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AVHANDLINGAR OCH UPPSATSER

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PETER KRESTEN

THE GRANITES  
OF THE VÄSTERVIK AREA  
SOUTH-EASTERN SWEDEN



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Address:

Peter Kresten

Sveriges Geologiska Undersökning

Box 670

S-751 28 UPPSALA

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## ABSTRACT

KRESTEN, PETER, 1985-12-19: The granites of the Västervik area, south-eastern Sweden. Sveriges geologiska undersökning, Ser. C, No. 814, pp. 1-35, Uppsala 1986.

The Early Proterozoic Västervik formation (mostly meta-arenites) is intruded by a number of granitoid plutonic rocks. On the basis of field and geochemical studies, it is concluded that the older, primorogenic intrusions are I-type granitoids emplaced in a Cordilleran-type environment, most likely a volcanic arc. Differences in the chemical composition between various primorogenic plutons are interpreted as being due to various degrees of partial melting of a quartzo-feldspathic parent. Late orogenic and postorogenic intrusions show S-type (Hercynio type) characteristics. The anorogenic Göttemar granite is an A-type, highly evolved, within-plate-type granite.

## INTRODUCTION

The Västervik formation of south-eastern Sweden is made up of Early Proterozoic (1700–2300 Ma) metasediments (predominantly quartzites) and metavolcanics, intruded by various basic dikes as well as granitoid plutons. The minimum thickness of the entire metasedimentary column is estimated to 5000 m. Metamorphic conditions range from greenschist facies to amphibolite facies; occasionally, hornfels facies rocks are found (Kresten 1971 b, S. Gavelin 1984).

The chronology of the major rock units is given in Table 1. A detailed account of the geology of the area has recently been presented by S. Gavelin (1984), mainly dealing with the supracrustal rocks. The present account of the granites of the area, based upon the author's field work from 1967 to 1973 and subsequent analytical work, complements S. Gavelin's (1984) paper.

The granites of the Västervik area have been discussed since A. Gavelin (1904) introduced the term "Loftahammar granite" for "a red, usually coarse-grained and markedly porphyritic gneissic granite" (*op. cit.*, p. 7, my translation), which he regarded as now being an older granite, possibly the basement of the Västervik formation. He noted the presence of intrusive basic dikes in the Loftahammar granite; similar intrusions were not to be found in the younger Småland granites. This was the starting point of a fierce discussion between Holmquist (1905a, b) and A. Gavelin (1905) regarding the differences between Loftahammar and Småland granites as well as the issue of the basement. In 1910, A. Gavelin re-defined the term "Loftahammar granite" as embracing not only the granites of the Loftahammar massif (Fig. 1), but even similar granites occurring elsewhere in the Västervik area. He acknowledged the evidence put forward by Holmquist (*op. cit.*) on the intrusive behaviour of the Loftahammar granite with respect to the metasediments.

Svenonius (1905, 1907, 1914) regarded the Loftahammar granite as a variety of the Småland granites, admitting that granites of somewhat different ages might exist. Sundius (1926) clearly distinguished older and younger granites by the occurrence of cross-cutting intraorogenic basic dikes in the former.

The obvious discrepancies in the geological maps, some distinguishing between older (brown colour on the map) and younger (red colour) granites, others showing all granites by red colour, has led to misinterpretations. Priem *et al.* (1969) carried out Rb-Sr age determination studies of one sample labelled "Lof-tahammar granite" and another labelled "Småland granite", both of which are in fact samples of the older granite intrusions. As the ages obtained are very similar – which, with better knowledge of the geology, would not have been surprising – Westra *et al.* (1969) concluded that "the granite gneisses form part of the so-called Småland granites".

The granite classification used here closely follows the one used by S. Gavelin (1984), adapted to the chronology of the Svecokarelian belt (Lundqvist 1979). The older (primorogenic) intrusions are sub-divided into older granodiorites and older granites. Younger intrusions are sub-divided into late orogenic intrusions, postorogenic intrusions (the Småland granites) and the anorogenic Göttemar granites.

For the interpretation of the age-relationships of the individual granite intrusions, the basic dikes play an important role. This was first realized by A. Gavelin (1904), who used basic dikes in order to distinguish older granites from the younger ones. Elbers (1971) briefly outlined the position of three major generations of basic dikes in relation to folding and metamorphism. Kresten (1972) described seven different generations of basic dykes with dacitic to basaltic compositions, linking them to tectonics, metamorphism and granite intrusion. A full discussion of these seven dike generations, with petrographic and chemical data, has been given by S. Gavelin (1984).

## PETROGRAPHY AND FIELD RELATIONS

### THE OLDER (PRIMOROGENIC) PLUTONIC SEQUENCE

The older (primorogenic) plutonic sequence is sub-divided into two major rock units: the older granites and the older granodiorites (Table 1). The former comprise the "Loftahammar granites" (A. Gavelin 1904) and the "Örö-Hamnö-granites" (Kresten 1974), among others. In order to avoid further confusion, these terms are used in a strictly geographical sense only.

#### OLDER GRANODIORITES

The older granodiorites were distinguished by Kresten (1974) as older plutons differing from the older granites in several respects. One of these is their apparently massive appearance, although a lineation is sometimes present. In 1974, the existence of older (primorogenic) plutons without pronounced schistosity was new to the area, although similar rocks were well-known from other parts of

TABLE 1. Proterozoic chronology of the Västervik area (modified after Lundqvist 1979).

Age, Ma	Major rock units
<i>Postorogenic and anorogenic complexes</i>	
900–1000	Dolerites
1350–1400	Götemar granites
1645–1690	Småland granites, Småland porphyries
<i>Late orogenic complexes</i> (1750–1800)	
	Dynestad massif?
	Aplitic granites?
<i>Primorogenic intrusions</i> 1845–1910	
	Older granites, Loftahammar
	Older granites, Örö-Hamnö
	Older granodiorites?
<i>Oldest supracrustals</i> ≤1950	
	Metavolcanics
	Gneisses, schists
	Västervik quartzite
<i>Inferred basement of Västervik quartzite (2200–2465 Ma)</i>	

southern and central Sweden (Lundqvist 1979). Subsequently, a systematic mapping of the area revealed that the older granodiorites constitute an important and abundant member of the older plutonic sequence (Fig. 1). Field observations indicate that they most often are somewhat older than the gneissic granites. As the older granodiorites have been treated only very briefly by S. Gavelin (1984), a more detailed presentation is included here.

The older granodiorites are generally grey to reddish grey, medium-grained, even-grained or slightly porphyritic rocks. In composition, they range from granite, granodiorite and quartzdiorite to tonalitic and monzonitic varieties; granodioritic compositions being most common. Xenoliths of metasediments and metabasites are much more frequent than in any other intrusions, except for the immediate contact zones of the Småland granites. In some cases, xenoliths constitute more than 50% by volume of the rock. In addition, xenoliths or clots of basic restite material (see White and Chappell 1977) are particularly abundant in the older granodiorites, as are flow layers (Mehnert 1968, Fig. 82). Typically, both texture, composition and xenolith content show rapid and seemingly irregular changes within one massif, similar to the primorogenic Jörn granite of Västerbotten county (S. Gavelin 1955). Restite xenoliths do not vary significantly in content within one massif.

In thin section, older granodiorites rarely show the granulation of quartz and feldspars typical for many of the gneissic granites (Kresten 1974), although not being a feature specific for the older plutonic rocks (S. Gavelin 1984). The contents of the major constituents vary considerably: quartz 10–25%, plagioclase ( $An_{25-40}$ ) 25–45%, microcline 15–25%, biotite and hornblende 10–40% (all by volume). Accessory phases include magnetite, sphene, apatite, zircon and pyrite.

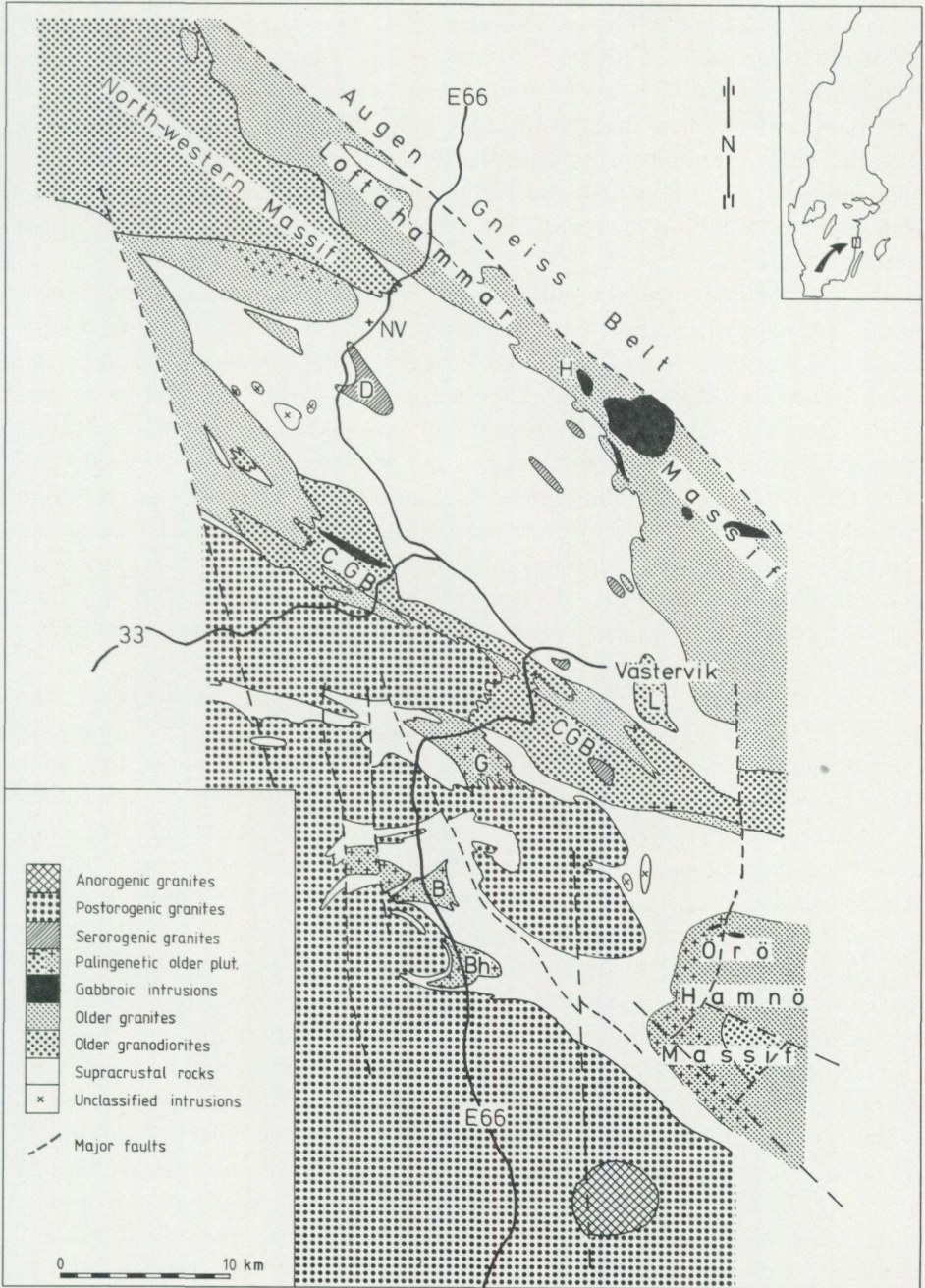


Fig. 1. Sketch map of the Västervik area, focussing upon granitoid intrusions. Abbreviations: B = Bofall massif; Bh = Blankaholm massif; CGB = central granodiorite belt; D = Dynestad massif; G = Gunnebo massif; H = Hula gabbroic intrusion; L = Lucerna granite, NV = Nya Vida. For more detailed map and sections, see S. Gavelin (1984).

Within the Örö-Hamnö-massif (Kresten 1974), the older granodiorites occupy a roughly triangular area (Fig. 1), with two of the boundaries being fault zones. Relationships between the older granodiorites and the older granites along the unfaulted contacts show that the two rock units either grade into each other, or that the older granodiorite is intruded by the older granite as well as by a paligenetic older granite. The older granodiorites are (reddish) grey, schlieric, with abundant xenoliths of amphibolite, restite clots, as well as some xenoliths of supracrustal rocks.

The rocks of the central granodiorite belt (Fig. 1) vary considerably in composition and texture. In its north-western parts, a coarse-grained gabbroic dike is found. Along its western termination, the latter brecciates the granodiorite; towards the east, on the other hand, the rocks seem to grade into each other, and at the eastern termination of the dike, it is brecciated by the granodiorite. This is interpreted to indicate a close temporal, and possibly genetic, relationship between the gabbro and the granodiorite. Similar relationships have been reported from the Jörn granites (S. Gavelin 1955) and can be found in the Falun area of central Sweden (Kresten, unpubl. map sheet). South of Västervik, the older granodiorites are markedly schlieric or layered, the latter pattern being emphasized by *lit-par-lit* intrusions of red leucocratic older granite, which here is clearly younger than the granodiorites.

Close to Västervik, a minor isolated intrusion of older granodiorite occurs, the so-called "Lucerna (or Judö) granite", which has been regarded as belonging to the postorogenic Småland granites by S. Gavelin (1984), although already in 1907, Svenonius noted that the rock was foliated. The Lucerna granite is here grouped among the older granodiorites, because of the presence of cross-cutting basic dikes, lineations, and a close resemblance to the other occurrences of older granodiorites. Flow layers and strictly oriented basic clots are particularly common in the Lucerna granite, indicating a principal flow direction from SE towards NW (inclination 45–60°), in accordance with the concept of the massif representing an off-shoot from the granodiorite belt in the south (Fig. 1). Xenoliths of supracrustal rocks (mainly quartzites), often of tabular shape, are common. Contacts between the Lucerna granite and the surrounding metasediments are sharp and characterized by contact metamorphic aureoles in the wall-rock.

The north-western massif is the largest coherent mass of older granodiorite in the area. The rocks were classified as belonging to the Småland granites by Sundius (1926). He noted, however, the well-developed gneissic texture in some parts of the massif, as well as the presence of intersecting dikes of gabbros and diorites, which sometimes show gradations to the wall-rock similar to those described above. Intersecting intraorogenic dikes (generation IV of Kresten 1972) are particularly common in the south-eastern part of the massif, where also intrusions of red, fully gneissic older granite occur. The contacts to the supracrustal rocks clearly demonstrate the intrusive behaviour of the older granodiorite.

This is also witnessed by the great abundance of xenoliths of supracrustal rocks in some parts of the massif. Spectacular plate-like quartzite xenoliths occur, 20–30 cm thick, at least 6 m high and 15 m long, as seen in a road-cutting north of Överum, in the south-central parts of the massif. To the north, the contacts with the older granites are complicated: a cautious interpretation would be that the granodiorites are slightly older than the gneissic granites.

Minor granite intrusions, mainly dikes, occur at Nya Vida (Fig. 1). They have suffered from deformation (S. Gavelin 1984, Fig. 59) and are therefore provisionally allocated to the older granodiorite group.

#### OLDER GRANITES

The older granites have been discussed in detail by S. Gavelin (1984), and only a brief summary is given here. They are usually gneissic to blastomylonitic, with (broadly) granitic compositions. Throughout the area, they seem to occupy antiformal structures, such as domes and ridges, arching up the supracrustal rocks, the s-surfaces in the older granites being parallel to the contacts. They appear to be synkinematic intrusions.

The contacts between the older granites and the supracrustal rocks are generally sharp. Typically intrusive contacts are rare. Xenoliths of metasediments and metabasites occur, although they are much less common than in the older granodiorites. Basic xenoliths and clots are rare. Cross-cutting dikes of basic rocks (generation IV) are common; in the Loftahammar massif, major gabbros occur (Fig. 1). Dikes of massive or slightly gneissic granites intersecting the older granites are common in all massifs. Within one massif, variations in texture, composition and xenolith content occur, although these are not as pronounced as in the older granodiorites.

The following major intrusions of older granites are found in the Västervik area: the Öro-Hamnö-massif (Kresten 1974), minor massifs around Bofall (S. Gavelin 1984), the intrusions south, south-west and north-west of Västervik (Fig. 1), and the Loftahammar massif, which is the most amply documented one (A. Gavelin 1904, 1910, Hahn 1971, Elbers 1971, Hoeve 1974, 1978, S. Gavelin 1984). A repetition of the field data for the older granites seems superfluous in view of the many detailed published descriptions referred to previously. Major differences in the chemistry of the individual older granite massifs will be dealt with below.

#### THE MELANOCRATIC AUGEN GNEISSES

North-east of the Loftahammar massif, a belt of melanocratic augen gneisses occurs, separated from the massif by a major fault zone (Fig. 1). Typical augen gneisses from this zone are made up of large – up to egg-sized – rounded

“porphyroblasts”, consisting of quartz, feldspars and little mafic minerals, set in a dark grey to almost black matrix composed of biotite, hornblende and sphene (A. Gavelin 1904, Fig. 1). These augen gneisses occur together with (mainly amphibolitic) metavolcanics, and various intrusions of older as well as younger granitoids.

Superficially resembling some of the older granites, they have been referred to as “dark Loftahammar granites” (A. Gavelin 1904). Field observations cast some doubt on their origin. Most probably, they have been formed by *in situ* metasomatism of a metasomatism of a volcanic suite composed of andesites to basalts with intercalated rhyolite. A detailed study on these rocks is in progress. At present, data are included in relevant diagrams merely for comparative purposes.

Wikström (1984) advanced a modified balloon tectonics model for the derivation of augen gneisses in the Finspång area from the postorogenic granites. Although not explicitly stated, it is evident that Wikström (1984) finds the model applicable to the formation of both the melanocratic augen gneisses and the older granites of the Loftahammar massif. For the Västervik area, Wikström's (1984) model lacks support from mineralogical, chemical, radiometric and field geologic evidence presented throughout the years for the differences between the older (primorogenic) and younger (post-orogenic) plutons of the area.

#### PALINGENESIS OF OLDER PLUTONS

The term “palingenesis” is used here in a purely descriptive sense, implying the regeneration and renewed intrusive activity of a pluton, independent of the genetical processes involved. The first examples of palingenetic processes affecting older plutons were provided by A. Gavelin (1904) for the Loftahammar massif. Since then, field work has produced ample evidence for palingenesis of the older plutons throughout the area, by plastic flow in the solid state, by partial melting processes, or by “digestion” of an older pluton by a younger one.

A striking example of palingenesis of the older granodiorite has been given by Kresten (1972, Fig. 12). At Händelöp, about 8 km south of Västervik, the older granodiorite is brecciated by basic dikes. Regeneration of the rock by laminar flow has resulted in the dike being incorporated as fragments in the granodiorite. S. Gavelin (1984) has supplied further details on the petrography and chemistry of the rocks involved.

Palingenesis of the older granites is found in all the massifs studied. Commonly, it is reflected by bent or broken basic dikes (A. Gavelin 1904, Kresten 1974, S. Gavelin 1984) within the fully gneissic older granite. Large-scale palingenetic processes leading to the formation of large masses of granite have been described by Kresten (1974). The palingenetic Hamnö granite has been formed by differentiation in the solid state, resulting in a leucocratic mobilizate and a more mafic

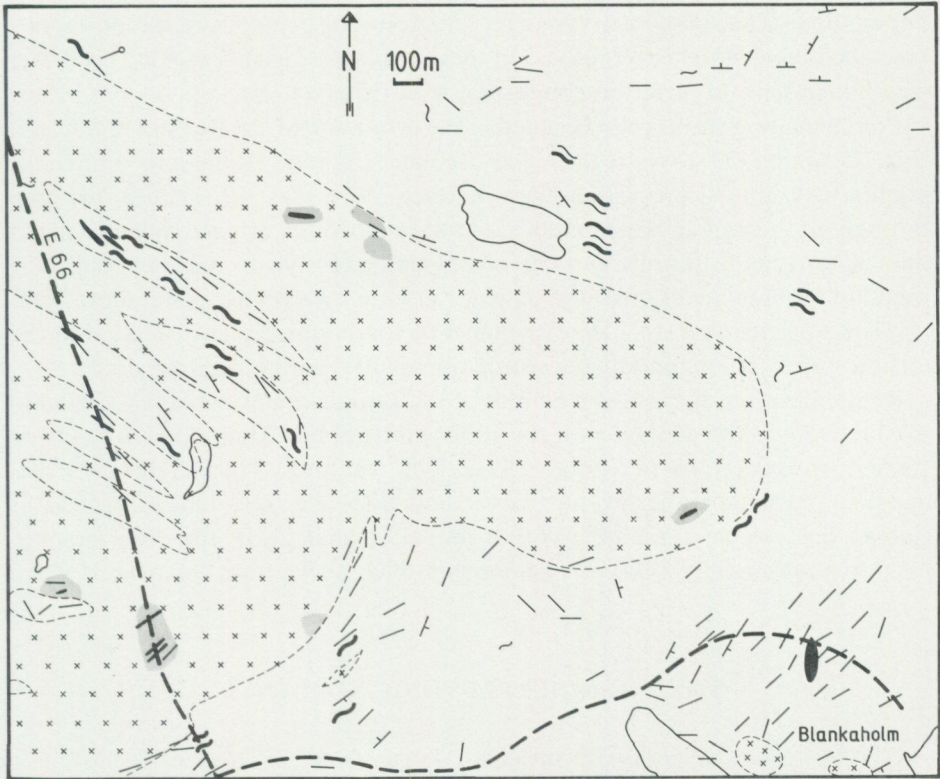


Fig. 2. Map of the Blankaholm massif. Apparently "younger" granite (crosses) with remnants of highly resorbed older granite (shaded), up-doming supracrustal rocks (blank). Intrusions of metabasite are shown in solid black; heavy wavy lines indicate granite veining.

residue. The mobilizate (i.e., the Hamnö granite), although apparently massive in hand specimen, has strictly oriented quartz, with the crystallographic *c*-axes parallel to the tectonic *a*-axes. The process, which is illustrated by field evidence and chemical data, seems to have taken place at fairly moderate temperatures, as contact metamorphism is absent in the meta-argillites of the contact zone. Contact metamorphism in the southern part of the Västervik area, leading to corundum-bearing assemblages, has been found in a dome-shaped structure, possibly overlying an intrusion of (older?) granite at depth (Kresten 1971b).

In some cases, older granites grade into typical younger granites of the Småland type via a series of intermediate rocks. One example is the small massif near Bofall (Fig. 1; S. Gavelin 1984, Fig. 60), showing a core of strongly porphyritic gneissic granite intersected by basic dikes, surrounded at first by a number of more fine-grained, gneissic or massive granites and, finally, by the Småland granite. The contact between the Gunnebo massif of gneissic granites (Fig. 1) and the Småland granites to the south is characterized by intense veining and breccia-

tion of the older granite by the younger one, resulting in a transition zone about 3 km wide between the two plutons. In these two cases, partial melting processes most likely have occurred in connection with palingenesis.

Partial melting seems to have acted in the formation of the Blankaholm massif (Fig. 2), which has to be regarded as a younger granite. Remnants of gneissic granite with intersecting basic dikes (Kresten 1974, Figs. 10, 11) are scattered throughout the massif, which seems to have retained the original dome-shape of the older granite intrusion (Fig. 2). Consequently, it may be called a pseudomorphous replacement of an older granite by a younger one, most likely involving partial anatexis. The fragments of supracrustal rocks included in the intrusion (Fig. 2) commonly consist of sillimanite-bearing flecky gneisses.

Remobilization of the older granite of the Loftahammar massif by partial to total melting at the contact with the gabbro intrusion at Hula (Fig. 1) has been studied by Bakker (pers. comm. 1971). The resulting "Hula granite" is red, massive and leucocratic. Major, minor and trace element data as well as Sr isotope data are in agreement with a model of anatexis of the older granite, including the transfer of some components, such as Sr, from the gabbro.

## THE YOUNGER PLUTONIC SEQUENCE

### LATE OROGENIC INTRUSIONS

Late orogenic, late kinematic intrusions seem to be rather rare in the area. Small massifs of red aplitic granite SSW and W of Västervik (Fig. 1) are here grouped among the late orogenic intrusions. Similar aplitic intrusions in the archipelago NNW of Västervik have been described by Sijperda (1968), Westra *et al.* (1969) and Hahn (1971). They cross-cut the intraorogenic dikes (generation IV), but are commonly somewhat gneissic. Sijperda (1968) classified them as being anatectic granites.

More medium-grained, slightly gneissic granites have been studied by Bakker (pers. comm. 1971). The published Rb-Sr whole rock isochron age of 1600 Ma (Priem and Bakker 1969; recalculated to the decay constants of Steiger and Jäger 1977) is within the range of ages obtained for the postorogenic Småland granites (Table 1).

The Dynestad massif near Gamleby (Fig. 1) is made up of reddish grey to reddish, medium-grained, slightly porphyritic granites. Most often, they are massive, but sometimes clearly gneissic. The massif is provisionally grouped among the late orogenic intrusions. The unclassified intrusions of granodioritic to monzodioritic rocks to the west of the Dynestad massif (Fig. 1) could represent either late orogenic or postorogenic intrusions.

It is admitted that the evidence presented for the existence of a late orogenic

group of granites is meagre. In Lundqvist's (1979, Table 2) chronology of major rock units in the Svecokarelian belt, south-eastern Sweden is apparently devoid of late orogenic intrusions. S. Gavelin (1984) groups all "younger granites" with the postorogenic intrusions. Detailed radiometric work is required in order to obtain additional evidence for the occurrence of late orogenic intrusions in the area.

#### POSTOROGENIC INTRUSIONS

The postorogenic Småland granites comprise a variety of different types. The principal varieties are grey, dark grey or reddish grey medium-grained, sometimes porphyritic granites (grey Våxjö type); they are succeeded by red, medium-grained, even-grained granites, followed by red, medium- to coarsegrained, sometimes porphyritic granites (red Våxjö type) and, finally, by flesh-red, strongly porphyritic granites.

Commonly, the Småland granites are massive, although B-tectonites, caused by the forceful intrusion of highly viscous magma, are found in some minor massifs. The large area of Småland granites are almost devoid of xenoliths. In areas close to contacts, the granites (particularly those of the grey Våxjö type) are crowded with xenoliths of supracrustal rocks and various metabasites. Gradational contacts, showing the effects of contact metasomatism, have been described, often showing intensive retrogressive metamorphism (Kresten 1971 a, b). Although development of veined gneisses is conspicuous along the contacts between the Småland granites and the Västervik formation, direct proof of contact metamorphism is rare. One example is the occurrence of spinel-bearing xenoliths of meta-argillites within the Småland granites (P. Fels, pers. comm. 1970).

A characteristic feature of the Småland granites – apart from the contact zones – is that they are rather homogeneous, with only minor variations in colour and grain size. Xenoliths are rare, basic clots almost absent, aplites and pegmatites occur only sporadically. This contrasts to the extraordinary variation encountered in virtually all older plutons, as outlined above.

#### THE ANOROGENIC GÖTEMAR GRANITE

The Götemar intrusion has been described by Kresten and Chyssler (1976). It is situated in the southern part of the investigated area (Fig. 1). The massif is roughly circular with a diameter of about 5 km. A major fault divides the massif into a western, deeper level and an eastern, shallower level. Three major granite types are found, of coarse-, medium- and fine-grained character. All are highly evolved alkali-rich granites, with high fluorine contents and low K/Rb ratios. intrusion is accompanied by pegmatites which invade the surrounding Småland

granites; the pegmatites often carry beryl and topaz. Along the contact zone, greisen formation has taken place in the Småland granites.

The Rb-Sr whole rock age of the Göttemar intrusion is  $1377 \pm 27$  Ma (Åberg 1978, Åberg *et al.* 1985). Rb-Sr whole rock – mineral ages are  $1352 \pm 21$  Ma (western part) and  $1380 \pm 21$  Ma (eastern part), reflecting a slower cooling history of the deeper parts (Åberg *et al.* 1985). K-Ar and U-Pb ages (Åberg 1978, Åberg *et al.* 1985, Smellie and Stuckless 1985) further illustrate the rather complex history of the Göttemar intrusion.

### Geochemistry

Geochemical research on the rocks of the Västervik area, conducted by a number of authors, has resulted in a large body of data. At present, a total of 182 whole-rock analyses of granitoid rocks from the Västervik area are available. S. Gavelin (1984) has listed a representative selection of analyses from the literature, together with several new analyses of granitoids. In order to avoid unnecessary duplication, the analyses of granitoids given in Table 2 include only new data.

In the following discussion of the major element geochemistry, the data have been provided as follows:

Older granodiorites: Kresten (1974), S. Gavelin (1984), Table 2.

Older granites: Svedmark (1904), A. Gavelin (1910), Sundius (1926), Hahn (1971), Bakker (pers. comm. 1971), Hoeve (1974), Kresten (1974), S. Gavelin (1984), Table 2.

Late orogenic granites: Hahn (1971), Bakker (pers. comm. 1971), S. Gavelin (1984).

Postorogenic granites: Svedmark (1904), Svenonius (1905), Kresten (1971a), S. Gavelin (1984), Table 2.

Anorogenic granites: Kresten and Chyssler (1976), Smellie and Stuckless (1985).

Analyses of supracrustal rocks (Loberg 1963, Russell 1969, Hahn 1971, S. Gavelin 1984) have been included in some of the diagrams. In addition, several hundred alkali analyses have been performed by the author and younger students.

Trace element analyses are from Bakker (pers. comm. 1971), Kresten (1974), Hoeve (1974), Kresten and Chyssler (1976) and Smellie and Stuckless (1985). Again, a large number of new analyses has been performed, most of which are reported in diagrams.

TABLE 2. Whole-rock analyses of granitoids from the Västervik area

Nr	1	2	3	4	5	6	7	8	9
SiO <sub>2</sub>	55.0	64.2	59.7	63.0	72.1	67.7	72.9	75.6	66.9
TiO <sub>2</sub>	1.3	0.82	0.93	0.95	0.41	0.48	0.26	0.29	0.77
Al <sub>2</sub> O <sub>3</sub>	20.8	16.8	16.2	16.1	13.8	15.9	12.8	12.3	16.0
Fe <sub>2</sub> O <sub>3</sub>	2.7	1.6	2.1	1.4	0.4	0.5	0.8	0.6	1.2
FeO	3.4	2.2	3.3	4.6	1.9	2.7	1.8	1.0	2.3
MnO	0.13	0.07	0.09	0.05	0.02	0.07	0.02	0.01	0.07
MgO	2.1	1.9	3.1	2.2	1.3	0.47	1.7	0.4	1.2
CaO	5.1	3.2	4.3	3.2	0.7	2.0	1.0	0.5	3.0
Na <sub>2</sub> O	4.1	3.2	3.1	2.0	2.6	3.5	4.5	2.5	2.9
K <sub>2</sub> O	3.5	5.1	4.8	3.5	5.5	5.8	1.1	4.9	2.9
H <sub>2</sub> O <sup>+</sup>	1.1	0.8	1.1	1.3	—	0.7	—	—	—
H <sub>2</sub> O <sup>-</sup>	0.1	0.1	0.2	0.2	—	0.1	—	—	—
P <sub>2</sub> O <sub>5</sub>	0.37	0.23	0.37	0.28	—	0.11	—	—	—
CO <sub>2</sub>	0.11	0.05	0.08	0.19	—	0.05	—	—	—
F	0.19	0.16	0.18	0.15	0.09	0.09	0.19	0.09	0.13
S	0.10	<0.02	<0.02	0.09	—	<0.02	—	—	—
BaO	0.28	0.19	0.18	0.07	0.08	0.13	0.02	0.02	0.21
Sum	100.39	100.62	99.72	99.28	98.90	100.30	97.09	98.21	98.98

1 PK 633 Older granodiorite SW of Västervik. 640415N, 154475E.

2 PK415 Older granodiorite north of Överum, north-western massif. 643450N, 153012E.

3 PK420 Older granodiorite, Överum, north-western massif. 643045N, 153010E.

4 PK-D4 Older granodiorite (?) dike, Nya Vida. 642460N, 153645E.

5 LOF04 Porphyritic older granite, core of Bofall massif. 649150N, 153805E.

6 PK405 Older granite, Storsjö, north-western part of Loftahammar massif. 643910N, 153275E.

7 LOF01 Metasomatically affected fragment of older granite, Blankaholm massif. 638555N, 154065E.

8 SM010 Apparently "younger" granite, Blankaholm massif. 638740N, 153995E.

9 GRA02 Grey equigranular Småland granite, quarry near Angehölm. 637808N, 154922E.

TABLE 2. (continued)

Nr	10	11	12	13	14	15	16	17	18
SiO <sub>2</sub>	70.0	65.5	71.3	67.0	71.5	66.6	69.8	65.4	68.7
TiO <sub>2</sub>	0.49	0.78	0.42	0.85	0.57	0.57	0.76	0.79	0.79
Al <sub>2</sub> O <sub>3</sub>	14.4	16.4	14.2	15.3	13.7	15.8	14.9	18.0	15.5
Fe <sub>2</sub> O <sub>3</sub>	0.9	1.6	0.9	1.7	1.0	1.6	1.8	2.5	1.4
FeO	1.6	2.2	1.2	2.5	1.5	1.8	1.6	1.7	1.7
MnO	0.05	0.08	0.04	0.10	0.05	0.08	0.06	0.08	0.08
MgO	0.9	1.4	0.8	1.4	1.2	1.6	1.3	1.2	1.5
CaO	1.7	3.0	1.6	2.5	1.1	2.5	2.1	3.3	1.9
Na <sub>2</sub> O	2.4	2.5	2.8	3.2	3.2	2.7	3.4	2.7	3.4
K <sub>2</sub> O	4.9	5.6	4.3	4.7	4.8	3.1	4.6	3.3	5.4
F	0.03	0.14	0.08	0.21	0.06	0.06	0.06	0.14	0.10
BaO	0.09	0.16	0.14	0.13	0.10	0.12	0.12	0.09	0.13
Sum	97.46	99.36	97.78	99.53	98.78	96.53	100.50	99.20	100.60

10 SM001 Småland granite, reddish grey, medium-grained, equigranular. W of Klintemåla. 637730N, 154985E.

11 SM008 Småland granite, reddish grey, medium-grained. Solstad mine. 638315N, 154445E.

12 SM009 Småland granite, greyish red, medium-grained. Solstadhalvön. 638312N, 154350E.

13 SM002 Småland granite, red, medium-grained. Almekärr. 637700N, 154790E.

14 SM003 Småland granite, red, medium-grained. Tjustgölen. 637555N, 154080E.

15 SM005 Småland granite, bright red, medium-grained. Mörtfors. 637855N, 153970E.

16 SM004 Småland granite, red, coarse-grained. Göljhult. 637570N, 154438E.

17 SM006 Småland granite, flesh-red, coarse, porphyritic. Tribbhult. 638130N, 153870E.

18 SM007 Småland granite, as above. Marsgölehult. 638280N, 153770E.

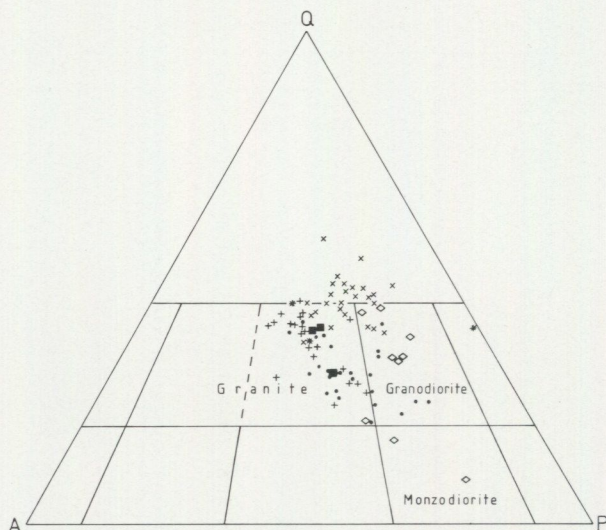


Fig. 3. Classification of the granitoid rocks of the Västervik area (mesonorm) in the scheme of Streckeisen (1967). Note that the older granites of the Öro-Hamnö massif are quartz-rich. Symbols as in Fig. 4.

### MAJOR ELEMENT GEOCHEMISTRY

Metasomatic alterations have changed the chemistry of both the supracrustal rocks and older plutons, mainly with reference to the alkali elements (see below), but also involving several other major, minor and trace elements. In the following discussion of the major element geochemistry, only samples which have not suffered from metasomatic alterations have been included. In the section on alkali element geochemistry, metasomatism will be discussed and analyses of metasomatites are included there.

### NORMATIVE COMPOSITIONS

The plot of quartz – K-feldspar – plagioclase, vol.-% of the mesonorm (Fig. 3) shows that the majority of the samples plot within the granite and granodiorite fields of Streckeisen (1976). Some of the analyses of older granodiorites plot within the monzodiorite field.

The gneissic granites of the Öro-Hamnö massif are often enriched in quartz and depleted in alkalis with reference to the major trend, which roughly coincides with the calc-alkaline-granodioritic (medium K) trend of Lameyre and Bowden (1982). Some of the granodiorites also show alkali depletion (Fig. 3) and seem to join up with the low-K trend of the Öro-Hamnö gneissic granites.

The plot Q – Ab – Or, weight-% of the katanorm (Fig. 4) further illustrates the differences between the gneissic granites of the Öro-Hamnö massif (Q enrich-

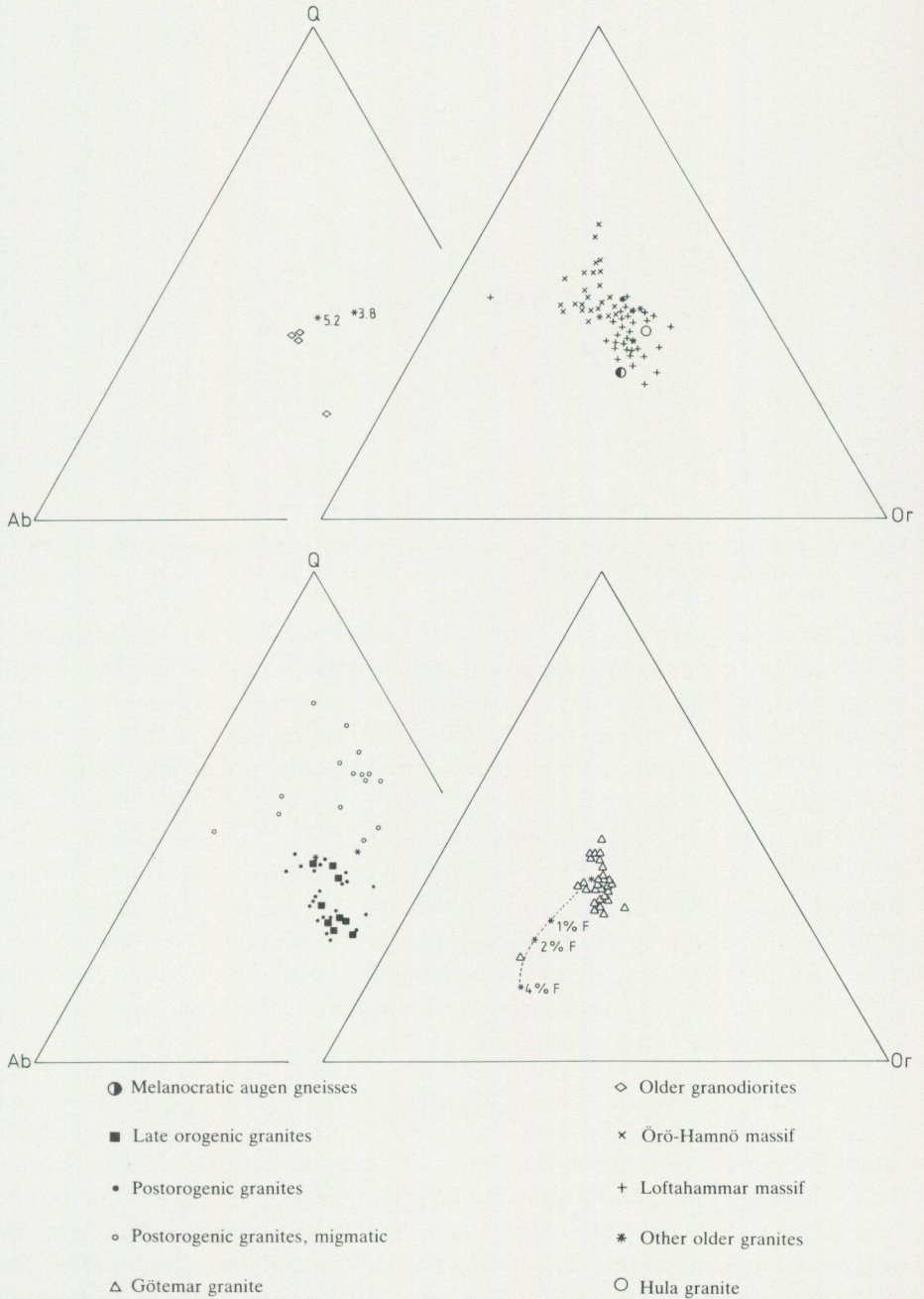


Fig. 4. Normative Q-Ab-Or (katanorm, weight-%) plot for the various granitoids. For Götemar granites, asterisks show eutectic compositions at 100 bars water pressure and effect of fluorine on the position of the eutectic (Manning and Pichavant 1983). In the other diagrams, asterisks are at eutectic compositions for Ab/An = 3.8 and 5.2, at 2000 bars water pressure (Winkler 1967).

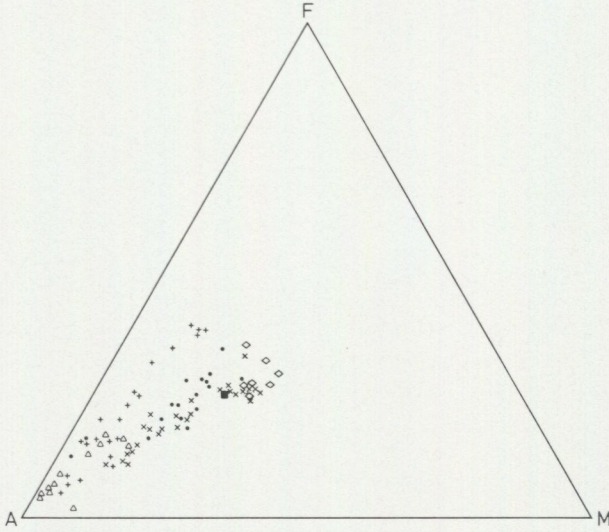


Fig. 5. A-F-M plot for the granitoids of the area. Two separate trends are evident. See text for discussion. Symbols as in Fig. 4.

ment, Or depletion) and those of the other occurrences. Most of the analyses of primorogenic, late orogenic and postorogenic plutons scatter around the eutectic in the system at 2000 bars water pressure, as do most analyses of granitoid rocks. Major deviations are recorded for the migmatic postorogenic granites: resorption of (quartzitic) metasediments is reflected by the often rather high contents of normative quartz (Fig. 4).

The analyses of the Götömar granites cluster close to the eutectic composition at 1000 bars water pressure (Fig. 4), with the exception of one sample (No.8 of Kresten and Chyssler 1976). Provided that fluorine has been an essential constituent of the vapour phase, as is apparent from the mineralogy and chemistry of these rocks, the deviating sample is explained by assuming a fluorine content of about 3% in the vapour phase during crystallization. Under these conditions, the sample has eutectic composition (Fig. 4).

#### AFM-PLOTS

The AFM-plot, Fig. 5, shows that the older granodiorites, the older granites of the Öror-Hamnö and central massifs, and the late orogenic, postorogenic and anorogenic granites define one clear trend, whereas the samples of older granites from the Loftahammar massif define a different trend at lower values of M. The question arises whether the different trend of the older granites of the Loftahammar massif is due to late-stage metasomatic alteration processes or not. Even if only samples which are interpreted as not having been affected by metasomatism are included in the diagram, the possibility of the "plagioclases" (Hahn 1971, Hoeve 1974) – patches or zones of intense alteration affecting both

the older granites and the wall-rock – being an expression of a more general but more subtle alteration of the whole massif is not totally excluded.

Employing Gresens' (1967) approach to calculate compositional changes during metasomatism, Hoeve (1974) demonstrated that the process involved depletion in K, Fe, Mg and Ti and addition of Na and Ca. Figs. 3 and 4 show that the older granites of the Loftahammar massif are not depleted in K and enriched in Na and Ca with respect to the other older granites. Also, Fig. 5 shows that there is not any significant depletion in Fe. Hence, the different trend in the AFM-plot for the older granites of the Loftahammar massif has to be explained by primary (source and/or process) differences.

Different trends similar to those shown in Fig. 5 are found in modern volcanic arc granites (Brown 1982), where the low-M trend is significant for more primitive arcs, the high-M trend for more mature arcs.

#### ALKALINITY

In Fig. 6, the alkalinity of the granitoids is expressed in terms of  $\log[\text{CaO}/(\text{Na}_2\text{O} + \text{K}_2\text{O})]$  versus  $\text{SiO}_2$ , with the demarcation line between calc-alkaline and alkali-calcic fields as given by Brown (1981).

The general trend coincides with those recorded for intrusive suites in modern arc environments, such as the Peru coastal batholith, Sierra Nevada batholith and the Alaska Range batholith (Brown 1982, Brown *et al.* 1984).

The older granites of the Öror-Hamnö massif define a calc-alkaline suite, together with the older granodiorites of the massif (field enclosed by dashed line, Fig. 6) and the granodiorites of the Lucerna massif. Again, the relatively high contents of  $\text{SiO}_2$  in the older granites of the Öror-Hamnö massif (see Figs. 3 and 4), particularly of the palingenetic Hamnö granite (inclined crosses, Fig. 6), are apparent.

The older granites of the Loftahammar massif and the central massifs scatter within the range of the palingenetic Hamnö granite and the younger granites. In the diagram, Fig. 6, the older granodiorites define a shallow sloping trend towards the older plutons of the Öror-Hamnö massif, a trend including the Nya Vida (S. Gavelin 1984) sample. It seems that plutonic activity started mildly alkali-calcic, and proceeded to a calc-alkaline main phase.

Most of the granites provisionally classified as being late orogenic are closely grouped within the alkali-calcic field (Fig. 6), including the analysis of the Dynestad granite (S. Gavelin 1984). The postorogenic Småland granites scatter around the calc-alkali – alkali-calcic demarcation line, similar to the postorogenic granites reported by Lindh and Gorbatshev (1984). The anorogenic Götemar granite is strictly alkali-calcic, often strongly so.

#### SIAM-CLASSIFICATION

The sub-division of granites into S-type (sedimentary) and I-type (igneous) by Chappell and White (1974), and White and Chappell (1977) has been modified

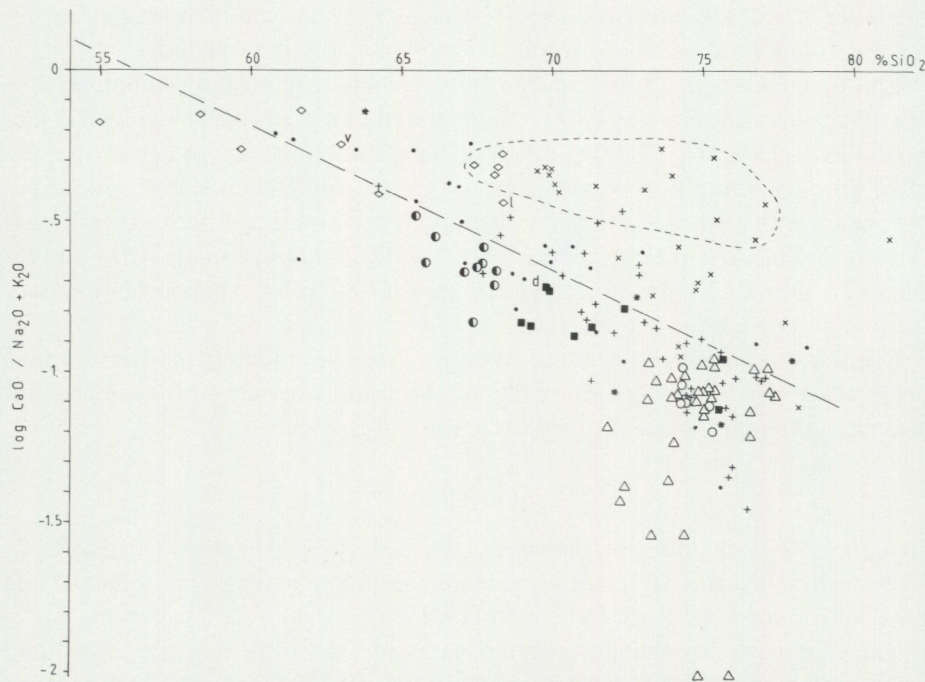


Fig. 6. Alkalinity of the granitoids, with demarcation line of Brown (1982). d = Dynestad granite, l = Lucerna granite, v = Nya Vida granite dike. Field of gneissic granites of the Örö-Hamnö massif surrounded by dashed line. Symbols as in Fig. 4.

from its original genetic concept, with S-type granites being representative for continent collisions, and I-type granites being the product of Andinotype or Caledonian-type uplift (Pitcher 1983). Additional granite types recognized are A-type granites (Collins et al. 1982), typically anorogenic intrusions, and M-type granites (White 1979) of oceanic arc environments.

Pitcher (1983, Table 1) gives a list of all characteristic features of S-, I-, A- and M-type granites, embracing field relations, mineralogy, chemistry and tectonic setting. Chemical parameters of particular importance are, among others, aluminosity, expressed as  $Al/(Na+K+Ca/2)$ , and the oxidation state  $Fe^{3+}/Fe_{tot.}$ , which have been used by Wilson (1980) in an attempt to classify Swedish granites. He grouped primorogenic, late orogenic and postorogenic intrusions as I-type granites, although a considerable overlap of characteristics was found. A number of granites fall outside the S-I-classification (Wilson and Åkerblom 1980), several of which are now referred to as A-type granites (Wilson, pers. comm. 1985).

A plot of aluminosity versus oxidation state (Fig. 7) of the granitoids analyzed demonstrates considerable scattering, parts of which may be due to metamorphism and/or late alteration affecting the oxidation state. According to the plot, the older granites of the Loftahammar massif would be I-type and the other older

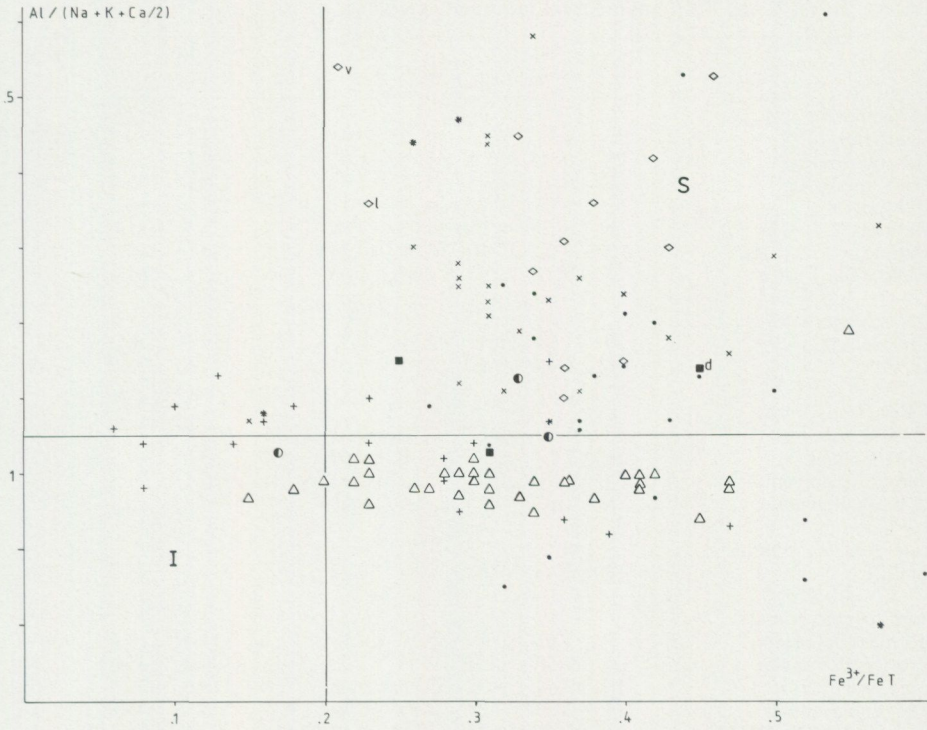


Fig. 7. Discrimination between S- and I-type granites. See text for discussion. Symbols as in Fig. 4.

plutons S-type intrusions. The late and postorogenic granites scatter (Fig 7), with most of the samples showing S-type characteristics. The Göttemar granite, with I-type characteristics and relatively high initial  $^{87}\text{Sr}/^{86}\text{Sr}$  (Åberg 1978, Åberg *et al.* 1985) shows considerable spread in oxidation state with little change in aluminosity. As the Göttemar granite is rather homogeneous with respect to mineralogy and major element geochemistry (Smellie and Stuckless 1985), the oxidation state appears to be a somewhat unreliable parameter. The Göttemar granite is classified as an A-type granite.

Applying the classification scheme of Debon and Le Fort (1982) to the Väster-  
vik granitoids has not yielded interpretable results. Older granodiorites are classified as calcic, meta- to peraluminous, without any clear trend. Older granites are either peraluminous (Örö-Hamnö) or meta- to peraluminous (Lof-tahammar and central parts), without any clear trends. Plots of late orogenic and postorogenic granites are scattered throughout the diagram. The Göttemar granites are peraluminous, with few exceptions leucogranitic and seem to define an aluminous type trend, roughly coinciding with the "Higher Himalaya trend" (Debon and Le Fort, Fig. 4). S- or I-type characteristics can not be deduced from this very scattered plot.

TABLE 3. Na, K and Rb in supracrustal rocks and granitoids

	Na			K		Rb			K/Rb
	n =	$\bar{x}$ , %	$\sigma$	$\bar{x}$ , %	$\sigma$	n =	$\bar{x}$ , ppm	$\sigma$	
<i>Metasediments</i>									
Quartzites	12	0.29	0.36	0.43	0.41	10	27.7	19.7	104
Mic. quartzites	28	0.30	0.38	2.73	1.32	14	123.6	51.4	258
Felsp. quartzites	26	0.91	0.75	3.32	1.59	5	119.8	38.9	216
Meta-arenites	53	1.06	0.73	4.39	1.11	8	129.4	59.5	306
Meta-argill. low gr.	6	0.59	0.68	4.03	0.85	4	131.5	41.6	299
Meta-argill. med. gr.	3	0.22	0.00	4.30	0.36	2	180.0	42.2	245
Meta-argill. high gr.	8	0.41	0.13	4.59	1.63	8	183.1	61.1	263
<i>Older Granodiorites</i>									
Örö-Hamnö	20	1.93	0.13	2.80	0.31	20	116.8	10.2	240
Lucerna	16	1.60	1.19	3.91	0.55	7	187.9	30.7	232
<i>Older Granites</i>									
Örö-Hamnö	75	1.84	0.18	3.00	0.61	75	122.5	14.0	244
Loftahammar	86	2.14	0.37	4.30	0.69	64	186.5	49.3	245
Hamnö (palingenetic)	54	1.99	0.20	3.53	0.51	54	135.1	21.3	263
Hula (palingenetic)	6	1.85	0.15	4.90	0.18	6	204.3	38.2	247
<i>Late orogenic granites</i>									
Aplitic	8	2.43	0.32	4.84	0.42	8	214.8	45.5	233
<i>Postorogenic granites</i>									
Hornblende-bearing	7	2.61	0.19	3.19	0.18	7	113.4	13.4	283
Grey, equigranular	23	2.30	0.54	2.86	1.08	12	100.8	35.0	253
Grey, porphyritic	15	2.44	0.32	3.23	0.48	8	118.6	34.5	286
Red, equigranular	24	2.53	0.33	3.83	0.49	16	155.1	44.8	253
Red, medium-grained	34	2.18	0.35	3.78	0.87	14	220.6	69.3	201
Porphyritic	4	4.48	0.17	3.83	0.46	3	200.0	23.6	203
<i>Anorogenic granites</i>									
Götömar	17	2.95	0.95	3.88	0.48	10	425.3	160.8	121
<i>Migmatites and metasomatites</i>									
Raft migmatites	24	1.33	0.55	3.20	0.87	8	150.7	56.3	229
Same, dioritic	11	1.84	0.66	2.13	1.12	4	74.2	17.5	178
K metasomatites	5	1.62	0.36	6.92	2.60	2	200.0	0.0	420
Na-metas. (metased.)	11	3.60	1.03	1.71	0.83	6	55.0	37.6	417
Na-metas. (older granite)	9	3.34	0.45	1.66	0.85	6	50.0	31.5	607

## ALKALI ELEMENT GEOCHEMISTRY

A summary of relevant data on sodium, potassium and rubidium in supracrustal rocks and granitoids from the Västervik area (sources as above) is given in Table 3.

## SODIUM AND POTASSIUM

In the Västervik area, as in most Proterozoic terrains, the mobility of sodium and potassium is easily demonstrated. Particularly at the contact between the older granites of the Loftahammar massif and the supracrustal wall-rock, and around inclusions of supracrustal rocks within the massif, sodic metasomatism leading to

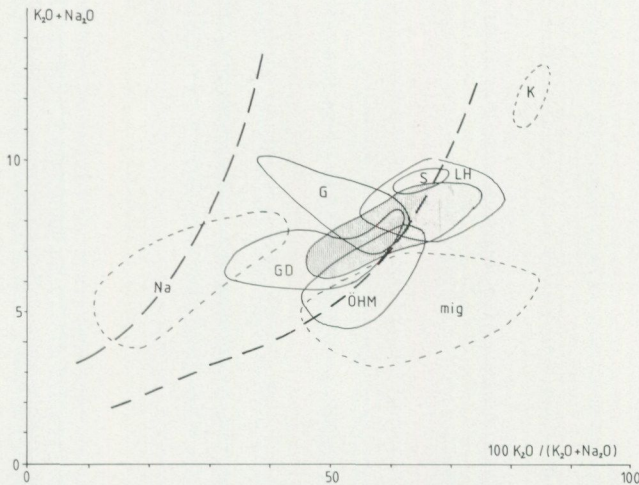


Fig. 8. Plot of the granitoids of the area in the "igneous spectrum" (heavy dashed lines) of Hughes (1972). GD = older granodiorites; ÖHM = older granites of the Örö-Hamnö massif; LH = older granites of the Loftahammar massif; S = late orogenic granites; shaded = postorogenic granites; G = Götemar granites; K = potash metasomatites; Na = soda metasomatic alterations of older granites; mig = migmatites.

the formation of the so-called "pagioclasites" (Hahn 1971, Hoeve 1974) is common. The question arises as to whether these metasomatic processes have affected large rock units, as advocated by Hoeve (1974), or are rather restricted phenomena (Hahn 1971). Based on my experience of these rocks, I prefer Hahn's (1971) interpretation of the metasomatism being a rather local phenomenon, affecting the contact rocks and immediate surroundings. Similarly, the contact zones between older granites and basic dikes or rafts are often characterized by sodic metasomatism of the granite, and potash metasomatism of the basic rock (Kresten 1971a, 1972, 1974).

Potash-dominated metasomatism has been described from the contact between supracrustal rocks and postorogenic granites (Kresten 1971a), in basic rocks (Kresten 1971a, 1972, 1974; S. Gavelin 1984) and, as small-scale processes, in the flecky gneisses and related rocks (summarized by S. Gavelin 1984). In all these cases, metasomatism appears only to affect restricted rock masses only.

A comparison of the major granitoid rock types with the "igneous spectrum" of Hughes (1972), Fig. 8, shows that the older granodiorites, the late orogenic granites and the Götemar granites plot within the spectrum. The older granites and the postorogenic granites both fall in part outside the spectrum (Fig. 8). Among the older granites, those of the Örö-Hamnö massif are rather low in their alkali contents, as noted above (see Figs. 3 and 4). The metasomatites and the migmatic postorogenic granites plot well outside the spectrum (Fig. 8). It seems unlikely that large-scale potash metasomatism affected both the older granites

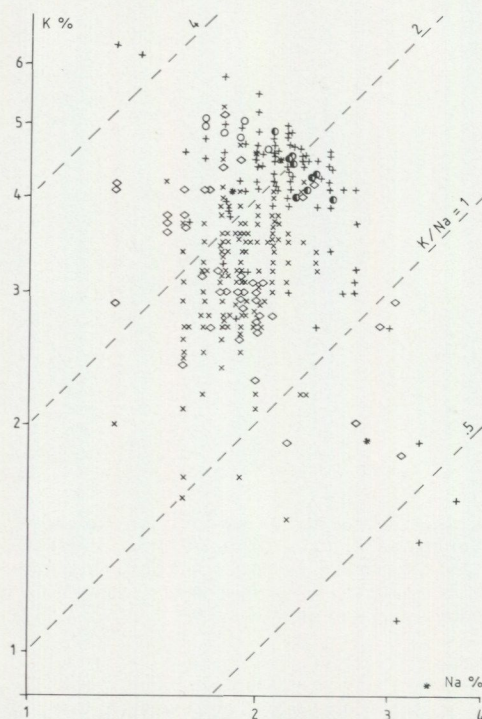


Fig. 9. Sodium *versus* potassium for the older (primorogenic) granitoids. The older granites of the Loftahammar massif are more potassic than those from other massifs. Symbols as in Fig. 4.

and the postorogenic granites, but not the older granodiorites and the late orogenic granites. Possibly, the boundary of the "igneous spectrum" should be extended to incorporate higher K contents.

A plot of sodium *versus* potassium for the older plutons (Fig. 9) shows that the older granodiorites show considerable scattering of values, as is expected for a plutonic sequence embracing a wide range of compositions. For single massifs, such as the one within the Öror-Hamnö massif, the spread is much more restricted (Table 3). The older granites of the Loftahammar massif are distinctly richer in potassium and somewhat richer in sodium than the older granites of the Öror-Hamnö massif (Fig. 9 and Table 2). The Hula granites, formed from the older granites by partial anatexis, are slightly enriched in potassium and depleted in sodium when compared with their parents (Fig. 9 and Table 3), as is to be expected. The melanocratic augen gneisses plot within the field of variation of the Loftahammar older granites (Fig. 9). Some of the samples plotted in Fig. 9 have obviously been affected by sodium metasomatism – certainly all those with  $K/Na > 0.5$ .

The corresponding plots for the late and postorogenic granites, Fig. 10, show

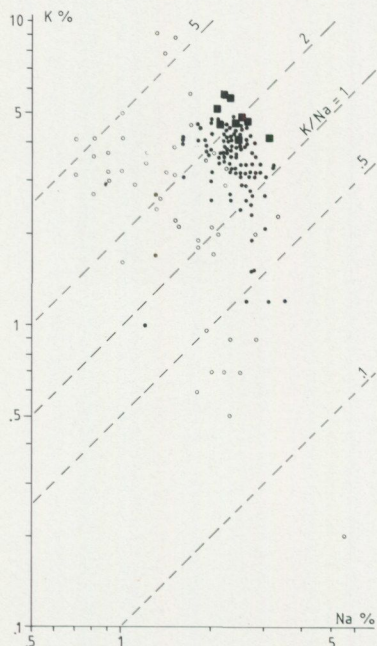


Fig. 10. Sodium *versus* potassium for late orogenic and postorogenic plutons. Compositional scatter mainly caused by wall-rock resorption. Symbols as in Fig. 4.

that the late orogenic granites are more potassic (Table 3) than the postorogenic granites. The latter also show a considerable scattering of values, which is explained by digestion of wall-rock material: resorption of metasediments causes a decrease in sodium, with or without increase in potassium, whereas resorption of basic rocks mainly leads to decreased potassium contents (see averaged values, Table 3).

This is evident from the sodium and potassium contents of various wall-rock samples, Fig. 11. Also shown are compositions of selected metavolcanics from the west central parts of the area (S. Gavelin 1984). The major compositional fields of the Öror-Hamnö gneissic granites, the Loftahammar gneissic granites and the late orogenic to postorogenic granites are outlined in Fig. 11. The compositions of the eutectic in the system  $Q - Or - Ab - An$  at 2000 bars water pressure (Winkler 1967) have been inserted. The older granites of the Loftahammar massif, the late orogenic and the postorogenic granites all have compositions in agreement with those expected from eutectic melts with  $Ab/An$  ratios in the range 5.2–3.3 (Fig. 11). The same holds true for the metarhyolites. The older granodiorites, as well as the older granites of the Öror-Hamnö massif, on the other hand, have too low K contents to be regarded as eutectic melts (compare even Fig. 4), whatever pressures (Winkler 1967) or additional components of the vapour phase (Winkler

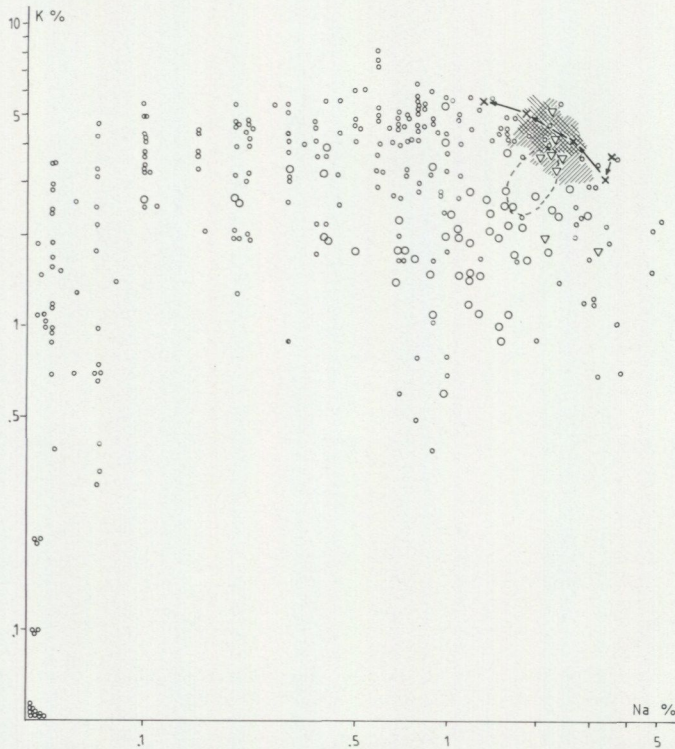


Fig. 11. Sodium *versus* potassium in wall-rock samples. Small circles = metasediments; inverted triangles = metavolcanics; large circles = metabasites. Main compositional variation of late orogenic and postorogenic granites shown by NW-SE hatching, of older granites of the Loftahammar massif by NE-SW hatching, and of older granites of the Öro-Hamnö massif by dashed line. Crosses are K and Na contents of eutectic melts with  $Ab/An = \infty, 7.8, 5.2, 3.8$  and 1.8, all at 2000 bars water pressure (Winkler 1967).

1967, Manning and Pichavant 1983) are assumed. Instead, they are probably melts of non-eutectic compositions, which indicates that much higher degrees of partial melting of a silicic crust must have been involved. The alternative explanation, that their compositions are not primary, has been discussed above.

#### RUBIDIUM

Potassium-rubidium relationships in rocks from the Västervik area are given in Table 3 and Fig. 12. Most of the samples show K/Rb ratios between 150 and 300, as are commonly observed in crustal material. Supracrustal rocks and metabasites (Fig. 12a) show substantial variations in K/Rb ratios which are independent of potassium content, due to varying amounts of K-feldspars and micas in these rocks.

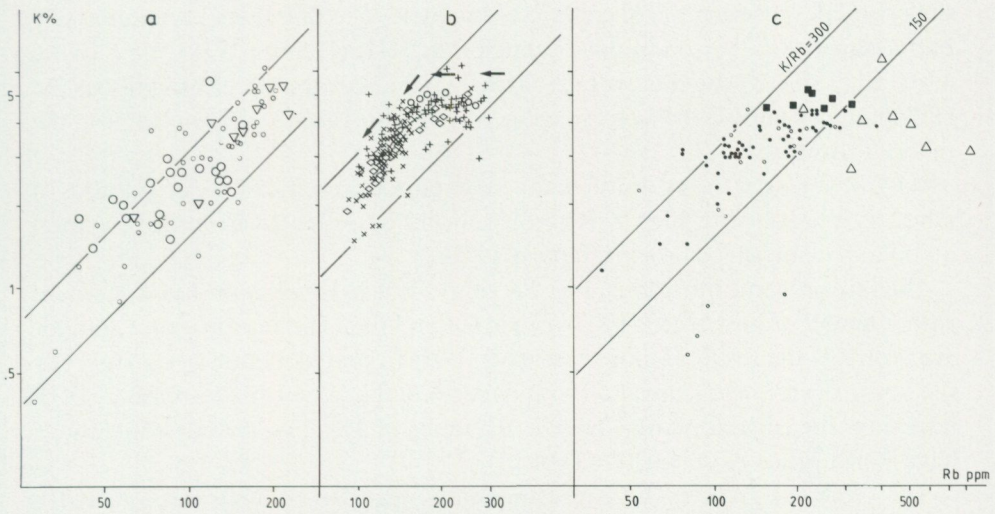


Fig. 12. Rubidium versus potassium for various rocks of the area.

a) Supracrustal rocks and metabasites (symbols as in Fig. 11)

b) Older plutonic rocks (symbols as in Fig. 4)

c) Younger plutonic rocks (symbols as in Fig. 4)

The variation in K and Rb contents with increased partial melting of a quartzo-feldspathic parent is indicated by arrows (see text for discussion).

The older plutons (Fig. 12b) cluster in a pattern which is defined by two trends:

1. Slightly increasing K/Rb ratios with increasing K contents: older granodiorites and older granites of the Öro-Hamnö massif.
2. Distinctly increasing K/Rb ratios with almost constant K contents: older granodiorites of the Lucerna massif, older granites of the Loftahammar massif, the palingentic Hula granites.

The pattern is exactly what would be expected for progressive melting of a quartzo-feldspathic rock. At low degrees of partial melting, K is almost constant, Rb decreases and K/Rb increases (Hanson 1978). After the K-feldspar has been consumed at about 30% partial melting, further melting will involve a decrease of both K and Rb contents in the melt, with K/Rb remaining virtually constant (Hanson 1978). The variations of K and Rb with increased partial melting are indicated by arrows in Fig. 12b. Consequently, the pattern observed is explained by a lower degree of partial melting of a quartzo-feldspathic (with some mica) protolith giving rise to the older granites of the Loftahammar massif and the older granodiorites of the Lucerna massif, while higher degrees of partial melting of the same, or a similar, protolith gave rise to the other older granodiorites and the older granites of the Öro-Hamnö massif.

It is also seen that the Hula granites, derived from the Loftahammar granite by partial melting processes, have K contents at a roughly constant level with increasing K/Rb ratios. Obviously, partial melting proceeded with a K phase in

the protolith buffering the K content of the melt. The theoretical K content of a buffered melt for the conditions assumed is 4.2% K (Hanson 1978), close to the 4.9% K (Table 3) for the average Hula granite. For the older granites of the Loftahammar massif, the average value of 4.3% K (Table 3) is even closer to the theoretical value.

It is unlikely that the protolith of the older plutons contained major amounts of mica, as granites with high K/Rb ratios would be expected to form by partial melting of a micaceous rock (Hanson 1978).

The late orogenic intrusions, Fig. 12c, also show K-Rb relationships consistent with a model of low degree ( $\leq 30\%$ ) partial melting. The postorogenic granites are probably the result of more extensive ( $\geq 30\%$ ) partial melting processes. For the postorogenic intrusions, K/Rb ratios seem to decrease with decreasing age of intrusion: the earliest plutons have K/Rb ratios of 253–286, the latest intrusions have K/Rb ratios close to 200 (Table 3).

The Götömar granites are characterized by high Rb contents and low K/Rb ratios (Table 3, Fig. 12c) typical for highly evolved granites.

## OTHER TRACE ELEMENTS

### RARE EARTH ELEMENTS

Rare earth element (REE) contents of various granitoids of the Öro-Hamnö massif are given in Table 4. The chondrite-normalized (Haskin *et al.* 1968) REE patterns, Fig. 13, are smooth, with La/Yb ratios of about 6, and small or no Eu anomalies. REE patterns of this type indicate little or no feldspar remaining in the source rock of the anatectic melt (Hanson 1978, Cullers and Graf 1984).

For older granites of the Loftahammar massif, REE contents have been given by Hoeve (1974). Although the general levels of REE contents and La/Yb normalized ratios are comparable to those found for Öro-Hamnö rocks, the chondrite-normalized patterns (Fig. 13) show much more pronounced Eu anomalies. This indicates remaining plagioclase and/or K-feldspar in the source rock, which is in agreement with the deductions from the K-Rb relationship that K-feldspar must have remained in the source rock.

Although some of the analyses seem to reflect metasomatically altered rocks with lowered REE contents – particularly the heavy REE – (Fig. 12), there is no obvious reason to assume that the negative Eu anomalies of the Loftahammar granites are due to Na metasomatism. The REE patterns of metasomatically altered granites (Humphris 1984) differ significantly from those observed for the Loftahammar granites. Thus, the different REE patterns confirm a somewhat lesser degree of partial melting during the formation of the Loftahammar granites, by comparison with the Öro-Hamnö granites.

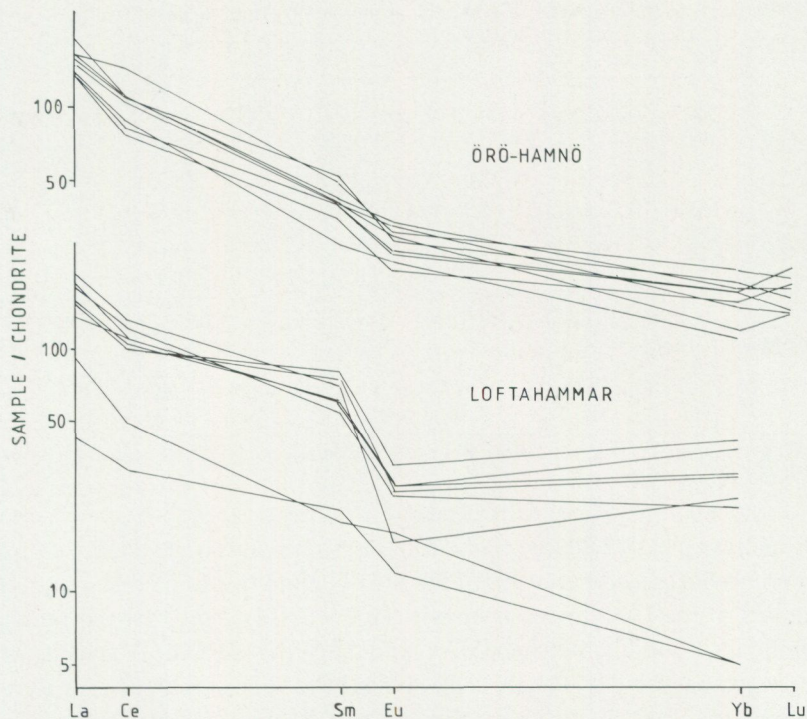


Fig. 13. Chondrite-normalized REE abundances for older granitoids from the Öro-Hamnö massif (Table 3) and the Loftahammar massif (Hoeve 1974). The more pronounced Eu anomalies of the Loftahammar samples are striking.

In the Falun area of south central Sweden (Kresten 1986), primorogenic intrusions show REE patterns very similar to those of the Öro-Hamnö granites: they are smooth and without any significant Eu anomalies. Late orogenic granites (mainly Malingsbo and Fellingsbro type) show distinctly negative Eu anomalies, which are yet more pronounced in the postorogenic Dala granites.

#### DISCRIMINATION DIAGRAMS

Pearce *et al.* (1984) have devised a set of trace element discrimination diagrams for the tectonic interpretation of granitic rocks, corresponding to the variety of discrimination diagrams frequently used for basaltic rocks. Four main tectonic groups are distinguished:

1. Ocean ridge granite (ORG)
2. Volcanic arc granite (VAG)
3. Within-plate-granites (WPG)
4. Syn-collision granites (sCOLG)

TABLE 4. Neutron activation analyses of granitoids from the Öro-Hamnö massif (values in ppm).

Sample	La	Ce	Sm	Eu	Yb	Lu	Sc	Cs	Hf	Ta	Th
<i>Older granodiorites</i>											
LH005	46	69	6.4	1.51	3.2	0.60	9.4	1.9	3.9	1.3	17.7
LH012	64	98	7.4	1.72	3.4	0.73	9.0	3.0	5.0	1.7	14.4
<i>Older granites</i>											
LC013	54	94	9.5	1.95	3.7	0.55	9.3	4.3	5.9	1.9	9.8
LC025	52	95	9.5	1.86	3.7	0.39	8.8	3.6	5.6	1.6	10.5
LC030	46	77	7.2	2.28	2.9	0.47	8.5	1.9	7.0	0.5	3.6
LC037	46	73	7.3	2.05	2.4	0.50	6.2	1.9	5.1	1.0	6.8
LD001	48	77	5.0	1.62	2.2	—	6.8	1.9	4.9	0.8	11.0
<i>Palingenic Hamnö granites</i>											
LA001	55	127	8.9	2.13	4.2	0.66	4.8	1.5	4.1	1.2	14.8
LA020	50	91	7.6	2.32	3.5	0.60	4.3	2.5	4.4	0.9	14.6
LA028	55	98	7.2	1.76	3.4	0.48	5.5	3.7	5.2	1.3	13.0

For details on the samples, see Kresten (1974). For analytical details and reference values, see Kresten and Brunfelt (1985).

One projection used by Pearce *et al.* (1984) is Ta versus Yb. Available data on the older granodiorites and granites of the Öro-Hamnö massif (Table 4) and the older granites of the Loftahammar massif (Hoeve 1974) show that the samples project along the boundary between VAG and the WPG-ORG overlap (Fig. 14). The other plots suggested by Pearce *et al.* (1984) have been employed only for the Loftahammar granites, as no values for Nb and Y are available for the Öro-Hamnö rocks. In the Nb versus Y plot (Fig. 15), the Loftahammar granites plot close to the WPG field. In Rb versus Y+Nb, Fig. 15, the samples plot along the VAG-WPG boundary.

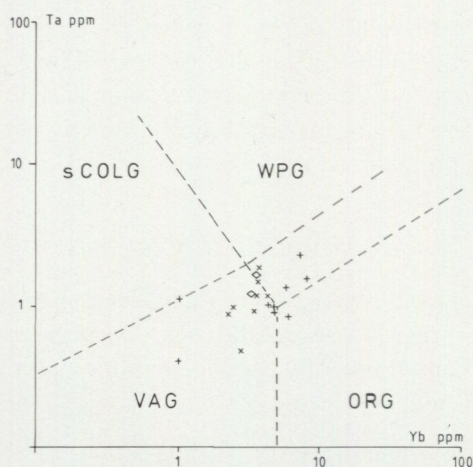


Fig. 14. Ta-Yb discrimination diagram of Pearce *et al.* (1984). Older granitoids plot close to the VAG (volcanic arc granites) - WPG (within-plate-granites) - ORG (ocean ridge granites) junction. Symbols as in Fig. 4.

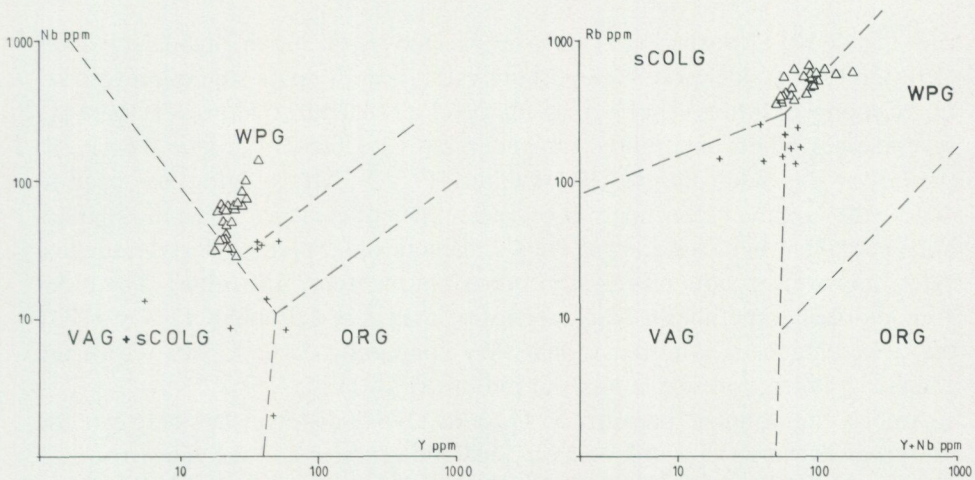


Fig. 15. Nb-Y and Rb-(Y+Nb) diagrams according to Pearce *et al.* (1984). Older granites of the Loftahammar massif plot as in Fig. 14. The anorogenic Götömar granites plot along the WPG - sCOLG (syn-collision granites) boundary. Symbols as in Fig. 4.

For the Götömar granites, suitable analyses are available (Smellie and Stuckless 1984), indicating a WPG setting, with some overlap into sCOLG.

It has to be kept in mind that the samples in Pearce *et al.*'s (1984) data bank represent relatively young granites; an application of the discrimination diagrams to Proterozoic plutons has yet to be regarded with caution. For the primorogenic intrusions, a VAG to WPG setting seems to make sense. My preference would be VAG, in agreement with a SIAMclassification of I-type Andinotype plutonism. Most of the VAG samples of Pearce *et al.* (1984) are derived from Cordilleran type of intrusions. For the Götömar granites, a WPG setting, alternatively post-collision setting (pCOLG, not in the diagrams of Pearce *et al.*, 1984), seems to be most plausible.

## DISCUSSION

S. Gavelin (1968) pointed out that a consistent classification of the granitic rocks of the Västervik area is difficult to achieve. This has become evident in the above discussion of the various palingenic (*sensu lato*) older granitoids. Accordingly, the sketch map (Fig. 1) differs to some extent from the map of S. Gavelin (1984) regarding granite classification.

Several different field criteria have been used by me in order to distinguish members of the older and younger plutonic sequences: these have included the relationship to intersecting dikes (basic to intermediate), contact relationships and the structural setting. Younger plutonics have not in any instance been found intruded by dikes of basaltic compositions (apart from the much younger dole-

rites, Table 1); also, they are rarely intersected by dacitic to rhyodacitic dikes (Kresten 1972). Older plutons almost invariably occupy dome-shaped megastructures; younger plutons usually cross-cut the older structures. However, there are several cases, where apparently younger granites are found in structural positions typical for the older plutons (Blankaholm, Fig. 2). My guideline has been to denote the original rock whenever there is sufficient evidence: thus, the Blankaholm massif has been assigned to the palingenetic older plutons (Fig. 1). In most cases, however, granite classification does not meet any difficulties. The older granodiorites, sometimes lacking schistosity, may pose a problem. One, possibly the best, diagnostic criterion is that they commonly occur together with the gneissic granites, forming composite plutons (Fig. 1).

Among the younger plutons, S. Gavelin (1984) distinguishes between the postorogenic, late- to post-kinematic Småland granites and the much younger Götemar granites. The existence of prekinematic younger granites was realized by Elbers (1971), who described metasediments and older granites cross-cut by pale red aplitic granite, which in turn was affected by a tectonic phase (F2). According to Elbers (1971), these younger granites are intersected by late basic dykes.

My own field work has resulted in the incorporation of the aplitic granites near Västervik with the late orogenic granites (Fig. 1), as well as the Dynestad massif (Fig. 1), probably corresponding to the Fellingsbro granites of central Sweden.

The postorogenic Småland granites offer little difficulty in the field, except when they induce palingenesis of the older plutons.

According to field relations and tectonic setting (Pitcher 1983) as well as to major element geochemistry, the granitic intrusions of the Västervik area are classified as follows:

Older granodiorites:	I-type (Andinotype)
Older granites:	I-type (?)
Late orogenic granites:	S-type (?)
Postorogenic granites:	S-type (Hercynotype)
Anorogenic granites:	A-type

Alkali element studies have indicated that the older granites of the Loftahammar massif, the late orogenic, postorogenic and anorogenic granites all can be interpreted as near-eutectic melts at pressures of about 2000 bars (1000 bars for the anorogenic granites). The older granites of the Loftahammar massif and the older granodiorites of the Lucerna massif have been formed by rather low ( $\leq 30\%$ ) degrees of partial melting of a quartzo-feldspathic parent; the other older plutons by a higher degree of partial melting, as has been shown by both K-Rb relationships and REE studies. The late orogenic granites resulted from fairly low degree partial melting, the postorogenic granites probably by somewhat

more extensive partial melting. For the anorogenic Götömar granites, a low degree partial melting model is suggested.

On the basis of trace element discrimination diagrams, the tectonic setting is indicated as VAG (volcanic arc granite) for the older plutons, and as WPG (within-plate-granite) for the Götömar granites. The results inevitably raise the questions: can trace element discrimination diagrams constructed on the basis of relatively young rocks be extrapolated to Proterozoic rock compositions? Are plate tectonic concepts applicable to Proterozoic environments?

Plate tectonic models for the Swedish Proterozoic have been commonly employed during recent years. In the Falun area of south central Sweden (Kresten 1986), situated further north along the Småland-Värmland belt of intrusions, geochemical studies on granites and metavolcanics seem to indicate volcanic arc settings. Unpublished results indicate transitions from volcanic arc setting to later within-plate setting.

S. Gavelin (1984), from a purely field geological point of view, interprets the Västervik area as the edge of a sinking platform, comparable to the Mississippi delta in the Gulf of Mexico. He repeatedly emphasizes that vast amounts of epiclastic sediments were deposited, with intercalated volcanic rocks, and that mainly basaltic igneous activity occurred repeatedly during a large time span.

The combination of rapid sedimentation processes combined with extensive basic to acid volcanism and alkali-calcic to calc-alkaline plutonism of Cordilleran type is interpreted as indicating an active continental margin, possibly with some back-arc rifting. The older plutonic sequence would thus represent volcanic arc granites, whereas the younger plutonic sequence will grade into within-plate-granites. Further studies along this line are hoped to contribute additional evidence to these processes.

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