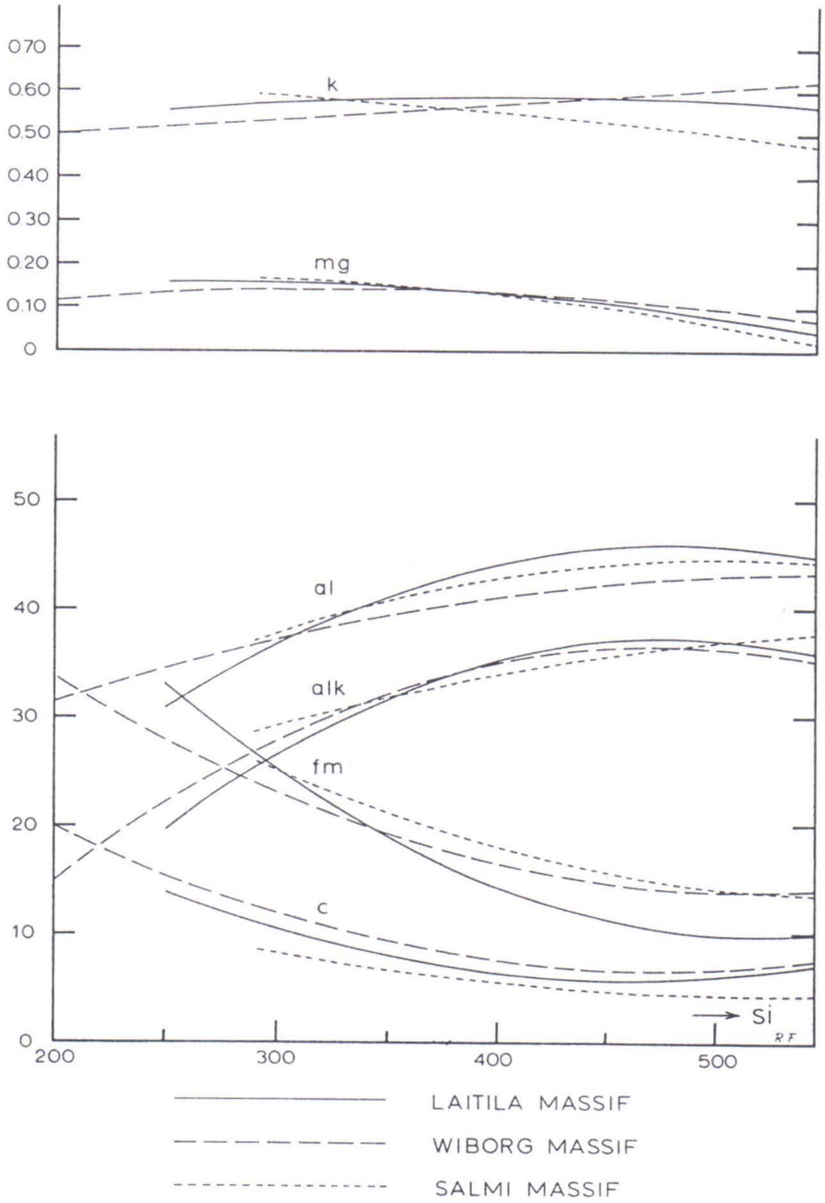

Fig. 3. The Niggli variation diagrams with average regression curves for the Laitila, Wiborg and Salmi batholiths. From Vorma (1976).

The fluorine content was almost the same and - at 0.38% - was much higher than in granitic rocks in general, which explains the almost diagnostic occurrence of fluorite.

Zirconium is also relatively abundant, the average for the Laitila batholith being about 300 ppm; for the Wiborg complex the corresponding figure is slightly higher, about 370-450 ppm. The high zirconium content is also reflected in the high hafnium values, the average for the Laitila batholith being 11.5 ppm.

As is to be expected from the low CaO values, the strontium contents are lower than in granitic rocks in general, the average for the Laitila batholith being 70 ppm. In view of the higher CaO of the Wiborg complex, Sahama's value of 100 ppm is probably correct for that area.

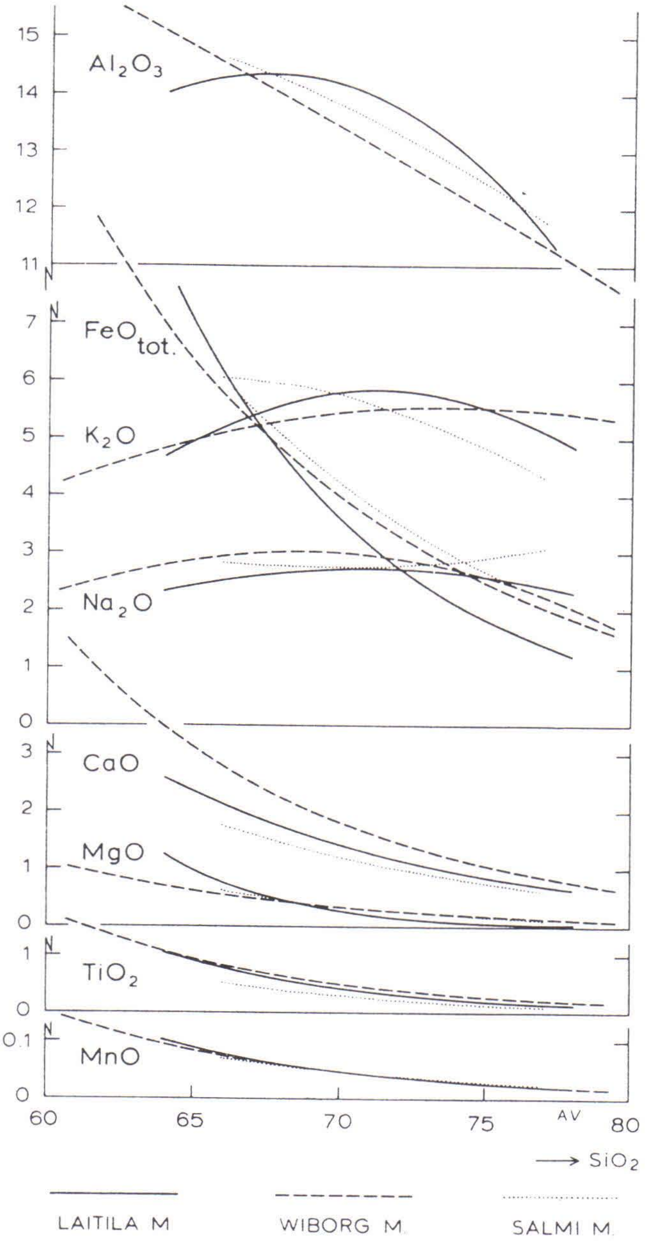

Fig. 4. Harker diagrams with average regression curves for the Laitila, Wiborg and Salmi batholiths. From Vorma (1976).

The REE are generally enriched in the rapakivi granites, and the biotite rich rocks pronounced europium minima. As a rule the trends are fairly steep, the lighter elements having been enriched by an order of magnitude more than the heavier ones (Fig. 5). In this and many other respects, the rapakivis have geochemical characteristics similar to those of the Proterozoic anorogenic granites of North America (Anderson, 1983).

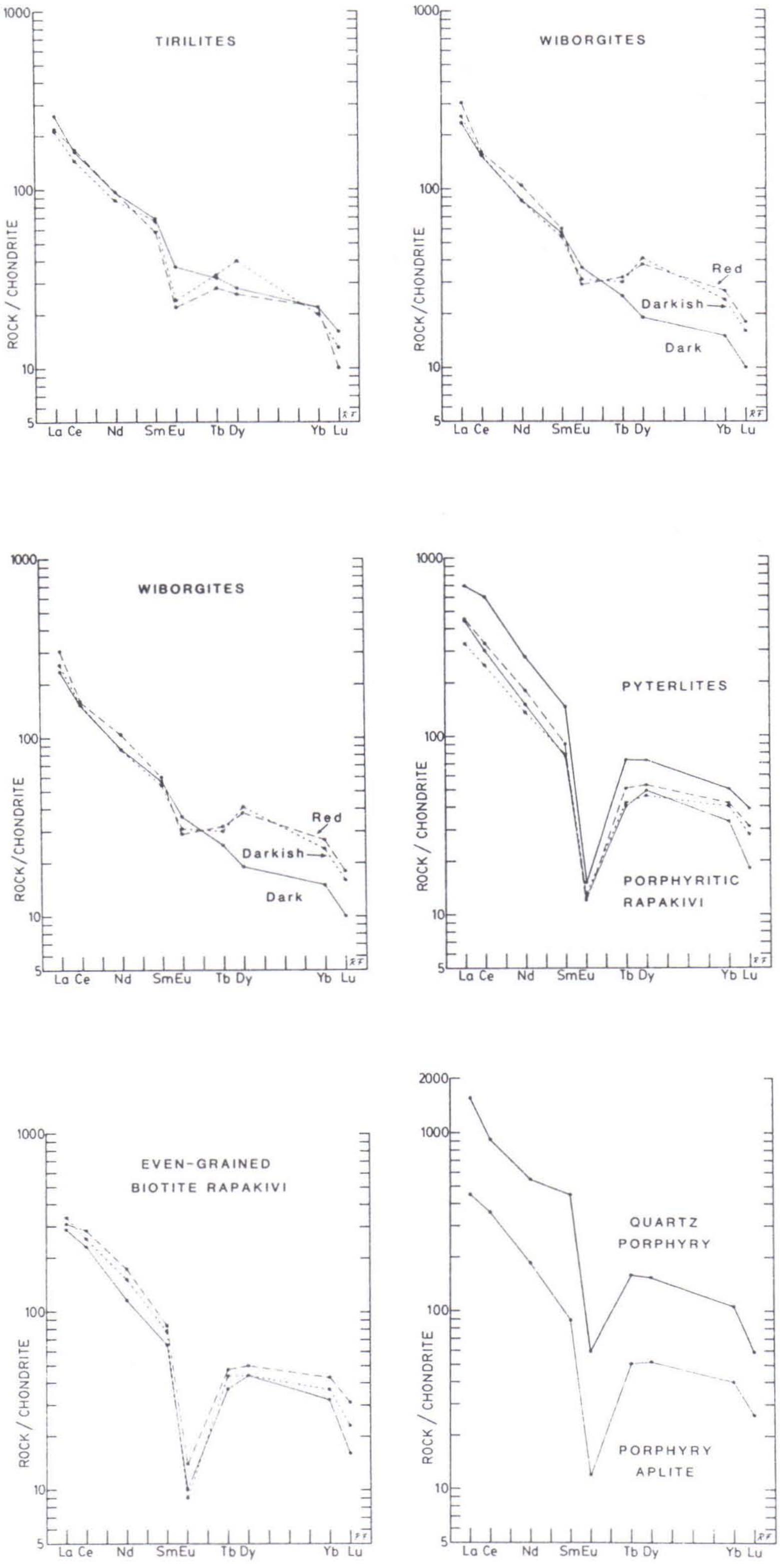

Fig. 5. Chondrite normalized REE patterns for various rapakivi granites from the Wiborg batholith. Courtesy by A. Vorma.

## METALLOGENESIS

Small sulphide mineralizations occur within the Finnish rapakivi batholiths and in their immediate surroundings. A number of them have been quarried for either silver or iron during modern history, but none is at the present of any economic importance. Only three of them (Inkeroinen, Virojoki and Pernaja) are briefly mentioned by Kahma (1973) in his treatise on Finnish mineral deposits. In the late 1960s and early 1970s, the Geological Survey of Finland studied the metallogeny of the rapakivi granites, using mainly petrographic and geochemical methods in an attempt to identify tin granites. It was found that greisen veins are often associated with the last intrusive phases. In the Eurajoki and Kymi areas the greisen bodies associated with topaz-bearing, geochemically anomalous granites contained cassiterite, wolframite, Be minerals and sulphides (Haapala and Ojanperä 1972, Haapala 1977a and 1977b). Exploration did not result in any mining operations, and the negative outcome may have been one reason why Isokangas (1976) listed the rapakivi granites among non-metalliferous areas of the Fennoscandian Shield.

In mode of occurrence, the ore mineralizations associated with the Wiborg batholith may be divided into three groups:

1) ore mineralizations in Svecofennian country rocks in the immediate vicinity of the batholith;
2) ore mineralizations associated with greisen bodies;
3) ore veins within the batholith, epigenetic in their mode of occurrence.

The chief minerals of the ores hosted by the Svecofennian country rocks are galena, sphalerite and chalcopyrite, with pyrite, arsenopyrite and pyrrhotite as occasional accessory sulphides. In some cases, the sphalerite contains blebs of chalcopyrite and pyrrhotite.

The Kymi stock intrudes the wiborgite and pyterlite north of Kotka. It comprises leucocratic, topaz-bearing granites, the topaz content of the marginal granite being higher and the biotite content lower than in the central granite. Both varieties are characterized by anomalously high F, Ga, Rb, Sn and Be and low Ba, Sr and Zr values (Haapala, 1977b). Greisen and quartz veins occur both in and around the stock, and some of them contain one or more of the following minerals: galena, sphalerite, chalcopyrite, wolframite, arsenopyrite, cassiterite, genthelvite and beryl (Haapala and Ojanperä, 1972). Galena is always associated with sphalerite, which often exhibits pseudoanisotropic zoning and lamellae caused by minute inclusions of chalcopyrite (Haapala and Laajoki, 1969). The latter mineral also occurs as larger blebs in sphalerite and as independent grains.

The epigenetic veins may be divided into two subgroups, differing greatly in ore paragenesis:

3a: Galena is the predominant ore mineral. Sphalerite and chalcopyrite are the principal accessory ore minerals. The sphalerite, which exhibits red inner reflections and usually contains exsolutions of chalcopyrite, is sometimes without inclusions. Chalcopyrite, which is occasionally altered to covellite, may form rims around the sphalerite.

3b: Galena is the chief ore mineral, but the wide occurrence of pyrite and honey-coloured inner reflections of sphalerite is the most conspicuous feature shared by the samples of this group. Chalcopyrite occurs as fissure fillings and is invariably associated with secondary covellite. In places hematite occurs together with spherulitic limonite.

## ON THE ORIGIN OF THE RAPAKIVI MAGMA

Most investigators of the rapakivi granites think that the genesis of rapakivi magma is in some way related to the genesis of basic magma because of the spatial coexistence of rapakivi granites with basic rocks of the same age.

Barker et al. (1975) presented a model for the gabbro-anorthosite-syenite-potassium granite suite according to which a mantle-derived, convecting alkali olivine basaltic magma reacts with the $K_2O$ poor lower crust under granulite facies conditions to produce a magma of quartz syenitic composition. The syenitic liquid reacts with the granodioritic to granitic intermediate crust of amphibolite facies and produces biotite and biotite-hornblende granites. The process involves both partial melting and reconstitution of refractory phases. Intermediate liquids are depleted in MgO and enriched in $Na_2O$, and precipitate anorthosites. The heat required for the partial melting of the rock is largely supplied by the heat of crystallization from the basaltic magma. According to this model, which is based on reaction melting the production of rapakivi magma and its emplacement are anorogenic.

In a study on crustal downfolding associated with postorogenic igneous activity in South Greenland, Bridgwater et al. (1973) demonstrated that the introduction of a major basic magma mass at depth melted the lower crustal rocks. The secondary magmas probably assimilated some mantle material and rose along graben-like structures; finally spreading out at higher levels in the crust and forming norite-rapakivi granite complexes.

Similar ideas were also proposed by Kranck (1968) for the origin of the anorthosite-mangerite-rapakivi suite. He noted the similarity between the tirilite in the Wiborg complex and the mangerites associated with the anorthosites in Canada and the USA. The difference between the rapakivi-anorthosite and the mangerite-anorthosite suites was attributed by Kranck to different levels of exposure. He assumed that the formation of the parental magma started in the basalt layer of the crust or in the upper mantle with the formation of olivine basalt magma. This magma then ascended into the lower crust where it came into contact with gneissic material of rather mafic composition. Partial melting of the gneissic material produced an anatectic granitic melt which probably had a high K/Na ratio. The mixing of this secondary melt and the primary olivine basalt melt produced a basic mangerite magma which, while rising through the crust, became increasingly felsic through crystal fractionation. Like other investigators of rapakivis, Kranck emphasized the anhydrous nature of these melts.

Sviridenko (1968) discussed the Salmi batholith in Soviet Karelia. She noted the similarity in chemical composition between rapakivi granites and acid charnockitic rocks and considered that the differences between the charnockite and rapakivi suites reflect different depths of emplacement. In her opinion the magma was generated at great depth and was not a derivative of other magmas, such as basic magma. Sviridenko further suggested that the different intrusive phases of the Salmi batholith were not all produced by magma from one and the same magma chamber.

On several occasions, Vorma (1971, 1976) has pointed out that the Finnish rapakivi granites are typical representatives of Buddington's (1959) epizonal granites. The Finnish rapakivis penetrated the cratonized roots of the already eroded Svecokarelian orogenic belt close to the Earth's surface, as is evidenced by their volcanic counterparts at Ruoholampi and Hogland (Vorma, 1975). According to Vorma, the high level of emplacement indicates that the slope of the P,T-curve was positive and that the magma itself was poor in $H_2O$. He concluded that the rapakivi magmas were generated deep in the continental crust at higher temperatures than the potassium granites migmatizing the Svecokarelian fold belt.

Further, Vorma (1976) proposed that Sederholm's (1934) group II, III and IV granites, emplaced at 1830, 1800 and 1670-1540 Ma, respectively, were products of a single process which acted for a very long time and created granitic magmas simultaneously at different levels of the crust. The granite formation would have proceeded in the following manner:

- during the culmination of the Svecokarelian orogeny, an anatectic melt, saturated with $H_2O$, was formed at a depth of 10-15 km. This melt was unable to rise upward in the crust and produced the migmatizing potassium granites (Sederholm's II group);
- in the lower continental crust, drier conditions and higher temperatures prevailed and an anatectic granite magma unsaturated in $H_2O$ was generated;
- when the compressional orogenic stage changed into a distensional stage, mantle derived basaltic magma erupted through the crust and formed the Subjotnian diabase dyke swarms;
- at the same time water-poor granitic melt collected to form larger homogeneous magma reservoirs and the diapiric rise of the magma began.

Vorma did not discuss the emplacement mechanism in detail, contenting himself with statement that the interpretation proposed by Bridgwater et al. (1973) was probably correct. The generation of Sederholm's group III granites would have been an intermediate stage between the formation of the migmatizing potassium granites and the rapakivi granites.

## ORIGIN OF THE RAPAKIVI TEXTURE

The rapakivi texture, which is marked by a plagioclase mantle around a potassium feldspar ovoid, has been explained either as a product of magmatic crystallization of plagioclase around a potassium feldspar crystal (Savolahti, 1962), as a metasomatic or autometasomatic replacement of plagioclase phenocrysts by potassium feldspar (Hawkes, 1967) or as an autometasomatic replacement of potassium feldspar by plagioclase (Velikoslavinskiy, 1953). Many of these explanations are based on experimental granite systems omitting the influence of anorthite.

Mineralogical studies on wiborgites show, however, that equilibrium was not reached during crystallization (Vorma, 1971). Thus the phase relations in the system Ab-Or-An-Qz-$H_2O$ (James and Hamilton, 1969) should be applied with some caution.

Vorma (1971) showed that most rapakivis with wiborgitic ovoids plot in the plagioclase field of the Ab-Or-Qz diagram when an An content typical of granitic rocks is taken into consideration (Fig. 6). However, low pressure fluorine-bearing hydrothermal fluids move the eutectic point towards the Ab corner and lower the eutectic temperature (Manning, 1982), suggesting that the potassium feldspar in the wiborgite began to crystallize before plagioclase, a contention supported by petrographic data.

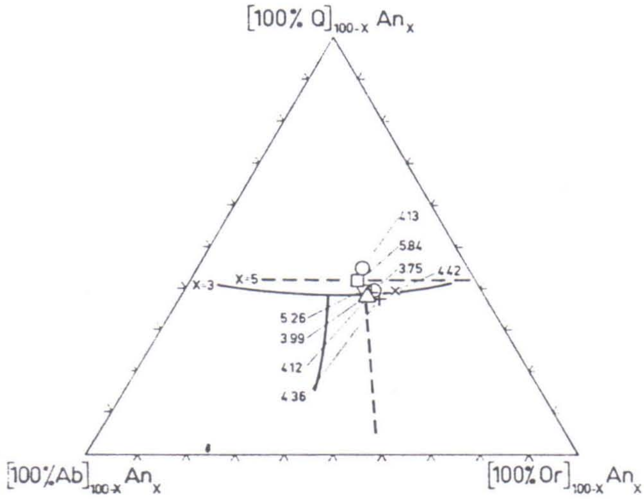

Fig. 6. Analytical results for various types of rapakivi granites from the Wiborg batholith on a normative Ab-Or-Qu diagram. The position of the eutectic point is shifted by assuming An contents of 3 and 5%. From Vorma (1971).

If one takes into consideration the fact that the Wiborg batholith, which has higher Ca contents than the other rapakivi complexes is also endowed with the most abundant wiborgitic texture, it may be argued that there is a connection between the rapakivi texture and the chemical composition. In the course of crystallization of the rapakivi magma, the chemical composition of the residual liquid shifted towards the plagioclase field; once it got there, crystallization of plagioclase began. In the Wiborg massif, with its higher Ca content, the shift was more pronounced and resulted in the crystallization of plagioclase mantles around the potassium feldspar.

It should be noted in this context that wiborgitic ovoids occur in other rocks besides rapakivi. Thus Härme (1954) described wiborgitic ovoids grown metasomatically in gabbros and gneisses intruded by granitic material, and some granites in central Finland exhibit wiborgitic ovoids although they lack any other textural features of rapakivi (e.g. euhedral quartz). Therefore, while admitting that differences in chemical composition may account for the textural differences between the various rapakivi complexes in Finland, we should bear in mind that the wiborgitic texture is most likely a consequence of several different processes.

## ISOTOPE GEOLOGY OF THE RAPAKIVI GRANITES

Radiometric ages have been reported previously from the Wiborg rapakivi batholith and other postorogenic rocks in southern Finland by Kouvo (1958) and Vaasjoki (1977). According to the latter, the main phases of intrusion are 1670-1650 Ma old, with the tin-bearing Kymi stock registering an age of about 1640 Ma. The Laitila and Vehmaa batholiths are definitely younger, with ages at about 1580 Ma, a result confirmed by recent research (Vaasjoki et al., 1988). Vaasjoki (1977) considered the Åland batholith to be coeval with the Wiborg complex, but more recent data (Suominen, in prep.) suggest that the rapakivis in the Åland area are mainly 1570 Ma old. The differences between the interpretations arise from the fact that many of the early samples represented single zircon fractions, and consequently conclusions were biased towards an interpretation relying on the use of the diffusion model of Wasserburg (1963).

Since the mid 1970s, improved analytical techniques have facilitated the analysis of smaller zircon samples and, more importantly, the use of supersaturated Clerici solution and the air abrasion technique (Krogh, 1982) have made it possible to obtain less discordant data. Therefore further zircon fractions were analysed from already existing material together with a Sm-Nd survey of the rapakivi granites.

New analyses have been made from the Wiborg batholith, and the upper and lower intersect ages are summarized in Table 1. On the whole, they suggest that many of the samples do not conform to a continuous diffusion model (lower intersects close to 0 Ma). Thus the main phases of the Wiborg batholith are somewhat younger than previously believed, ranging from 1646 Ma for the even-grained darkish rapakivi variety (tirilite) to about 1630 Ma for the youngest wiborgite samples. What is probably the youngest rapakivitic rock in the NW corner of the batholith, the Jaala-Iitti dyke, is slightly younger than its country rock, the porphyritic and highly siliceous granite of Verla. The previously enigmatic quartz porphyry dyke at Hamina is the youngest rock within the Wiborg complex. No further data have yet been obtained from the Kymi stock.

The oldest ages measured from the Wiborg batholith are those for the gabbro-anorthosite from Ylijärvi (1645 Ma) and the even-grained, darkish rapakivi variety from Värtö (1646 Ma). The wiborgite from Muurikkala is almost of the same age, as is the sample from the gabbro-anorthosite surrounding the Mäntyharju satellite. The Nikkari quartz porphyry dyke intersecting the Suomenniemi stock is about 1635 Ma old, which is the same age as the Mentula and Kiesilä dykes (Neuvonen, 1986). Three samples from the northern contact of the Wiborg batholith register ages of 1630-1635 Ma. This result is corroborated by other evidence, as in this area the rapakivi brecciates the Lovasjärvi mafic intrusion, dated at 1645 Ma (Siivola, 1987).

The new data suggest that, although the Wiborg batholith is slightly younger than previously thought, the radiometric results still suggest a prolonged period of intrusion with a duration of 15-20 Ma. Moreover, there is still a definite age difference between the Wiborg batholith and the rapakivi intrusions of western Finland, which are dated at about 1580 Ma.

Neodymium isotopic results from an ongoing study of the rapakivi granite-anorthosite-diabase association of Finland are shown in Fig. 7. Initial Nd ratios are plotted as $\varepsilon_{Nd}(t)$ relative to the CHUR evolution line of bulk Earth ($^{147}Sm/^{144}Nd=0.1966$) and a depleted mantle evolution line according to DePaolo (1981). Also shown are Nd data on the Svecofennian crust (Huhma, 1986; Patchett and Kouvo, 1986) and on the Karelian granitoids of eastern and northern Finland (Huhma, 1986); the evolution path for the Archaean crust in Finland. The Svecofennian crust was formed of mainly mantle derived material during the main stage of the Svecokarelian orogeny 1.91-1.87 Ga ago. Archaean crustal material was, however, involved to a considerable extent in the generation of the Karelian granitoids of eastern and northern Finland (Huhma, 1986).

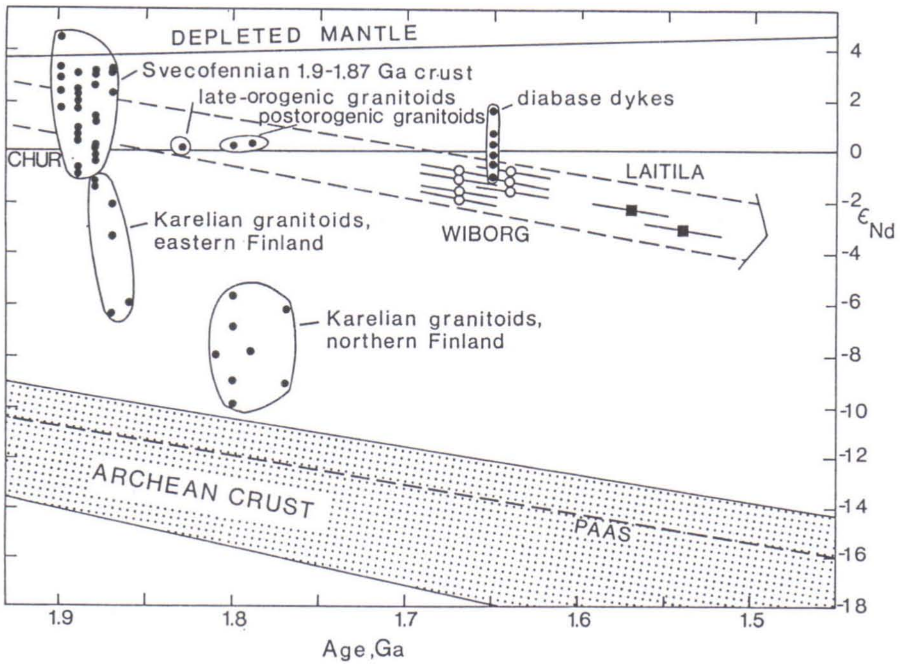

Fig. 7. Nd isotopic results from the Wiborg and Laitila batholiths and the rapakivi-age Subjotnian diabase dykes on an $\varepsilon_{Nd}$,t diagram. Evolution lines for the rapakivi granite samples are marked with thin lines and a common evolution path for the Wiborg and Laitila samples is denoted. The Nd isotopic data of the svecofennian and Karelian (1.9-1.8 Ga) igneous rocks and the evolution path for the Fennoscandian Archean crust are from Huhma (1986) and Patchett and Kouvo (1986). Marked in the figure are also the evolution line of undifferentiated Earth (CHUR), depleted mantle (according to DePaolo, 1981) and post-Archean average Australian shale (PAAS) of Nance and Taylor (1976).

Rapakivi granites and quartz porphyry dykes from the Wiborg batholith are strongly enriched in LREE and exhibit a narrow range of $\epsilon_{Nd}(t)$ values from -0.8 to -1.9, while the spatially and temporally associated diabase dykes are less strongly enriched in LREE and their $\epsilon_{Nd}(t)$ values are higher with a wider range from +1.6 to -1.0. Compared with the samples from the Wiborg batholith, the granites from the Laitila batholith are equally enriched in LREE and show $\epsilon_{Nd}(t)$ values of -2.3 and -3.1.

The $\epsilon_{Nd}(t)$ values of the rapakivi granites and quartz porphyry dykes might be attributed to mixing of depleted mantle and crustal material (see Patchett and Arndt, 1986). However, the nearly constant time integrated $\epsilon_{Nd}$ values argue against a mixing hypothesis, as substantial scatter of $\epsilon_{Nd}$ values would result from the mixing of such sources. The mean $T_{DM}$ model age (DePaolo, 1981) of the Wiborg and Laitila samples, 2.07±.04 Ga, agrees well with the mean $T_{DM}$ (2.12±16 Ga) of the Svecofennian granitoids analysed by Huhma (1986) and the mean $T_{DM}$ (2.09±.14 Ga) of Svecofennian volcanic and plutonic rocks analysed by Patchett and Kouvo (1986). On the basis of these observations, it was conluded (Haapala and Rämö, 1989; Rämö and Haapala, submitted June 30, 1988 to GAC) that the rapakvi granite magma was generated by partial melting of the Svecofennian crust. This corroborates Huhma's conclusion (1986) that the Svecofennian crust is a possible source for the rapakivi granites. The crustal source has also been proposed by Vorma (1976) and Haapala (1985).

Haapala (1985, 1988) and Nurmi and Haapala (1986) suggested that the partial melting of the crust producing rapakivi granite melt was caused by mantle-derived mafic magmas, now represented by diabase dykes and gabbroic rocks. On the basis of the initial Nd isotopic compositions, it can be concluded that the rapakivi granites and the diabases are not comagmatic. The latter are, however, enriched in LREE and have a range of $\epsilon_{Nd}(t)$ values distinctly lower than the $\epsilon_{Nd}(t)$ value for the comtemporaneous depleted mantle (+4.2; according to the model of DePaolo, 1981). The diabases probably crystallized from mantle-derived mafic magmas, which experienced variable crustal contamination during their passage through the Svecofennian crust (Haapala and Rämö, 1988; Rämö, 1989).

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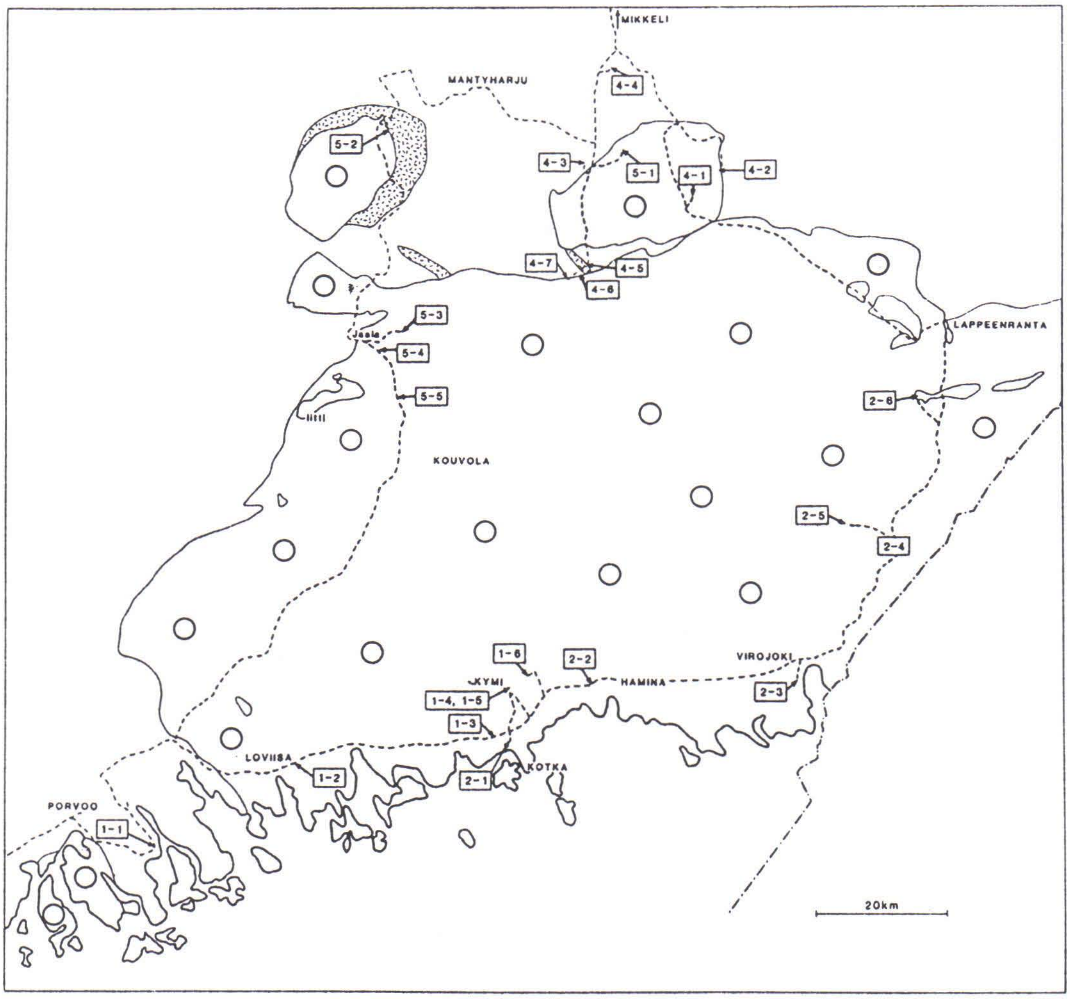
# DESCRIPTIONS OF THE EXCURSION SITES



Route map for excursion A2. The stops are denoted by numbers in squares indicating the day and the number of the stop on that day. The stops in the Lappeenranta area (day 3) are indicated on a separate scetch on page 26.

## DAY 1: Route: Helsinki-Porvoo-Loviisa-Kotka

### STOP 1: Orbicular granite **(no hammers)**

The orbicular granite at Virvik lies within Svecofennian migmatites and is visible on a single outcrop. It consists of two different types, which can be distinguished by the size of the orbicules. The matrix between the orbicules consists of a medium-grained granitoid, which at one instance forms a seam between the two types of orbicular rock. In the variety with the smaller (2-5 cm) orbicules the orbicules contain a nucleus consisting usually of an aggregate of plagioclase, rarely of a single crystal. Around the cores there occur 1-3 shells of alternating biotite-rich and plagioclase-rich composition. In the variety with the larger (15-30 cm) orbicules the cores are often rich in biotite, and the thickness of the individual shells varies from 1mm to a few cm. The orbicules show a tendency of being parallel to the direction of the regional elongation, N60E. The orbicules have also suffered a partial assimilation by the matrix. In most of the orbicules, the outer shells are more or less incomplete, being replaced by the reddish granitic matrix material.

### STOP 2: Porphyry aplite

The porphyry aplite is a rapakivi granite which contains sparsely distributed, mantled or unmantled ovoids of potassium feldspar in a fine-grained aplite-granitic matrix. The mineral and chemical composition of the porphyry aplite is similar to that of pyterlites and even-grained rapakivi granites, i.e. they are usually rather siliceous (>70% $SiO_2$) biotite granites.

At Tesjoki, the rock is medium-grained, and contains smaller wiborgitic ovoids with altered plagioclase mantles and a few larger pyterlitic ovoids. In the W-end of the road cut, there occurs a 3 m wide dyke with a ground-mass finer than that of the typical rock in the outcrop.

### STOP 3: Pyterlite

Pyterlite is a rapakivi variety where most of the ovoids are not mantled by plagioclase and usually the rock contains less plagioclase and more potassium feldspar than the wiborgite. Biotite is the predominant Fe-Mg silicate, while hornblende is minor or lacking.

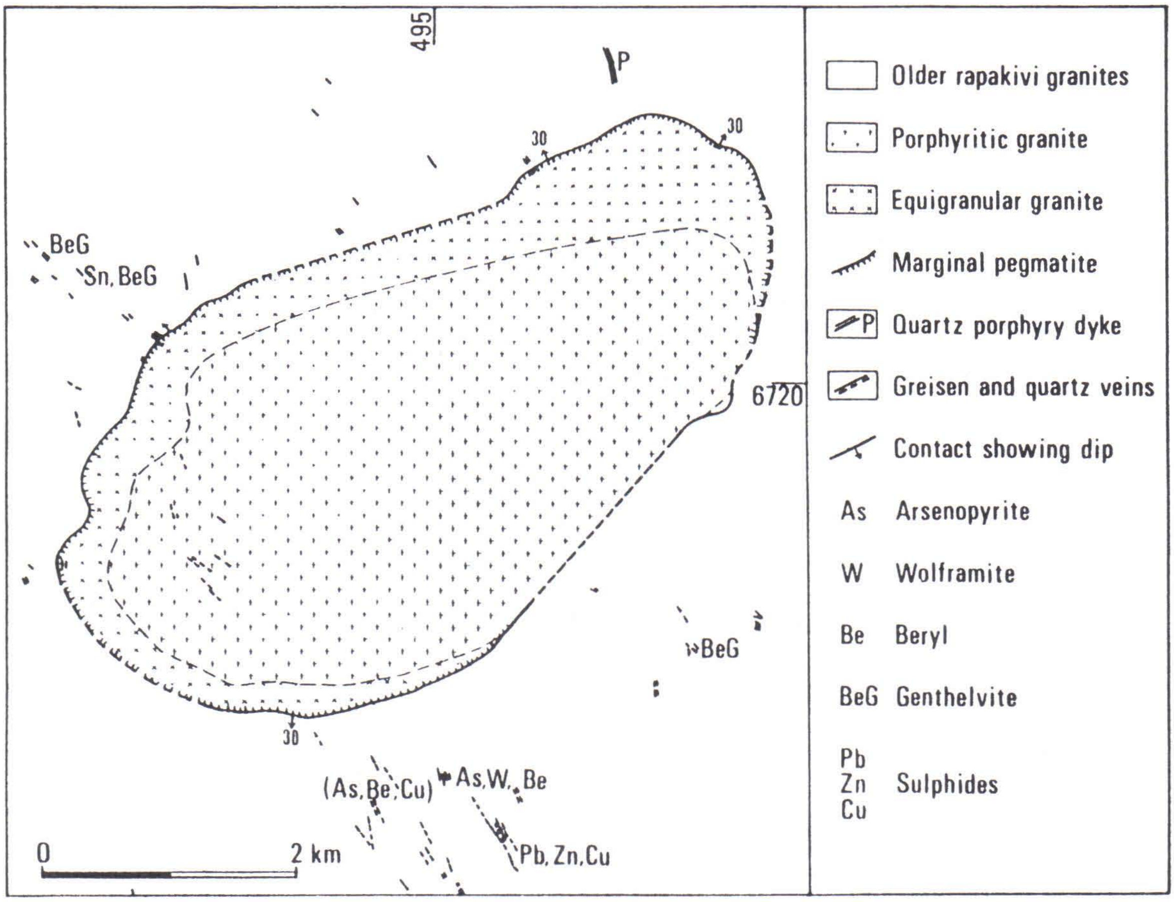
The rock at this stop is special in being transitional between a pyterlite and a porphyritic rapakivi, as it contains a large amount of porphyritic phenocrysts and none of the ovoids exhibit a plagioclase mantle. An unusual feature is also the red quartz.

### STOP 4: Weathering of the rapakivi

The name rapakivi is Finnish, and means literally crumbly rock. The name was given to the rock by the common people because of its conspicuous habit of weathering. The final result of the weathering, often often occurring as over 1 m thick beds, was used as a substitute for gravel and was called moro.

At Suljento, the weathering of a rapakivi consisting both of pyterlite and wiborgite can be seen. A few minor greisen veins, emanating from the Kymi stock, are also encountered.

STOP 5a: Granites of the Kymi stock

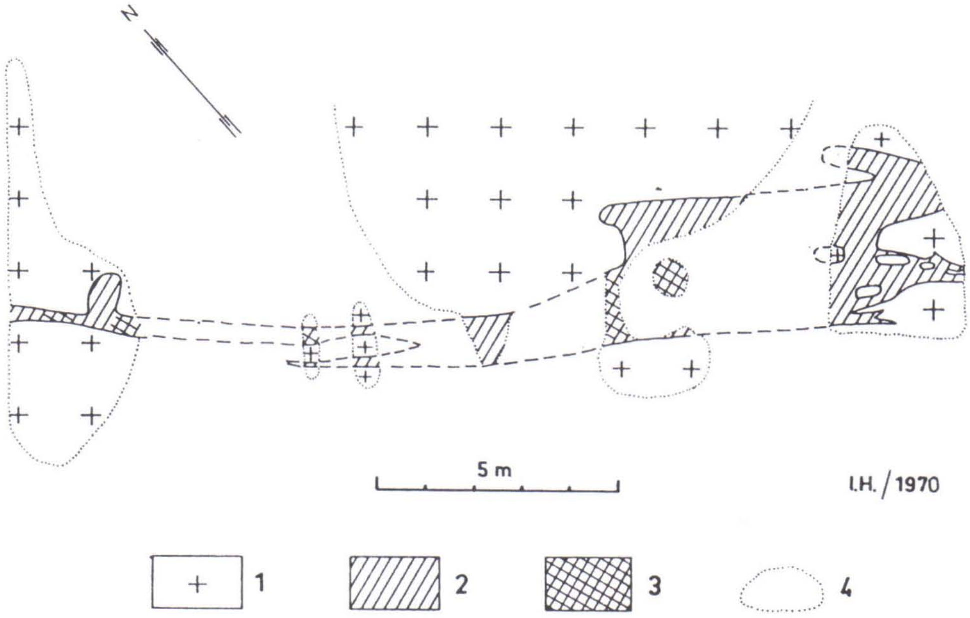


The oval Kymi stock (6x2.5 km) intrudes the normal rapakivi granites north of Kotka. The stock comprises two main rock types: an even-grained marginal variety and a porphyritic central body. The contact between the two rock types is exposed, but the age relationship is hard to determine on its basis. Both rocks are leucocratic topaz-bearing biotite granites characterized by anomalously high F, Rb, Sn and Be and low Ba, Sr and Zr contents.

STOP 5b: Contact of the Kymi stock

At the outer contact of the Kymi stock, against the normal rapakivi granite varieties, there is a rim composed of pegmatite and even-grained granite. This zone is only a few metres or less in width and corresponds to the marginal pegmatites (Stockscheider) commonly observed in the contact zones of stanniferous granites. Besides quartz, feldspars and mica, the pegmatites often contain topaz as well as small amounts of fluorite, arsenopyrite, tourmaline, molybdenite, bastnaesite and monazite.

### STOP 6: Genthelvite-bearing greisen



The genthelvite-bearing greisen body (occurrence 1) from Kymi. (1) Wiborgite; (2) greisen; (3) genthelvite-bearing greisen; (4) outcrop.

Genthelvite occurs as one of the main minerals in a greisen lode cutting wiborgite. Of the various styles of mineralization, muscovite-chlorite and muscovite-chlorite-genthelvite greisens are the most prominent. Genthelvite occurs primarily as irregular disseminations or as small streaks in the greisen. It is also found in quartz veinlets in the central part of the greisen lode. The disseminated genthelvite crystals have often replaced the plagioclase mantles around the former potassium feldspar ovoids. The genthelvite and fluorite crystals are commonly partly replaced by muscovite and chlorite.

## DAY 2: Route: Kotka-Hamina-Virojoki-Lappeenranta

### STOP 1: Intrusive breccia in the Wiborg batholith

An intrusive breccia of the Wiborg batholith occurs at the parking lot of the former Imperial fishing lodge at Langinkoski. The country rock is a wiborgite with relatively small ovoids, while the angular breccia fragments are Svecokarelian migmatites. Some of the smaller breccia fragments are partly assimilated by the rapakivi magma, thus demonstrating its relatively high intrusion temperature. A special feature of the outcrop is a large roundish conglomeration (diameter ca. 5 m) of wiborgitic ovoids surrounded by a 1-2 cm wide shell of plagioclase.

STOP 2: Typical wiborgite

The typical wiborgite contains all the textural features of the rapakivi sensu stricto. The potassium feldspar ovoids vary from 1 to 10 cm in diameter, and their majority is surrounded by a plagioclase mantle. The unmantled ovoids are often larger than the mantled ones. The quartz is pseudomorphic after high quartz (the so-called drop quartz), and both feldspars occur in the groundmass as well. Other minerals in the groundmass, which constitutes about 25% of the total rock, are hornblende, biotite, zircon and fluorite. A special, though not uncommon feature of this outcrop is the incipicient horizontal weathering under about 2 m of fresh rock. There also occur two types of later veins (aplitic and pegmatitic).

STOP 3: Typical pyterlite at Virojoki

Pyterlite is texturally related to wiborgite, in as much as the potassium feldspar occurs in ovoidal form. However, the ovoids are not mantled by plagioclase. Usually no sharp contacts to the surrounding wiborgites are observed, but the transition is gradual. However, according to Sviridenko (1968), three distinct intrusive phases, consisting of wiborgite, an even-grained rapakivi granite and pyterlite in that order can be discerned in the Salmi batholith. This particular stop is the type locality of the pyterlite. The quarries in this area date back to the 16th century, and in the 19th century most of the rock was shipped as building material to Leningrad (at that time St. Petersburg).

STOP 4: Wiborgite quarry at Husu

Owned by Suomen Kiviteollisuus Oy, this quarry is one of the largest in eastern Finland. The rock is shipped from here as raw blocks, which are later refined to monumental and building stones partly in Finland and partly overseas.

STOP 5: Spectrolite quarry at Ylijärvi **(no hammers)**

One of the anorthosite bodies associated with the rapakivi granites occurs at Ylämaa as an inclusion in the Wiborg batholith. The body consists of various basic rock types ranging from gabbros to pure anorthosites in mineralogical composition. The quarry at Ylijärvi contains a labradorizing plagioclase variety, which is commercially called spectrolite and is used mainly for jewelry. At the observation site, the anorthosite is brecciated by a gabbro-norite, and the sequence is cut by rapakivi dykes, the largest of which is about 1 m wide.

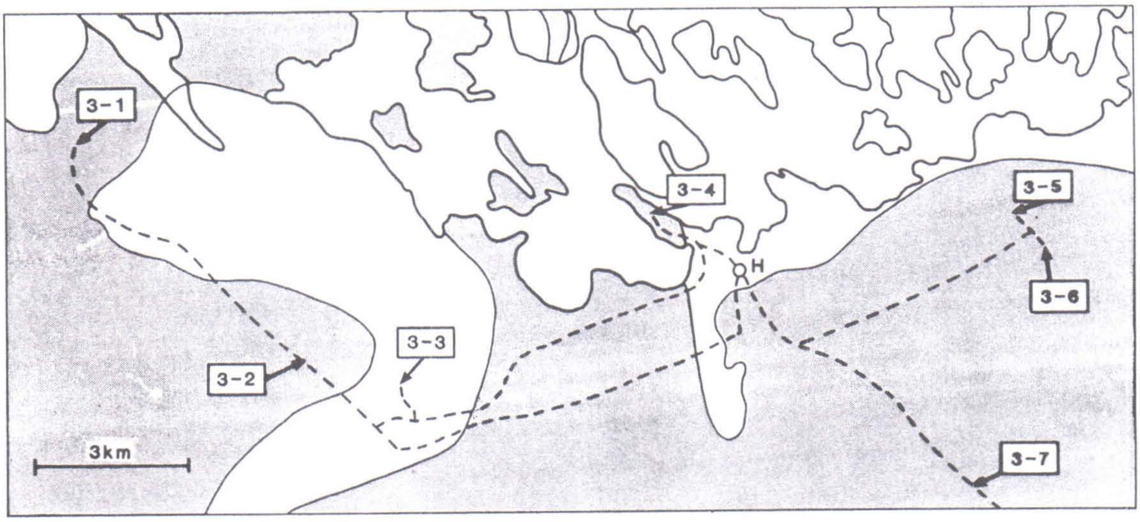
STOP 6a: Porphyritic granite in the Toivarila roof pendant

The porphyritic granite looks at a first glance surprisingly like the rapakivi granites, but closer examination reveals that it does not contain drop quartz and that it contains cordierite, which certainly is not part of the rapakivi paragenesis. Also, the feldspar phenocrysts are slightly orientated. Biotite is the main mafic mineral, and the dominating feldspar in the groundmass is oligoclase-andesine. Radiometric dating demonstrates clearly the Svecofennian origin of the rock.

## STOP 6b: Rapakivi and porphyritic granite brecciating roof pendant rocks

The Toivarila roof pendant consists mainly of the porphyritic granite (seen at the previous stop), which occasionally contains gneiss fragments. In the southern part of the roof pendant there occurs an "eruptive breccia" described by Hackman (1934). The fragments are both Subjotnian diabases and Svecokarelian migmatites in a groundmass consisting of both even-grained and small ovoidal rapakivi. Some of the breccia fragments in the rapakivi appear to be breccias themselves, their matrix possibly consisting of the porphyritic granite.

## DAY 3: The Lappeenranta area



## STOP 1: Dark even-grained rapakivi (tirilite)

The dark even-grained rapakivi variety is considered to be the oldest intrusive rapakivi phase in the Lappeenranta area. It is a fayalite-bearing horblende granite characterized by a relatively large amount of plagioclase, which sometimes occurs as idiomorphic phenocrysts. Occasionally the rock contains some scattered mantled or unmantled potassium felspar ovoids. The rock at this site has been dated to be 1646±4 Ma old. Within this former quarry there also occurs a subhorizontal pegmatite vein.

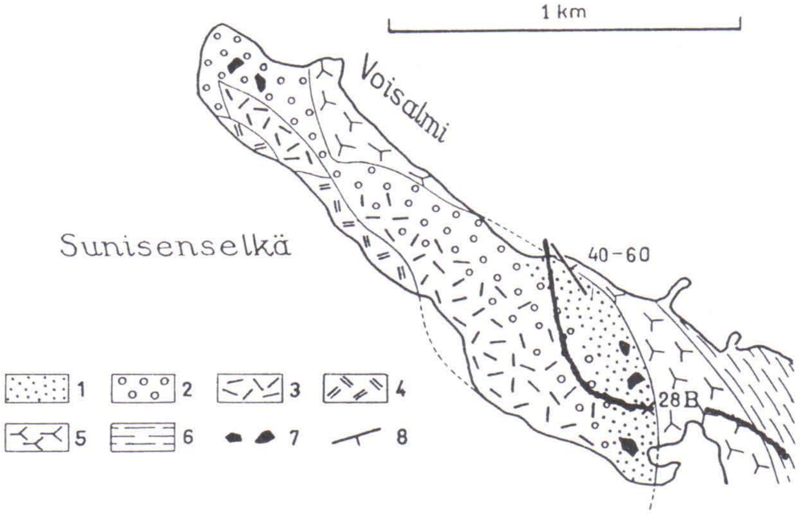
## STOP 2: Wiborgite veins in tirilite

At Myllylampi wiborgite veins intersect the tirilite, thus showing the mutual age relationships of both rocks. The wiborgite has been dated to be measurably younger than the tirilite. At the upper contact of the steeply dipping wiborgite, there occurs a fine-grained granitic rim.

## STOP 3: Subvolcanic rapakivi porphyry

The Hiidenniemi porphyry occurs in the Ruoholampi roof pendant, which mainly comprises Svecofennian rocks. White potassium feldspar and darkish quartz phenocrysts are densely scattered in a phaneritic groundmass. Occasionally, the phenocrysts are slightly aligned. The groundmass has an allotriomorphic-granular texture and consists of potassium feldspar, quartz and oligoclase-andesine with minor biotite, epidote, opaque minerals and poikiloblastic muscovite. Fluorite, zircon, apatite and monazite are the most common accessory minerals. The rock has been dated at 1640±6 Ma, and is thus within experimental error of the same age as the surrounding tirilite. Younger quartz veins have caused local alteration of this subvolcanic rock.

## STOP 4: Contact of Svecofennian rocks with rapakivi porphyry



Lappeenrannan Tyysterniemen kallioperä. Alue I kuvassa 1. 1. Pienirakeinen rapakivigraniitti. 2. Rapakivigraniittiporfyyri. 3. Porfyyrinen rapakivigraniitti. 4. Karkeaporfyyrinen rapakivigraniitti. 5. Granodioriitti. 6. Amfiboliitti, diopsidiamfiboliitti ja karsikivi. 7. Peruskalliobreksiakappaleita rapakivessä. 8. Rapakiven ja peruskallion välinen kontaktipintahavainto.

*The bedrock in the Tyysterniemi peninsula in Lappeenranta. Area I in Fig. 1.*
*1. Fine-grained rapakivi granite. 2. Rapakivi granite porphyry. 3. Porphyritic rapakivi granite. 4. Coarsely porphyritic rapakivi granite. 5. Granodiorite. 6. Amphibolite, diopside amphibolite and skarn rocks. 7. Breccia. 8. Observed contact surface.*

The rapakivi porphyry dyke of Tyysterniemi shoots out from the rapakivi batholith into the Svecofennian country rocks. In the northern end of the road cut, the contact between the dyke and the country rock and several apophyses of the dyke can be observed. The dyke consists of a marginal, almost even-grained small porphyritic rock and a central coarse porphyritic variety, which grade into each other. Numerous miarolitic cavities and and a few quartz veins intersecting the rapakivi porphyry occur within the road cut.

### STOP 5: Transition of tirilite into Lappee granite

The even-grained, darkish tirilite grades into the likewise even-grained but more reddish hornblende granite of Lappee. The main petrographic difference is that the fayalite is ubiquituous in the tirilite, while the Lappee granite commonly lacks it. In the outcrop, interfingering tirilitic and Lappee type portions are usual and generally grade into each other within a few cm.

### STOP 6: Lappee granite

The Lappee granite is medium-grained biotite-hornblende granite and is quite uniform in appearance over a fairly large area. Bigger potassium feldspar phenocrysts and rare unmantled ovoids are sparsely scattered throughout the rock. An interesting feature are numerous fine-grained dark inclusions, which occur almost on every outcrop of the Lappee granite studied so far. These inclusions contain some augite, which is a difference to the tirilite. The inclusions differ from the tirilite also texturally, as both fayalite and augite occur together with poikilitic biotite and hornblende. There also occur occasional granitic inclusions, of which at least two types, rapakivitic and country rock-like, can be recognized.

### STOP 7: Sinkko granite

The Sinkko granite is a light grey porphyritic granite with densely distributed, angular, white potassium feldspar phenocrysts between 0.5 and 1.5 cm in diameter in a medium-grained groundmass. Large ovoidal feldspars are rare. The dominating dark mineral is biotite. According to Vorma (1971), this rock grades into the Lappee granite and is thus older than the wiborgite.

## DAY 4: Route: Lappeenranta-Suomenniemi-Lovasjärvi-Mikkeli

### STOP 1: Quartz syenite dyke in rapakivi

The Kirvesniemi quartz syenite belongs to a NW-trending set of peralkaline syenite dykes emplaced in the eastern part of the Suomenniemi rapakivi granite batholith. The dykes cut sharply the rapakivi granites but no difference has been detected in U-Pb zircon ages of the two rock types. The syenites typically exhibit hypersolvus characteristics with aegirine-augite as the main mafic silicate filling the interstices between feldspar grains. Sphene is a conspicuous minor constituent, and melanite garnet is sporadically encountered.

The Kirvesniemi dyke is exposed for a length of about 20 m in an outcrop running across a country road. It is 5 m wide in the southern part of the outcrop and becomes narrower towards the north. The quartz syenite cuts an even-grained hornblende granite, and can be readily distinquished as the minor quartz in the syenite is not easily detected while the granite has drop quartz typical of rapakivi granites. The quartz syenite is slightly cataclastic and also shows evidence for strong deuteric reactions: primary mafic silicates have been replaced mainly by a fibrous green amphibole.

## STOP 2: Composite diabase-quartz porphyry dyke

In the Kuusenhako area, a NW-trending diabase-quartz porphyry composite dyke cuts rapakivi granites. The dyke is 20 m wide, dips steeply to the southwest and consists of 1 m wide marginal diabases and a major central quartz porphyry. The diabase margins are composed of a medium-grained tholeiitic rock with plagioclase, amphibole and acicular oxides as the main components. Some scattered plagioclase phenocrysts are met with, too. The quartz porphyry is akin to the quartz porphyry dykes that cut both the Suomenniemi batholith and the early Proterozoic Svecofennian country rocks around it. It consists of K-feldspar, quartz, plagioclase and biotite phenocrysts in a fine-grained granitic matrix.

At the exposed SW contact the marginal diabase is strongly chilled against the rapakivi granites, which here comprise an even-grained biotite-hornblende granite and a slightly porphyritic biotite granite. The granites exhibit a sharp mutual contact that also is cut by the composite dyke. The contact between the diabase margin and quartz porphyry is sharp and slightly sinuous in detail, and the diabase shows chilling also against quartz porphyry. Approximately at the center of the diabase margin there is a 10-20 cm wide zone of hybrid rock with felsic material enclosing mafic globules.

At the exposed NE contact a similar sequence is found with the diabase chilled against biotite-hornblende granite and quartz porphyry. Moreover, there are anorthositic fragments in the diabase, and a quartz porphyry apophyse has intruded the diabase and coalesces into the zone of hybrid rock in the middle of the margin.

## STOP 3: Composite quartz porphyry-diabase dyke

Near the lake Korpijärvi, NW of the Suomenniemi batholith, a composite dyke is found that differs from that at Kuusenhako: it is composed of a central amphibole-pyroxene diabase and quartz porphyry margins. The dyke is about 25 m wide, nearly vertical and can be followed in outcrops for about 2.5 km.

An almost completely exposed section across the Korpijärvi dyke is seen near Viitalampi. In the section the dyke consists of 3 m wide quartz porphyry margins and a 15 m wide central diabase. The marginal quartz porphyries cut sharply a Svecofennian foliated granite, and between the quartz porphyries and diabase there are about 2 m wide zones of mingled rock where diabase with K-feldspar and quartz phenocryst occurs as pillow-like globules enclosed in quartz porphyry. The K-feldspar crystals have a micrographic margin and the quartz crystals are mantled and partly resorbed by an amphibole rim. Towards the center of the diabase the K-feldspar and quartz phenocrysts show increasingly thicker micrographic margins and amphibole mantles, respectively, diminish in size and finally fade out so that the central part of the diabase is devoid of these silicic components. The central part contains, however, conspicuous plagioclase megacrysts.

## STOP 4: Subjotnian K-feldspar diabase

At Kirkkovuori, 10 km N of the Suomenniemi batholith, a 20 m wide NW-trending pyroxene diabase dyke with an exposed length of 400 m is found cutting the Svecofennian migmatites. All along the outcropping area, the dyke represents chilled margins against the country rock. The NW end of the exposed part of the dyke is composed of a porphyritic rock with K-feldspar megacrysts (average diameter about 5 cm) and quartz phenocrysts in a fine-grained basaltic matrix. The K-feldspar megacrysts are partly resorbed and some of them are mantled with plagioclase. Pockets of quartz porphyry relics intruded by diabase and fragments of country rock are also encountered.

In the SE part of the dyke diabase brecciates folded Svecofennian schists and pegmatite granite. Near the contacts of the dyke there are local units of diabase loaded with K-feldspar megacrysts, quartz phenocrysts and quartz porphyry relics. Some rapakivitic granite fragments occur as well.

## STOP 5: Subjotnian mafic intrusion brecciating Svecofennian rocks

The differentiated mafic intrusion at Lovasjärvi is over 5 km long and 800 m wide. The contacts to the country rocks are near vertical. It consists mainly of a plagioclase-olivine rock, olivine diabase and diabase which are considered to be differentiates from a rather mafic starting material. The coarse-grained diabase is the major rock type and forms the central and SE parts of the intrusion.

At Hakosaari the diabase brecciates the Svecofennian country rocks. The fragments consist of microcline granite, granodiorite, amphibolite and mica schist. Some chemical alteration in the fragments is evident. The Lovasjärvi intrusion has been dated to be 1643±5 Ma old.

## STOP 6: Rapakivi brecciating Subjotnian mafic intrusion

At Halkoniemi, the Lovasjärvi mafic intrusion is in its turn brecciated by the rapakivi of the Wiborg batholith. There is hardly any chemical alteration to be observed in the diabase fragments surrounded by the rapakivi groundmass.

## STOP 7: Northern contact of the Wiborg batholith

The immediate contact variety of the rapakivi is a dark, fine-grained rock, the major minerals being potassium feldspar, quartz and albite. Fayalite and biotite occur as minor constituents, and flow-sorted feldspar phenocrysts are observed. The rock belongs clearly to the rapakivi batholith, forming about a 3 m wide layer parallel to the contact. On the side of the rapakivi, it exhibits a sharp contact against a next layer of similar composition, which contains a larger amount of feldspar phenocrysts and grades into a pyterlite indicating strong laminar flow. The pyterlite occasionally contains segregations of biotite and amphibole. At the southern end of the road cut, some 200 m from the contact the rock is texturally wiborgitic. The contact variety, the pyterlite and a wiborgite about 2 km south of the contact road cut have been dated radiometrically in the range of 1630-1635 Ma.

The surrounding outcrops demonstrate that the laminar flow structures at the contac extend over at least 100 m in length, but that the contact is very uneven and no general direction of the contact can be established at the site.

## DAY 5: Route: Mikkeli-Mäntyharju-Jaala-Helsinki

### STOP 1: Orbicular rapakivi granite

The orbicular granite at Hämeenjärvi occurs in the NW part of the Suomenniemi batholith. It is associated with a WNW-trending aplitic dyke cutting a coarse-grained biotite granite. Three separate, irregularly formed pockets of orbicular granite are encountered in the dyke. The pockets lie about 5 m apart from each other and their diameter ranges from 0.5 to 2 m. The orbicules in the pockets are undeformed, tigthly spaced, spherical in shape and 5 to 18 cm in diameter.

A K-feldspar crystal constitutes the nucleus of the orbicules. The nuclei are rounded or angular and 1-3.5 cm in diameter. The mantle of the orbicules consists of K-feldspar, quartz and green biotite with fluorite as conspicuous minor component. K-feldspar occurs as anhedral, 1-5 cm long crystals arranged radially around the nucleus. Quartz is anhedral and graphically intergrown with K-feldspar. Biotite is mainly found as 1-20 mm long and a few mm wide flakes that coalesce to form dendritic clusters arranged radially (occasionally concentrically) around the nucleus. At the outer edge of the orbicules, there commonly occurs a shell of graphically intergrown K-feldspar and quartz completely devoid of mafic constituents. The matrix between the orbicules is medium to coarse-grained biotite granite. Locally, leucocratic albite-rich matrix is met with.

A characteristics feature of the orbicular granite is the fluorite in the mantle of the orbicules. It is found as euhedral cubic crystals ranging from 0.1 to 0.5 mm in diameter and averaging 3.6 % by volume of the mantles.

### STOP 2: The main rock types of the Mäntyharju rapakivi-anorthosite complex

The main rock types of the Mäntyharju complex can be observed at Leviänlahdenvuoret in a rather restricted area. Anorthosite forms several 20-30 m large oval bodies which are surrounded by hornblende gabbro and monzodiorite. No direct evidence exists on the age relationships between the anorthosite and the gabbro, but both are definitely older than the monzodiorite, as they occur in it as breccia fragments. The even-grained biotite rapakivi is in turn younger than the monzodiorite, as the former contains fragments of the latter. The quartz porphyry dike in the

NW corner of the outcrop area is the youngest rock to be observed: it cuts the hornblende gabbro and the biotite rapakivi and exhibits a narrow chilled margin against them. The anorthosites of the Mäntyharju complex have been dated to be 1646±5 Ma old.

## STOP 3: Porphyritic rapakivi granite at Verla

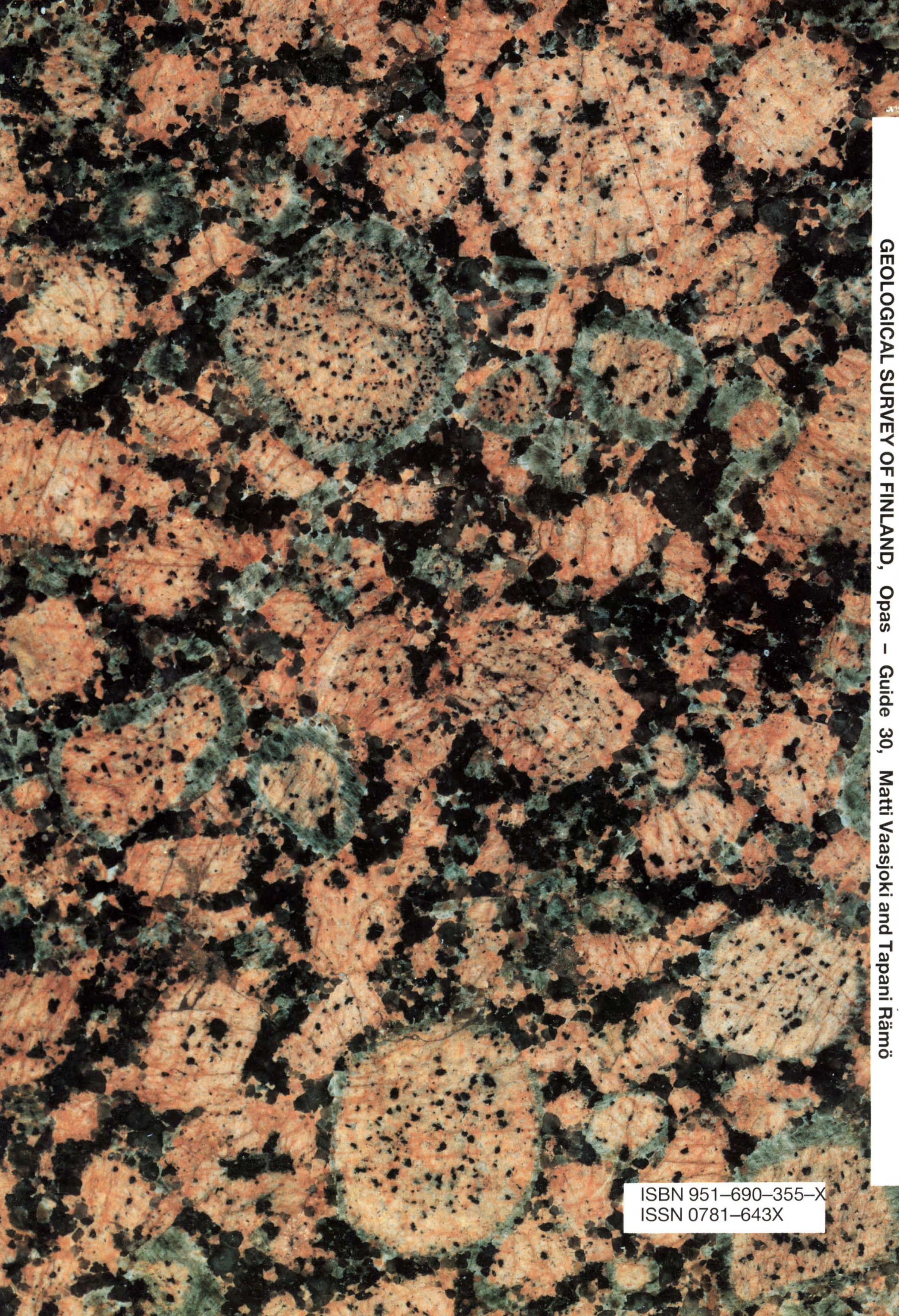
The rock is characterized by abundant angular potassium feldspar phenocrysts and the conspicuous occurrence of drop quartz, which reflects the high $SiO_2$ content of the rock (76%). The groundmass is medium- to coarse-grained, and there are gradual transitions of clearly porphyritic varieties to almost even-grained types. The mineralogical and chemical compositions of the rock is very similar to those of pyterlite. The rock has been dated to be 1638±8 Ma old.

## STOP 4: The Jaala-Iitti dyke and its contact

For the most part the Jaala-Iitti dyke consists of hornblende rapakivi. Outwardly it varies in appearance, but the chemistry of the different varieties do not appreciably differ from each other. Also, no contacts or short-distance transitions have been observed between the various types and the changes are very gradational. For most part, the rock is a porphyritic hornblende granite, but biotite always occurs as a minor constituent and is at the observation site the main Fe-Mg mineral. In the southern end of the roadcut, the contact of the dyke to the porhphyritic granite may be observed. The Jaala-Iitti dyke is definitely younger than the surrounding rapakivi granites with a radiometric age of about 1625±7 Ma.

## STOP 5: Sphalerite veins in wiborgite

The wiborgite is intersected by four sphalerite-bearing greisen veins at Oravala. Along the veins, the rapakivi has been altered into a garnet and pyrite bearing rock. The outer parts of the veins contain gahnite, sphalerite and garnet, whereas their central parts consist of massive sphalerite, quartz and chlorite. In addition to the veins, quartz porphyry and pegmatite dykes and patches of even-grained granite are encountered.



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