Caledonian granitoids in the Frøya-Froan area, central Norway

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Introduction

The Frøya and Froan archipelago is dominated by Caledonian granitoids which constitute the northernmost part of the Smøla-Hitra Batholith (SHB). The batholith extends between the islands of Grip in the SW and Halten in the NE, a distance of c. 140 km (Fig. 1). Dioritic rocks predominate on Smøla and Hitra, however, there is a compositional range from gabbro to granite (Gautneb & Roberts 1989 and references therein). A number of dates from the batholith have given ages between 450 and 428 Ma (Tucker 1988, Gautneb 1988).

The Frøya-Froan area

Compared to the Smøla-Hitra area, few geological studies have been carried out on Frøya and the broadly SW-NE trending array of islands, collectively termed Froan, from northern Frøya to Halten (Fig. 1). A fluidisation breccia which occurs at Skaget (NE Frøya) was described by Torske (1983). He also described the host rock of the breccia, the so-called Frøya Granite, which according to Askvik & Rokoengen (1985) occupies the northern part of Frøya and adjacent islands to the north.

Mapping in the Frøya-Froan area was carried out by NGU in 1988-91 (Nordgulen et al. 1990, Bøe et al. 1992a,b, Nordgulen & Solli 1992). This work has shown that the intrusive rocks can be subdivided into a number of plutons (Fig. 1). In the following we briefly describe the main features of each pluton, as well as of granitoids from southwestern Hitra (see Table 1 for a summary).

Granitoids on southwestern Hitra. A few samples of quartz dioritic to tonalitic rocks occurring on southwestern Hitra were sampled and analysed for comparative purposes. The rocks are medium-grained and equigranular and consist of plagioclase, biotite, hornblende and quartz. Microcline is a minor interstitial mineral and accessory minerals include apatite, epidote, titanite, zircon, opaques and chlorite. A weak mineral alignment is present in places. The rocks are cut by dykes of aplite and pegmatite.

The Nordskaget Pluton. The major part of Frøya is occupied by foliated, pale grey, medium- to fine-grained, tonalitic rocks with locally abundant, variably sized, elongate inclusions of marble, calc-silicate rocks and minor amphibolite oriented parallel to the NE-SW trending foliation in the host rocks. These rocks are shown as Proterozoic orthogneisses on map-sheet Kristiansund (Askvik & Rokoengen 1985). However, compositional data (see below) indicate that the foliated tonalites are Caledonian in age, and that they have intruded metasedimentary rocks which now occur as xenoliths within the intrusive rocks. The tonalites consist essentially of plagioclase, quartz and biotite with small amounts of microcline, zircon and opaques.

The Gurvikdalen Pluton. A narrow NE-SW trending zone of medium- to coarse-grained, strongly foliated, dark grey tonalite occurs in the Gurvikdalen-Nesset area (Fig. 1). It consists of plagioclase, quartz, biotite and hornblende with interstitial microcline. Epidote, allanite, titanite, zircon and opaques are accessory minerals. The foliation in the pluton is parallel to that of the Nordskaget Pluton to the south.

The Rottingen Pluton. This pluton constitutes a part of the intrusive unit termed the Frøya Granite by Torske (1983). Although there is substantial textural and compositional variation among the granites assigned to this pluton (Fig. 1, Table 1), we suggest they are provisionally regarded as part of the same intrusive unit.

The pluton consists of equigranular to sparsely megacrystic to megacrystic granite. Megacrysts of microcline may be pale yellowish grey, but are usually pale reddish to pink, rectangular and less than 2.5 cm in length. They are set in a medium-grained groundmass consisting of grey plagioclase, biotite and quartz; minor hornblende occurs locally, and accessory minerals include titanite, epidote, apatite, zircon, opaques, chlorite and muscovite. A weak orientation of megacrysts is common. Inclusions of calcareous metasedimentary rocks occur at Uttian and adjacent islands. The pluton is cut by numerous granite and aplite dykes.

The Gjæsingen Pluton. To the west, the pluton is delimited by an occurrence of polymict conglomerate of probable Devonian age which occurs at Vingleia (Sæbøe 1972, Nordgulen et al. 1990). On Tarbuskjera, west of the Vingleia conglomerate (Fig. 1), a variety of granitoids including strongly foliated dioritic rocks, medium-grained granite and red megacrystic granite are present.

The eastern part of the Gjæsingen Pluton consists of strongly foliated, mesocratic, medium-grained and equigranular quartz monzodiorite

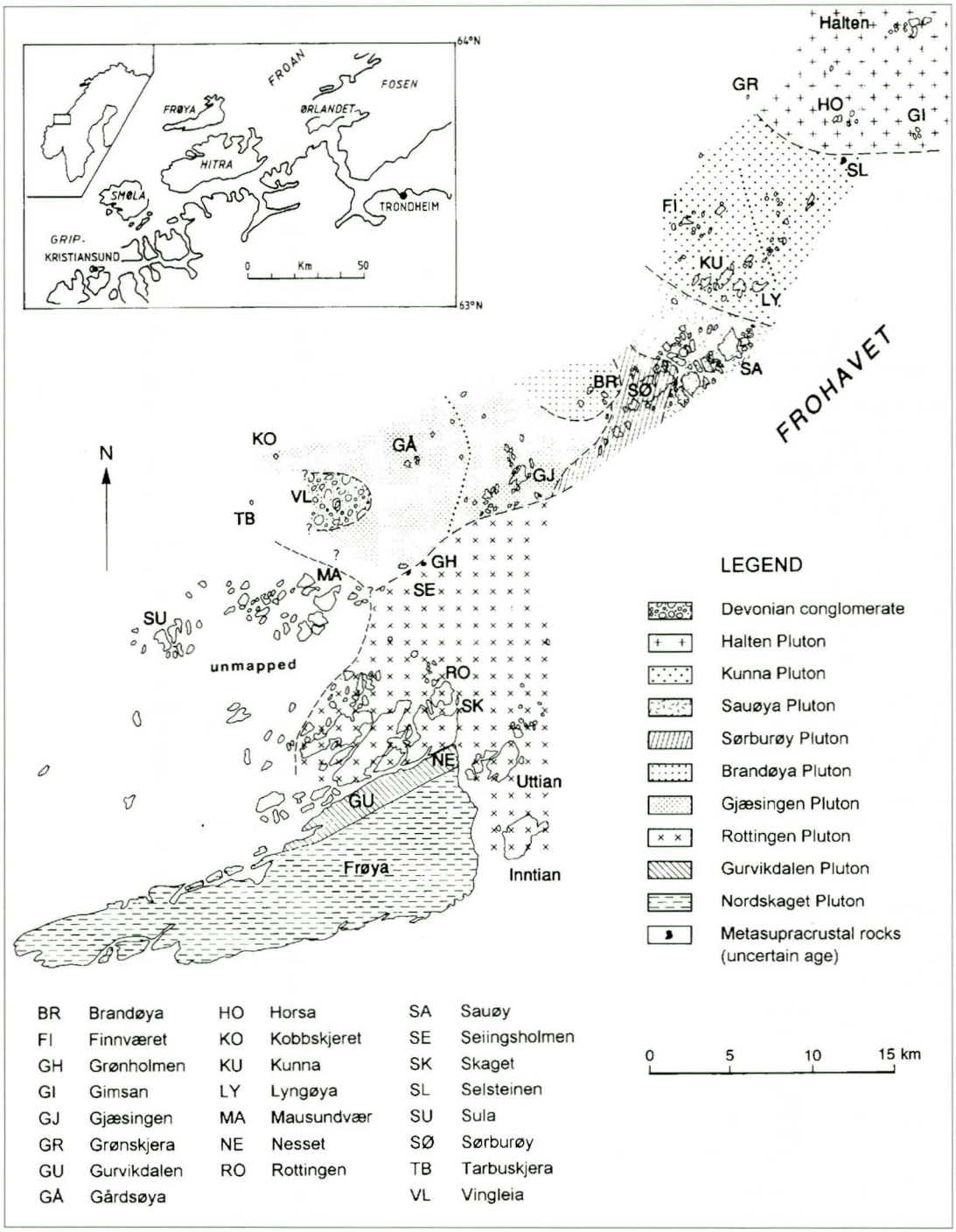

Fig. 1. Geological map of the Frøya-Froan region. Stippled lines indicate inferred geological boundaries. Dotted lines denote internal transitional boundaries within the Gjæsingen and Kunna plutons.

with abundant elongate mafic enclaves oriented parallel to the foliation. There appears to be a transitional relationship (dotted line on Fig. 1) between quartz monzodiorite in the east (SiO_2 < 63%) and fairly massive, medium- to coarse-grained, equigranular granodiorite (SiO_2 > 63%) with few mafic enclaves which occurs in the Gårdsøya-Kobbskjeret area.

The texture of the rocks is idiomorphic to hypidiomorphic with grey plagioclase, greyish pink orthoclase, hornblende (in places with clinopyroxene in the core) and biotite as rock-forming minerals. The accessory minerals include titanite, apatite, zircon, opaques and chlorite.

A preliminary U-Pb zircon date on quartz monzodiorite at Gjæsingen yielded an intrusive age of c. 435 Ma (Ø. Nordgulen & M.E. Bickford, unpublished data).

The Brandøya Pluton. This pluton consists of pale greyish pink, medium-grained, equigranular granite to granodiorite which is cut by a few granitic dykes. Plagioclase, microcline, quartz and biotite are the major minerals. Accessory minerals comprise hornblende, titanite, epidote, zircon, apatite, chlorite and opaques.

The Sørburøy Pluton. The pluton is composed of medium-grained, equigranular quartz monzodiorite to granodiorite with hornblende, biotite, orthoclase, plagioclase and quartz as rock-forming minerals; hornblende is absent in the most evolved varieties. Accessory minerals comprise titanite, allanite, apatite, zircon and opaques. The rock is characterised by a weak mineral orientation and by mafic clots consisting of biotite and hornblende.

Angular xenoliths of metasedimentary rocks are common on Sørburøy. The pluton also contains inclusions similar to megacrystic quartz monzonite of the Kunna Pluton as well as monzodiorite of the Gjæsingen Pluton. This indicates that the pluton is younger than c. 435 Ma, and thus probably Silurian in age.

The Sauøya Pluton. The pluton consists of foliated, medium-grained, equigranular, mesocratic quartz monzodiorite to granodiorite. Hornblende and biotite are commonly forming elongate mafic aggregates. Other major minerals comprise quartz, anhedral plagioclase and K-feldspar which appears to be transitional between orthoclase and microcline. Accessory minerals include epidote, titanite, apatite, zircon and opaques.

The pluton has a strong fabric defined by a preferred orientation of feldspar and mafic aggregates. Small shear zones are common. Mafic enclaves are elongate and oriented parallel to the foliation. Pink granitic to aplitic dykes are abundant and cut the foliation in the pluton.

The Kunna Pluton. The western part of the pluton consists of megacrystic to sparsely megacrystic quartz monzodiorite to granodiorite. The orthoclase megacrysts are reddish to pale pink (1-4 cm, usually less than 2 cm) and are set in an inequigranular, medium-grained groundmass consisting of euhedral hornblende (< 7mm), plagioclase, biotite and quartz with apatite, titanite, epidote, zircon and opaques occurring as accessory minerals. The eastern part of the pluton consists of strongly foliated, medium-grained quartz diorite to quartz monzodiorite. The rocks lack megacrysts and are generally more mafic than those in the western part of the pluton. The nature of the boundary between the two parts of the pluton (dotted line on Fig. 1) is uncertain, but probably is transitional.

Mafic enclaves and metasedimentary xenoliths are common. Large rafts of banded, fine-grained, dark grey to green calc-silicate rocks occur in the

Pluton/unit	Rock type	SiO_2	K_2O	ASI	Alkali-lime index	$(^{87}Sr/^{86}Sr)_0$	ε_{Nd}
Hitra (4)	QDI-TON	57.5 - 66.7	0.7 - 2.2	0.87 - 0.98	60-63	0.7043- 0.7046	1.0 – 3.1
Nordskaget (8)	TON	65.0 - 71.6	1.3 - 2.4	0.93 - 1.04	60-63	0.7045 - .7078	-0.9 – 4.3
Gurvikdalen (2)	TON	63.4 - 67.7	1.8 - 2.0	1.01	60-63	0.7089	-2.7
Rottingen (10)	GDI-GR	64.0 - 74.2	3.0 - 5.2	0.96 - 1.04	58	0.7053 - 0.7056	-3.1 – - 0.6
Gjæsingen (14)	QMZDI-GDI	59.6 - 67.4	2.2 - 3.8	0.88 - 1.00	60	0.7063 - 0.7102	-3.3 – -1.5
Brandøy (3)	GDI-GR	69.0 - 73.4	3.2 - 4.1	1.02 - 1.04	not defined	0.7079 - 0.7092	-3.0
Sørburøy (7)	QMZ-GDI	58.5 - 63.7	3.8 - 4.3	0.82 - 0.99	55	0.7075 - 0.7096	-6.0 – - 4.9
Sauøy (4)	QMZDI-GDI	60.7 - 65.0	3.5 - 3.9	0.90 - 0.95	60	0.7067 - 0.7076	-6.1 – -3.6
Kunna (14)	QDI-QMZDI-GDI	57.6 - 66.2	1.6 - 4.5	0.82 - 0.89	56	0.7071 - 0.7073	-2.9 – 0.2
Halten (7)	GDI-GR	67.6 - 72.7	3.9 - 5.2	1.00 - 1.04	57-60	0.7066 - 0.7074	-5.3 – -0.6
Gran. dykes (7)	GDI-GR	62.5 - 76.0	3.4 - 6.4	0.94 - 1.03	not defined	0.7056 - 0.7092	n.d.
Ton. dykes (2)	TON	65.3 - 65.4	1.7 - 2.2	1.00 - 1.03	not defined	0.7070 - 0.7082	n.d.

Table 1. Summary of compositional parameters for plutonic rocks of the Frøya-Froan area. The number of samples from each pluton/unit is shown in brackets. The alumina saturation index (ASI) is defined as the molecular proportion $Al_2O_3/(CaO+Na_2O+K_2O)$. The alkali-lime index for a suite of rocks is defined as the value of SiO_2 at which $CaO=Na_2O+K_2O$. The values for $(^{87}Sr/^{86}Sr)_0$ and ε_{Nd} were calculated assuming an age of 440 Ma. n.d.: not determined.

Finnværet area and on the island Selsteinen in the northeastern part of the pluton.

The Halten Pluton. The northeastern part of Froan (Horsa-Gimsan-Halten) consists of sparsely megacrystic to megacrystic red granite to granodiorite termed the Halten Pluton (Fig. 1). The microcline megacrysts range in size up to 3 cm and occur in a medium-grained groundmass of plagioclase, quartz and biotite. The accessory minerals include muscovite, titanite, apatite, zircon and opaques. Inclusions of medium-grained gabbro occur at Gimsan, and on Halten there are inclusions of quartzite and calc-silicate rocks. The pluton tends to have a very weak mineral orientation; however, on Halten the rock is locally strongly foliated.

The composition and origin of the rocks

The main compositional features of the plutons are summarised in Table 1. The data show that the granitoids range in composition from intermediate to acid. Most of the plutons have alkali-lime indices between 57 and 60 and are high-K calc-alkaline. The Kunna and Sørburøy Plutons are alkali-calcic to calc-alkaline. Leucocratic tonalites in the southern part of Frøya, as well as on southwestern Hitra, are calcic to calc-alkaline with low contents of K and large-ion-lithophile elements (LILE). The rocks are generally metaluminous; the highest ASI value is 1.04 (Table 1). The variation in composition within and between plutons suggests that the parental magmas from which the plutons were derived were compositionally distinct.

Radiogenic isotope data (Sr and Nd) show that $(^{87}Sr/^{86}Sr)_0$ and ε_{Nd}, assuming an age of 440 Ma, are generally less than 0.710 and greater than -6.1, respectively (Table 1). The tonalites on Frøya and Hitra, which have very low contents of LILE, stand apart in having the lowest $(^{87}Sr/^{86}Sr)_0$ and highest ε_{Nd} (> -1). The isotopic data are broadly similar to those obtained for the Bindal Batholith (Nordgulen & Sundvoll 1992, Birkeland et al. 1993); however, positive values for ε_{Nd} have not previously been reported for Caledonian granitoids in Scandinavia.

The compositional data may indicate a depleted mantle source component for the Hitra and possibly also the Frøya tonalites. The LILE-rich quartz dioritic to quartz monzonitic rocks were probably derived from melts generated from an enriched, peridotitic source; however, both for these rocks and for the rocks of granitic composition, contributions from various crustal sources may also be envisaged. There is a general, but no unique relationship between the composition of the source and tectonic setting of granitoids (Cobbing 1990). Thus, for granitoids as compositionally variable as those of the Smøla-Hitra Batholith, it is not tenable to use only the composition of the rocks as an indicator of tectonic setting; and it is even possible that they were generated in different settings. Further evaluation of these questions will have to await future analytical work, including precise age determinations on a number of plutons in the study area.

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