CHEMICAL AND MODAL COMPOSITION OF GRANITOIDS IN THREE DIFFERENT GEOLOGICAL UNITS, SOUTH-POHJANMAA, WESTERN FINLAND

by
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Introduction

Chemical and mineral (modal) compositions are the two most used numerical and effective parameters in classifying and describing granitoid rocks (Streckeisen 1976, Streckeisen & Lemaître 1979, Pearce et al. 1984, Barbarin 1990). These properties have relatively close relationships, but the mineral composition does not strictly correlate with the chemical composition of the granitoids. For example, the A/CNK values that are used to discriminate I- and S-type granitoids have no direct relationship to the modal composition of the rock. The chemical and modal composition of granitoids are related to a large number of factors, such as variable magmatic source and differentiation processes (e.g. Clarke 1992). Moreover, regional or contact metamorphism can later change the mineral modes of granitoids. The chemical composition of granitoids can, however, be used to establish genetic links between spatially associated granitoid rocks.

This paper gives an introduction to the chemical and modal compositions of the granitoids in three different, neighbouring geological units within a restricted area (4000 km²) in the Palaeoproterozoic Svecofennian domain (age 1.93-1.82 Ga), South-Pohjanmaa, western Finland (Fig. 1) (cf. Korsman et al. 1997). The different units of the research area are the Central Finland granitoid complex, the Pohjanmaa schist belt and the Vaasa granitoid complex (Fig. 1). The most abundant granitoids in the area are tonalites, granodioritic diatexites and porphyritic granites. The less common rocks include granodiorites, pyroxene granitoids, granitic gneisses and pegmatites (cf. Laitakari 1942).

The term granitoid, as defined in the IUGS classification, refers to a plutonic rock with a quartz content between 20 and 60 volume% (see Bates & Jackson 1980). The authors have used in the present study the term granitoid in a wider sense and included in the granitoids also the quartz monzonites, diatexites and granitic gneisses.

Our chemical data consists of 143 bulk rock analyses. The modal composition of 135 rock samples was determined by point counting. The samples were collected from the various granitoid types and areas shown in the bedrock maps (cf. Sakela 1934, Lahti & Mäkitie 1990, Mäkitie et al. 1991, Lehtonen & Virransalo, in press). The chemical and modal composition of these granitoid types and areas are shown as average values (Table 1). The authors have collected the samples studied here in detail during bedrock mapping, ore prospecting and granitoid studies of the Geological Survey of Finland.

Regional geological setting

The research area in South-Pohjanmaa, Finland, is a part of the Palaeoproterozoic Svecofennian accretionary arc complex of central and western Finland (age 1.90-1.87 Ga) (Korsman et al. 1997). There are three major geological units in this area...
Fig. 1. Simplified geological map of the research area in South-Pohjanmaa. The numbers in boxes are A/CNK-values of the granitoid areas studied. The map is modified after Saksela (1934), Tyrväinen (1970, 1971), Lahti and Mäkitie (1990), Mäkitie et al. (1991) and Lehtonen and Virransalo (in press).

(Fig. 1) (cf. Korsman et al. 1997): A) the southern part that is a part of the Central Finland granitoid complex (CFGC) (age 1.89-1.87 Ga) (cf. Väyrynen 1923, Nurmi & Haapala 1986), B) the middle part consists of supracrustal rocks of the Pohjanmaa schist belt (PSB) (cf. Laitakari 1942), and C) the northern part that is composed of granitoid rocks of the Vaasa granitoid complex (VGC) (earlier called the Vaasa granite) (age 1.89-1.88 Ga) (cf. Laitakari 1942).

The rocks of the Central Finland granitoid complex (ca. 45,000 km²) are mostly collision related granodiorites and tonalites with a lot of granites that mainly post-date the main stage of crustal thickening (Korsman et al. 1997, Elliott et al. 1998). Most of the rocks of the CFGC in the research area are tonalites (age 1882±9 Ma) and little younger porphyritic granites occur as less abundant (Mäkitie & Lahti 1991).

The characteristic rocks in the about 50 km wide Pohjanmaa schist belt are mica schists and mica gneisses, originally pelites and greywackes metamorphosed in conditions of low pressure amphibolite facies. Mafic metavolcanic rocks are less abundant. Orogenic granitoids occur as small intrusions and locally granitic pegmatites are common (e.g. Mäkitie & Lahti 1991, Vaarma & Pipping 1997).

The Vaasa granitoid complex (ca. 6000 km²) is mainly composed of rather homogeneous, porphyritic to even-grained granodioritic rocks (Laitakari 1942),
Table 1. Chemical and modal composition of the studied granitoids. n.d. = not determined, + = rarely detected, - = not detected. ‘Others’ refers to zircon, opaque, chlorite etc. (continues on next page)

<table>
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<tr>
<th>Geological unit</th>
<th>Central Finland granitoid complex (CFGC)</th>
<th>Others</th>
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<td>Granodiorites</td>
</tr>
<tr>
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<td>S-part</td>
</tr>
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which in the research area are diatexites according to the authors. Diatexite refers to a rock having a fairly plutonic texture, which is formed by complete or nearly complete melting of supracrustal source material (cf. Mehnert 1971). The VGC rocks locally resemble plutonic rocks, but also various nebulitic migmatite types are known. The contact between the VGC and the PSB is gradual, and is composed of metatexitic garnet-cordierite-mica gneisses. Metatexitic is a textural term that is used to describe
high-grade metamorphic migmatitic supracrustal rocks, which are partially melted (cf. Mehnert 1971).

The regional metamorphic grade in the research area varies from lower amphibolite facies to granulite facies with a low-pressure intermediate type (Mäkitie 1990, Mäkitie & Lahti 1991). The pyroxene-bearing granitoid intrusions have overprinting contact metamorphic aureoles. There are major shear zones in the area (see Korsman et al. 1997).

<table>
<thead>
<tr>
<th>Granitoid types</th>
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### Field classification and petrography

Granitoids of the research area were classified into three main groups on the basis of their geological unit (geological surroundings) (cf. Table 1). Each main group is further divided into several petrographical subgroups as follows:

Table 1. Continued.

<table>
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<tr>
<th>Geological unit</th>
<th>Pyroxene granite</th>
<th>Porphyritic quartz monzonite</th>
<th>Granitic gneisses</th>
<th>Granodioritic intrusions</th>
<th>Pegmatite/Aplite granite</th>
<th>Pegmatite diorites</th>
<th>Porphyritic diorites</th>
<th>Even-grained diorites</th>
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A) Granitoids of the Central Finland granitoid complex:
1. Tonalites
2. Granodiorites
3. Porphyritic granites
4. Pyroxene granite
5. Porphyritic quartz monzonite
6. Granitic gneisses

B) Granitoids within the Pohjanmaa schist belt:
7. Granodioritic intrusions
8. Pegmatite granites and aplitic granites

C) Granitoids of the Vaasa granitoid complex:
9. Porphyritic diatexites
10. Even-grained diatexites

Tonalites, porphyritic granites, porphyritic diatexites and even-grained diatexites, as the four most extensive granitoid types, were studied in still smaller subareas to understand the possible variation within the granitoid type (cf. Table 1). The boundaries of the subareas are shown by lines in Figure 1.

Tonalites (1). Tonalites are synkinematic, intrusive rocks belonging to the CFGC. The main rock type is a predominantly even-grained (1 - 3 mm) grayish tonalite, locally gneissic in texture, and typically containing more biotite than hornblende, and a few dark enclaves and granitic veins (Fig. 2a). Tonalite occupies large areas in the Jalasjärvi and Peräseinäjoki area (Lahti & Mäkitie 1990).

Tonalites were studied from seven different subareas, named after their geographic position: a) SE-part, b) S-part, c) middle part, d) NW-part, e) N-part, f) Luhtalankylä and g) contact aureole of Luopa quartz monzonite (cf. Fig. 1 and Table 1).

The Luhtalankylä tonalite, which locally grades into granodiorite, is situated inside PSB but very near the main body of the CFGC. Tonalite samples from the contact aureole have distances less than 100 m from the porphyritic quartz monzonite of Luopa.

Granodiorites (2). Limited areas near the tonalites contain even-grained or poorly porphyritic granodiorites, which locally intersect tonalites (cf. Fig. 2a) (Lahti & Mäkitie 1990). Often these granodiorites are weakly foliated and include 1-2 % epidote. The grain size of K-feldspar is usually slightly coarser than that of plagioclase. Two small granodiorite areas were studied, one of them is situated on the northern and the other on the southern side of the village of Ratikylä, about 10 km east of the church village of Jalašjärvi (Fig. 1).

There is also a variable group of chloritized tonalites and granodiorites, hornblende-rich quartz diorites and streaky gneissic granodiorites within the research area. The compositional variation of these minor rock types are not studied.

Porphyritic granites (3). Reddish gray, porphyritic hornblende-bearing granite occurs in four localities. The texture of the rock is characterized by phenocrysts (1-3 cm) of K-feldspar. The granites studied near the villages of Koskue and Ahonkylä are parts of large plutons that continue outside the research area. Those granites observed in the Nikola and Kalakoski villages form small intrusions (Fig. 1) (cf. Lahti & Mäkitie 1990). The Nikola granite is smaller in grain size (2-7 mm) than the other granites. These rocks intersect surrounding tonalites. The granites are usually weakly foliated.

Two sets of samples were taken from the Koskue and from the Kalakoski granites, one of them from the inner parts and the other from the border parts of the intrusions - to see the possible zoning within...
the intrusions (cf. Table 1).

**Pyroxene granite (4).** Reddish gray, pyroxene-bearing granite occurs at Luopa, about 30 km southwest of the town of Seinäjoki. It is weakly porphyritic and in places weakly deformed. Pyroxene granite is spatially closely associated with Luopa quartz monzonite. The contact between the pyroxene granite and the neighbouring porphyritic granite of Ahonkylä is not found.

**Porphyritic quartz monzonite (5).** Some 20 km southwest of the town of Seinäjoki and 5 km northeast of the village of Luopa there is an irregular, almost undeformed, post-kinematic porphyritic quartz monzonite stock (age 1871±1 Ma) (Lahti & Mäkitie 1990, Mäkitie & Lahti 1991). Phenocrysts (1-4 cm) of the rock are composed of K-feldspar. The mafic main minerals in the quartz monzonite are hornblende, biotite, clinopyroxene and fayalite. The intrusion is composed of two different colour-types: a dark greenish variety and a gray pinkish variety that is less common (Table 1). The quartz monzonite is often strongly weathered. The rock intersects surrounding tonalites and pyroxene granites.

**Granitic gneissses (6).** Granitic gneisses, which have gradual contacts to the surrounding rocks occur in two localities, one of them at Varvenkylä, Ilmajoki and the other at Kalajärvi, Pääräseinäjoki. These gneisses are located at the boundary of the CFGC and the PSB, and in the vicinity of major faults and deformation zones. The various granodioritic gneisses at Varvenkylä gradually change from meta-arkosites and mica gneisses. The relatively homogeneous granitic gneiss at Kalakoski has a gradual contact, associated with the increase of deformation, to the surrounding tonalite. Dark elongated inclusions, porphyroblastic K-feldspar grains, the absence of hornblende and strong deformation are typical features in the granitic gneisses.

**Granodioritic intrusions within the PSB (7).** There are relatively small (< 30 km²) separate, mostly granodioritic intrusions in the central parts of the Pohjanmaa schist belt (e.g. Mäkitie & Lahti 1991, Lehtonen & Virransalo, in press). In the research area they are called the Orisberg, Vittinki and Nurmo-Hirvijärvi intrusions (Fig. 1). Biotite is the characteristic mafic mineral. Hornblende is found only in the southeastern part of the Nurmo-Hirvijärvi intrusion.

These deformed granitoids are relative homogeneous in outcrop scale, but their texture and composition often differ between outcrops. The abundances of K-feldspar and plagioclase vary so widely that some variations are actually tonalites and granodiorites.

**Pegmatite granites and aplite granites (8).** The granitic pegmatites in the research area have been described in many publications and reports (e.g. Haapala 1966, Oivanen 1983, Kärkkäinen 1986, 1993, Alviola 1989). In this study the chemistry of coarse-grained pegmatite granites and medium-grained aplite granites in the surroundings of the town of Seinäjoki are studied. Both rock types form tens of metres wide intrusions in the area. The smaller pegmatite dykes are mineralogically very complex and their composition is not discussed in this connection.

**Porphyritic and even-grained diatexites (9-10).** The granitoids studied in the VGC are typically fairly homogeneous, porphyritic or even-grained granodioritic diatexites (Fig. 2b), in places gneissic in texture. The contact between these diatexites is gradual. Biotite is a characteristic mineral, but hornblende, sphene and dark enclaves are absent. Relicts of concretions and schists are fairly common. Garnet and secondary muscovite are often common accessory minerals. As important accessory minerals the VGC granitoids locally contain minor monazite, sillimanite and andalusite. The porphyritic nature of the rocks varies; locally the diameter of phenocrysts can reach 6-7 cm, but there also occur poorly porphyritic types.

The VGC granitoid samples are from five localities. Even-grained (2-5 mm) rocks are from the Söderskogen, Kaurajärvi N and Lehmajoki areas around the Vöyri commune (Fig. 1). Inclusions are rare in diatexites of the Kaurajärvi area. Porphyritic rocks are from the Lägelpelt area, a few kilometers southeast of Vöyri, and from the Järviranta area about 20 km southeast of Vöyri.

**Modal composition**

At least three thin sections were point counted from each granitoid type or area (cf. Table 1). The pegmatite granites and aplite granites were not point counted. Granitoids from the VGC and from the PSB are mostly granodiorites by the classification of Streckeisen (1976) (Fig. 3a). Granitoids from the CFGC are more dispersed within four fields of Streckeisen’s diagram (Fig. 3a).

At the boundary of the CFGC and the PSB there occur mineralogically two varieties of tonalites. Hornblende-rich tonalite is common near the pyroxene-bearing quartz monzonite of Luopa, but hornblende is rare in tonalites situating further away from the quartz monzonite (cf. Fig. 1 and Table 1). Also the granite of Ahonkylä, which situates near
the Luopa pyroxene granitoids, includes relatively much hornblende compared to other granites (Table 1). Pyroxenes in the tonalites within the contact aureole of Luopa quartz monzonite are metamorphic minerals. Sphene and epidote in these pyroxene tonalites are not stable due to the high-grade metamorphic conditions of the aureole.

**Chemical composition**

**General**

The samples used for chemical analyses are drill powder, core samples and hand specimens weighing 1-3 kilograms. Samples were analysed in the Chemical Laboratory of Geological Survey of Finland, in the Technical Research Centre of Finland and in the Chemical Laboratory of the Rautaruukki Company. The major elements and Rb, Sr, Ba and Zr were analysed by the XRF- and ICP-MS-methods, Ga and Y by OES, and Cs, Sc, La, U and Th by INAA and XRF.

The average SiO₂ content of the granitoid types from the research area ranges from 59.27 to 73.78 wt% (Table 1). Standard deviations of the analyses are given in Appendix 1, and codes of all the analysed samples are in Appendix 2.

Only the quartz monzonite is classified in the field of alkaline rocks in the alkalis-silica diagram of Irvine and Baragar (1971), even though in the Streckeisen diagram it is clearly not an alkaline rock. CIPW normative (weight norm, FeO and Fe₂O₃ after Irvine and Baragar 1971) mineral classification differs by some degree from Streckeisen’s modal-based classification. Granodioritic diatexites of the VGC and granodioritic intrusions within the PSB are granodiorites by modal classification, but in normative mineral classification they are granites (Figs. 3a and 3b). These differences are mostly due to the relatively high mode of biotite in the rocks. Biotite contains much K₂O, which increases the amount of normative orthoclase (K-feldspar) so much that these granitoids plot in the field of granites in the normative mineral classification. Biotite belongs to mafic minerals in the diagrams of Streckeisen (1976), and is not used in the classification of granitoids.

**Harker and minor element diagrams**

In Harker diagrams the studied granitoids usually are distributed within a more or less linear trend (Fig. 4). In the CaO-SiO₂ diagram the VGC diatexites and the CFGC granitic gneisses cluster slightly separately compared to other granitoids (Fig. 4). In the Na₂O against SiO₂ diagram the linearity of the plots is poor. A clearly different group of Harker and other chemical diagrams is the quartz monzonite with, for example, the unexceptional high Fe/Mg
Phosphorus and Ti generally decrease during magmatic differentiation of granitoids, until an increase of P in the latest fractionation products, granitic pegmatites (Fig. 4). The granodioritic diatexitcs in VGC contain relatively much titanium and locally P. This is likely due to the composition of melted source material that is suggested to contain a high proportion of sedimentary rocks.

Ba/Rb-ratio, a common fractionation index, is generally lower in VGC diatexitcs and in PSB granodioritic intrusions compared to the CFGC plutonites (Fig. 4). Another fractionation index, Rb/Sr, separates nicely the tonalites, granodiorites and quartz monzonite from other granitoids (Fig. 4). The fractionation index, K/Rb, is rather similar in all granitoids except the quartz monzonite (Table 1).

**Source and geotectonic diagrams**

There exist many approaches to link the chemical composition of granitoids to their source rocks and tectonic setting (e.g. Barbarin 1990). In the research area A/CNK value, alumina saturation-index (after molar Al₂O₃, CaO, Na₂O, K₂O, Shand 1947), varies between 0.91 and 1.32. Generally the A/CNK values increase from the Central Finland granitoid complex to the Vaasa granitoid complex (Figs. 1 and 5a). The CFGC is characterized by the I-type (A/CNK < 1.1) granitoids. The VGC is composed of S-type (A/CNK > 1.1) granitoids. Pegmatite granites, aplite granites and granodioritic intrusions within the PSB belong also among S-type granitoids. The quartz monzonite of Luopa is a metaluminous (A/CNK < 1.0) rock. Low A/CNK values (<1.1) imply source
rocks of mafic to intermediate igneous composition or infracrustal derivation, but high A/CNK values (>1.1) imply source rocks of sedimentary or supracrustal protoliths (Chappell & White 1974). Noteworthy is that a ‘hornblende out’ isograd occurs in granitoids between CFGC and VGC (cf. Fig. 1).

The Koskue and Kalakoski porphyritic granites of CFGC seem to be zoned, because the border parts have lower A/CNK values compared to the inner parts of the intrusions (Table 1). This is in consistent with the observation that the inner parts include less hornblende compared to the border parts (which are more mafic). However, fractionation indexes (as Rb/Sr) do not clearly agree with interpretation that the inner parts of these intrusions represent a more fractionated granitic material.

In the Rb-SiO₂ diagram of Pearce et al. (1984), all rocks of the research area belong to within-plate granites (WPG) (Fig. 5b). Quartz monzonite and tonalites plot in the field of volcanic arc granites (VAG), but other granitoids are transitional between the syn-COLG and VAG granites (Fig. 5b).
The post-kinematic quartz monzonite of Luopa has some high Ga/Al ratios detected from the analysed granitoid samples. This supports (cf. Whalen et al. 1987) - with other chemical characteristics - the fact that Luopa quartz monzonite has a different source compared to other granitoids within the research area.

**Modal-chemical diagrams**

Many differences in the modal composition of granitoids in relation to the chemical composition depend on the concentrations of Ca, Na, and K, which are components in the A/CNK ratio. The sum of CNK can be similar in different samples, but at the same time the element concentrations (Ca, Na, K) may vary widely. For example, tonalites have higher CaO but smaller K₂O than granites, and thus the element concentrations (Ca, Na, K) may vary widely. For example, tonalites have higher CaO but smaller K₂O than granites, and thus tonalites contain abundant andesitic plagioclase, but granites are enriched in K-feldspar.

The modal-chemical diagrams show that the tonalites and porphyritic granites have relatively similar A/CNK values, even though the modal variation of plagioclase is large (Fig. 6a). As opposite, in other granitoid types, the modal variation of plagioclase is often small, although the A/CNK values are largely different in the same samples.

Diatexites of the VGC separate from other granitoids by their high values both in the A/CNK and modal biotite (Fig. 6b). The granitoids of the VGC are characterized by high mode of biotite, however, simultaneously there is much overlap with other element concentrations (Figs. 6c-6e). For example, in the VGC granitoids all iron is predominantly concentrated into biotite, whereas the CFGC granitoids include also another Fe-bearing mineral, hornblende (Fig. 6d). The NK/A values in the CFGC granitoids do not correlate with the hornblende content of the rocks (Fig. 6f).

**Discussion**

The observed chemical and modal compositions of the main rock types in the Central Finland granitoid complex and in the Vaasa granitoid complex support the idea of a different source of the rocks. The granitoids from the CFGC have an igneous origin, whereas the VGC granitoids have a sedimentary source, even though many granitoids in the VGC are texturally almost plutonic indicating total melting and true magmatic stage. By contrast the granitoids of the CFGC are locally gneissic in appearance but their chemical composition indicates plutonic source. The granodioritic intrusions within the Pohjanmaa schist belt differ from the granitoids of the CFGC and the VGC in that they mostly have clear plutonic texture but still they belong to S-type granitoids.

The modal and chemical classifications of the granitoids studied do not strictly correlate. Tonalites and porphyritic granites locally have similar A/CNK values, even though their modal composition varies. In addition, the chemical and modal compositions are regionally variable in the tonalites and porphyritic granites of the CFGC and in the VGC even-grained diatexites. Thus, it is important to have comprehensive field observations when studying the compositional data of granitoid rocks.

**References**


Lehtonen, M.I. & Virransalo, P. Jurva. Geological Map of
Appendix 1. Standard deviations of the analyses shown in Table 1. - = not determinated, 0 = very small.

<table>
<thead>
<tr>
<th>Geological unit</th>
<th>Central Finland granitoid complex (CFG)</th>
<th>Pohjanmaa schist belt</th>
<th>Vaasa granitoid complex</th>
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<td>Granodiorites</td>
<td>Porphyritic granites</td>
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Appendix 2. Codes of the chemical analyses used in the present study (cf. Table 1). Analyses are archived in the Geological Survey of Finland (KALTIE-database).

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<th>Granitoid type</th>
<th>Codes of the analysed samples</th>
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