Field relations and geochemical evolution of the Gothian rocks in the Kvamsøy area, southern Western Gneiss Complex, Norway

ØYVIND SKÅR

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The igneous rocks of the Kvamsøy area in the southern parts of the Western Gneiss Complex (WGC) of Norway comprise a wide variety of granitic, syenitic, granodioritic and gabbroic compositions and formed in the interval 1640 to 1622 Ma during the Gothian orogeny. Strongly deformed gneissic equivalents of the igneous rocks form the granodioritic and granitic basement gneisses, which are the dominant lithologies in the Kvamsøy area as well as elsewhere in the southern parts of the WGC. The gneisses show variable amounts of partial melting during the Sveconorwegian migmatisation event dated at 965 ± 12 Ma.

Quartzites in the Kvamsøy area represent remnants of a pre-Gothian basement through which the Gothian rocks were emplaced. All the Gothian igneous rocks are predominantly metaluminous, and the granodioritic rocks have calc-alkaline to high-K calc-alkaline compositions, indicating that they had igneous sources. Sm-Nd and Rb-Sr isotope data indicate that the sources for the rocks had either a substantial component of juvenile melts or a short crustal residence time. The contribution of pre-Gothian basement was probably minor. The granodioritic rocks were most likely generated by partial melting of underplated mantle-derived basaltic rocks, while alkali-calcic granitic and syenitic rocks may alternatively have been generated by partial melting of more evolved rocks such as tonalites. The geochemistry of the igneous rocks is consistent with generation within a tectonic setting at an active continental margin, or by remobilisation of young magmatic rocks at a continental margin during a collision or post-collision setting.

Øyvind Skår, Geological Institute, University of Bergen, Allegt. 41, N-5007 Bergen, Norway.
E-mail: Oyvind.Skar@geol.uib.no.

Introduction

The southern parts of Scandinavia are composed of Proterozoic rocks which became increasingly younger to the southwest (Fig. 1). The Svecofennian Orogen (2000-1750 Ma) in the east is bordered to the west by the Trans-Scandinavian Granite-Porphyry Belt (1780-1600 Ma)(also called the Trans-Scandinavian Igneous Belt), and the western- and southernmost parts of Scandinavia belong to the Southwest Scandinavian Orogen (1750-900 Ma)(Fig. 1). The Western Gneiss Complex (WGC) forms the northwestern parts of the Southwest Scandinavian Orogen (Fig. 1). The Proterozoic rocks of the WGC were formed during the Gothian (1750-1500 Ma) and Sveconorwegian (1250-900 Ma) orogenies, while the main Caledonian, Scandian orogeny (450-380 Ma) caused metamorphic and tectonic overprinting in large parts of the complex (Gorbatschev 1985, Kullerud et al. 1986). About 80 % of the rocks at the present level of erosion in the southern part of the WGC were generated during the Gothian orogeny. The rocks show wide compositional variation including felsic, intermediate, mafic and ultramafic plutonic rocks, and minor amounts of various supracrustal rocks (Kullerud et al. 1986, Austrheim & Mørk 1988, Bryhni 1989, Skår 1998). These rocks were deformed and migmatised at the end of the Gothian orogeny (Gorbatschev 1985). The Sveconorwegian orogeny generated the remaining 20 % of the rocks of the southern part of the WGC. The Sveconorwegian intrusions range in size from minor dykes to large, syn- to post-kinematic intrusions, and the rock compositions are mainly intermediate to felsic (Kullerud et al. 1986, Skår 1998). During the Scandian orogeny, the western and northwestern parts of the WGC were strongly deformed and metamorphosed during the collision between Baltica and Laurentia, while in the eastern parts only sporadic shear zones were formed (Milnes et al. 1997).

The WGC represents a major part of the Precambrian crust in southern Norway (Fig. 1), and this study was carried out in the southeastern part of the complex (Kvamsøy area)(Figs. 1 and 2), where Caledonian overprinting is minor (Milnes et al. 1988). In this contribution, the field relations, petrography and geochemistry of Gothian rocks in the Kvamsøy area will be presented, and the petrogenesis and the tectonic setting of the rocks will be discussed.

Regional geology

A compilation of age determinations of rocks from the WGC demonstrates that the complex has been affected by three orogenies, the Gothian, Sveconorwegian and Caledonian (Kullerud et al. 1986). The dominant Gothian rocks are orthogneisses of dioritic to granitic compositions (Kildal 1969, Lutro & Tveten 1996). In the Nordfjord area (Fig. 1), Bryhni

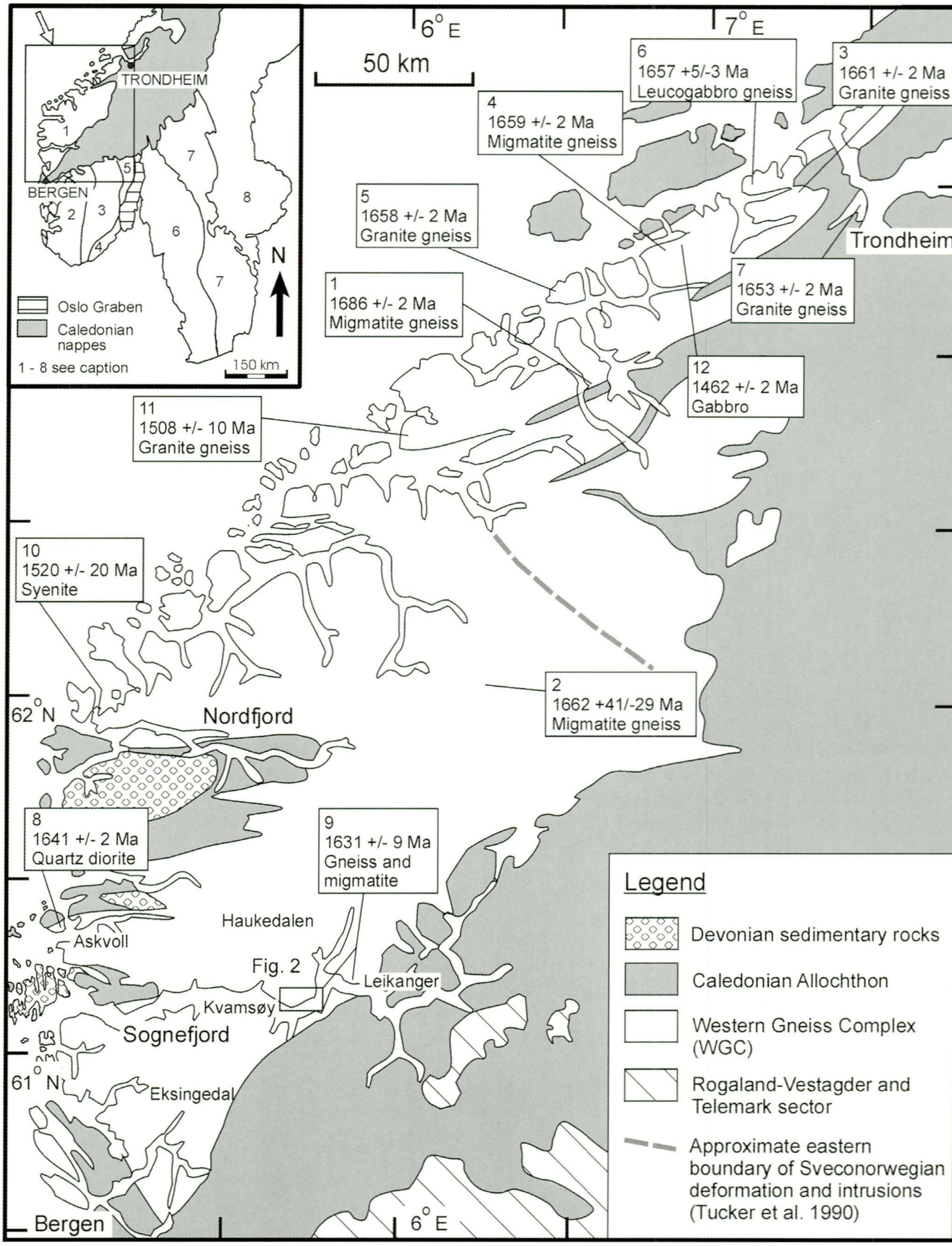


Fig. 1. Sample locations for published U-Pb ages in the WGC. The data are presented in Table 1. References to the map: Sigmond (1992), Tucker & Krogh (1988). Inset map: Precambrian geology of the Baltic Shield. 1-6, Southwest Scandinavian Domain (1750-900 Ma); 1, WGC; 2, Rogaland-Vestagder sector; 3, Telemark sector; 4, Bamble sector; 5, Kongsberg sector; 6, Østfold sector and coeval sectors in Sweden; 7, Trans-Scandinavian Granite-Porphyry Belt (1780-1600 Ma); 8, Svecofennian Orogen (2000-1750 Ma). After Gaál & Gorbatschev (1987), Gower et al. (1990) and Tucker et al. (1990).

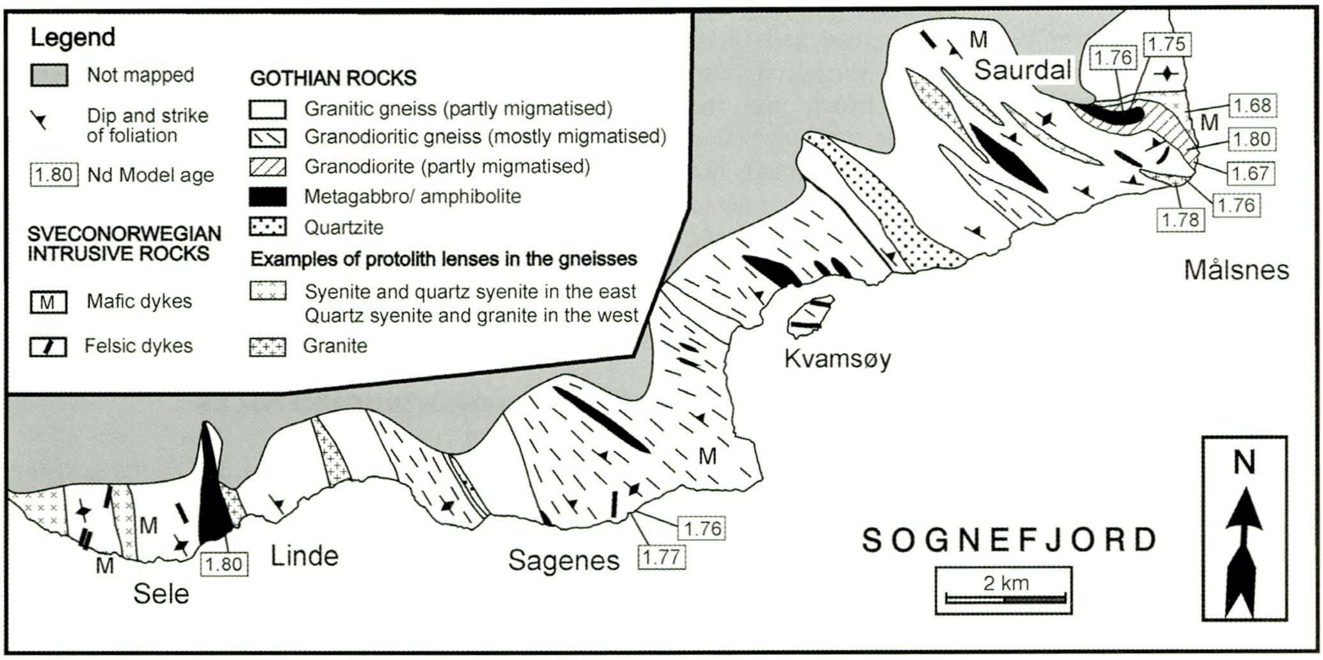


Fig. 2. Geological map of the Kvamsøy area. The location of the map is marked in Fig. 1.

(1966) has demonstrated that the composition of the orthogneisses is predominantly granodioritic, and for the central parts of the map area Bakke (1981) has subdivided the gneisses in the Haukedalen area (Fig. 1) into granitic and granodioritic varieties. Similar gneiss lithologies are the dominant rocks in the Kvamsøy area (Fig. 2), and in the southernmost parts of the WGC, to the south of the Sognefjord (Ragnhildstveit & Helliksen 1997). Rb-Sr and Sm-Nd ages from the WGC suggest that the orthogneisses of the WGC were formed in the time period 1750-1600 Ma (Kullerud et al. 1986). More precise U-Pb ages in northern parts of the WGC are in the interval from 1686 to 1647 Ma, whereas in the southern parts of the WGC the U-Pb dates fall in the range 1641-1631 Ma (Fig. 1, Table 1). Mafic rocks are common in the WGC, while ultramafic rocks occur only in northwestern areas (Kildal 1969, Lutro & Tveten 1996). Field relations indicate that most of the mafic and ultramafic rocks are of Gothian age, though only few published age determinations support this suggestion (Kullerud et al. 1986). Supracrustal rocks in the southern part of the WGC are restricted to minor quartzites, whereas in the central and northern parts, kyanite- and/or sillimanite-bearing gneisses and marbles are present (Bryhni 1989). Feldspathic quartzites, mica schists, garnetiferous and micaceous gneisses, and banded amphibolites have been interpreted as supracrustal rocks (Bryhni 1989), but this is difficult to demonstrate due to the strong tectonic overprinting. Generally, the absolute ages of the supracrustal rocks are not well constrained, but supracrustal rocks interfolded with the Proterozoic rocks and affected by pre-Caledonian foliations are clearly of Proterozoic age. To the south of the Sognefjord, quartzites are intruded by Sveconorwegian plutons (Kildal 1969,

Table 1. U-Pb ages from the Western Gneiss Complex, Norway.

	Rock	Locality	Method	Minerals		Age (Ma)		Reference:
1	Migmatite gneiss	Tingvoll	U-Pb	Zircon	Titanite	1686	± 2	Tucker et al. (1990)
2	Migmatite gneiss	Breidalsvatn	U-Pb	Zircon		1662	+ 41/- 29	Tucker et al. (1990)
3	Granite gneiss	Sagfjord	U-Pb	Zircon	Titanite	1661	± 2	Tucker et al. (1990)
4	Migmatite gneiss	Åstfjord	U-Pb	Zircon	Titanite	1659	± 2	Tucker et al. (1987)
5	Granite gneiss	Frei	U-Pb	Zircon	Titanite	1658	± 2	Tucker et al. (1990)
6	Leucogabbro gneiss	Damvatn	U-Pb	Zircon		1657	+ 5/- 3	Tucker et al. (1990)
7	Granite gneiss	Ingdal	U-Pb	Zircon	Titanite	1653	± 2	Tucker & Krogh (1988)
8	Quartz diorite	Askvoll	U-Pb	Zircon		1641	± 2	Skår et al. (1994)
9	Gneiss and migmatite	Kvamsøy	U-Pb	Zircon		1631 (a)	± 9	Skår (1998)
10	Syenite	Flatraket	U-Pb	Zircon		1520	± 20	Lappin et al. (1979)
11	Granite gneiss	Molde	U-Pb	Zircon		1508 (b)	± 10	Tucker et al. (1990)
12	Coronitic gabbro	Selsnes	U-Pb	Zircon	Baddeleyite	1462	± 2	Tucker et al. (1990)

(a) One gneiss and two migmatites yielded a common upper intercept age.
(b) An upper intercept age produced by a construction from 395 Ma through one discordant zircon.
A Rb-Sr whole-rock date of the rock has yielded an age of 1506 ± 22 Ma (Carswell & Harvey, 1985).

Ragnhildstveit & Helliksen 1997). In the northern parts of the WGC, it has been demonstrated that supracrustal rocks also occur as Caledonian thrust nappes folded into the Precambrian gneisses (Krill 1985, Robinson 1995). The timing of Gothian migmatisation and deformation events is not well constrained in the WGC, but it is regarded to be prior to 1500 Ma, when post-orogenic granites, syenites and mafic plutonic rocks intruded the orogen (Gorbatschev 1985, Fig. 1 and Table 1).

The Late Sveconorwegian plutonic intrusions in the southern part of the WGC are mostly composite, consisting of a minor component of gabbro and monzonite, and a major component of porphyritic quartz monzonite, quartz syenite or granite (Skår 1998). Dykes with similar compositions are common, together with pegmatites and aplites. The ages of the dated Sveconorwegian intrusions range from about 1009 to 880 Ma; however, most ages are Rb-Sr whole-rock ages with large uncertainties (Kullerud et al. 1986, Skår 1998).

A major deformation and migmatisation event in the southern part of the WGC is dated to 965 ± 12 Ma (U-Pb zircon age) in the Kvamsøy area (Fig. 1) (Skår 1998). This deformation is interpreted to have been responsible for the regional, Late Sveconorwegian foliation in the southern parts of the WGC, which can be followed to the south of Sognefjord (Ragnhildstveit & Helliksen 1997), and to the north in the Haukedalen area (Bakke 1981). An eastern limit of the Sveconorwegian deformation and intrusions in the WGC was suggested by Tucker et al. (1990)(Fig. 1). Thus, to the east of this limit, the deformation of the basement must have occurred during the Gothian orogeny, or possibly during the later Caledonian orogenic event that caused extensive tectonic and metamorphic reworking of the western and northwestern regions of the WGC (e.g., Milnes et al. 1997).

Geology of the rocks in the Kvamsøy area

Introduction

In the Kvamsøy area the dominant rock types are granitic and granodioritic gneisses of Gothian age (Fig. 2). Both types are heterogeneous rocks that consist of an undeformed or weakly deformed protolithic part, a strongly deformed gneissic part, and a migmatised part. This study has focused on the protolithic parts of the gneisses, which crop out as elongated lenses within the gneissic rocks. Zircon fractions of three igneous rocks from the Kvamsøy area yielded a single discordia line with an upper intercept age of 1631 ± 9 Ma, interpreted to represent the magmatic age of the rocks (Skår 1998). The dated rocks comprise a gneiss sample of the quartz syenite at Leikanger (Fig. 1), a migmatite sample of the granodiorite at Sagenes, and a sample of leucosome of granitic gneiss at Målsnes (Fig. 2). The Sveconorwegian deformation and migmatisation event (965 ± 12 Ma, U-Pb zircons) has obliterated the primary contacts of the Gothian intrusions, and resulted in concordant contacts between them; thus, their relative ages are not possible to determine. Two occurrences of quartzite form several, km-long layers in the granitic gneiss (Fig. 2). Minor amounts of mafic rocks occur as synmagmatic enclaves and dykes in the felsic protoliths of the gneisses. Large concordant lenses (up to 0.5 x 2 km) as well as minor lenses and layers of metagabbro occur in both the granitic and the granodioritic gneisses. In addition to the Gothian rocks, Sveconorwegian dykes (0.5-10 m wide) of granitic, syenitic and monzonitic compositions are common in the Kvamsøy area (Skår 1998).

Pre-Sveconorwegian rocks

Granodiorite

The granodioritic gneisses at Sagenes occur as (1) a foliated, homogeneous rock containing minor amounts of mafic lenses, and (2) a banded, heterogeneous rock consisting of alternating layers (1-100 cm thick and tens of metres long) of granodioritic and amphibolitic composition. The foliated, homogeneous gneiss dominates, and it is usually strongly migmatised. The central part of the granodioritic gneiss at Sagenes consists of the banded heterogeneous variety. The granodiorite has a heterogranular texture, and consists of plagioclase, microcline, amphibole, quartz and biotite. Accessory minerals are titanite, apatite, opaques, zircon and secondary epidote.

The granodiorite at Målsnes is less deformed compared to that at Sagenes. It appears as a homogeneous rock, or a foliated gneiss containing minor amounts of mafic rocks. Mineralogically, it is similar to the granodiorite at Sagenes, but it contains only minor amphibole.

Granite and syenite

The lithology termed granitic gneisses also includes components of syenitic gneisses, but they are not separated on the map (Fig. 2). At Saurdal and Målsnes (Fig. 2), the granites are orange, medium grained and equigranular. The major constituents are microcline perthite, plagioclase, quartz and biotite. Biotite defines a lineation, or in some places, a foliation in the rocks. Accessory minerals are titanite, apatite, zircon and opaque oxides. Secondary garnet and epidote occur in the granite at Målsnes. The granite at Saurdal contains mafic lenses of monzogabbro composition. The lenses are altered and consist of saussuritic plagioclase, amphibole and microcline, with minor amounts of biotite, apatite, titanite, zircon and opaques. The pink quartz syenite at Leikanger (Fig. 1) is mineralogically similar to the granite at Målsnes, but contains more microcline and less quartz. The granite at Linde has a similar mineral assemblage as the others, but contains secondary muscovite. It has a stronger foliation, with quartz occurring as aggregates of recrystallised subgrains.

At Målsnes, there is a lens of red to white, medium-grained and equigranular syenite that grades into monzonite. The rock possesses a lineation defined by amphibole and biotite, but in the central parts of the lens it lacks deformation structures. The syenite is composed of perthitic microcline, plagioclase, quartz, amphibole and biotite, and minor amounts of apatite, zircon, opaques, titanite and secondary epidote. Minor enclaves of monzonite occur in the central part of the body, and lobate contacts with the syenite suggest a syn-magmatic relationship. At Saurdal, a ca. 2 km-long lens of quartz syenite occurs parallel with the foliation of the granitic gneiss. The mineral composition is similar to that of the syenite, but it has higher contents of quartz and plagioclase, thus grading into quartz monzonite. The quartz syenite encloses retrograded mafic lenses of monzogabbro. At Sele, there is a mingled assemblage of quartz syenite, granite and monzogabbro. Both the quartz syenite and the granite consist mainly of perthitic microcline, plagioclase and quartz. There is abundant biotite in the quartz syenite. Accessory minerals are apatite, zircon and opaques. Secondary minerals include garnet, titanite and epidote.

Metagabbro

Lenses of metagabbro, 1-500 m wide and up to 2 km long, are common in both the granitic and the granodioritic gneisses (Fig. 2). The metagabbros are medium- to coarse-grained, and the smallest lenses are commonly foliated. In the larger lenses, evidence of deformation is variable, and doleritic texture is preserved in the less deformed parts. The undeformed parts contain orthopyroxene, but secondary amphibole and biotite, in places in symplectitic intergrowth with plagioclase, usually replace the primary mafic minerals. Plagioclase is commonly saussuritic, and accessory minerals include ilmenite, magnetite, apatite, and secondary garnet in some of the gabbros. The gabbro at Sele is rich in oxides and contains a 2-3 m-wide zone of massive ilmenite-magnetite mineralisation. The gabbro contains small enclaves (10-50 cm) of medium-grained gabbro with lobate margins enclosed in a coarse-grained quartz gabbro, indicating mingling between the different rock types.

At Sele, monzogabbroic rocks occurring as irregular lenses and fragmented dykes are associated with the granites and quartz syenites. The dykes of monzogabbro contain perthitic microcline, plagioclase, amphibole and biotite as the major minerals. Amphibole and biotite are secondary minerals suggesting that the dykes are retrograded. Accessory minerals are apatite, zircon and opaques.

At Sagenes, the monzogabbroic rocks occur as concordant lenses in granodioritic gneiss. Monzogabbroic rocks at Målsnes also appear as lenses within gneissic quartz syenite.

Quartzite

Two layers of quartzite occur with concordant contacts to the granitic gneisses in the Kvamsøy area (Fig. 2). The quartzites are homogeneous, containing only small patches of granitic rocks. They are coarse grained and recrystallised, consisting of more than 95% quartz. Other minerals are minor muscovite, microcline, plagioclase, actinolite, opaques, epidote and zircon. The foliation in the adjacent gneisses is interpreted to have been formed contemporaneously with the migmatisation event at 965 ± 12 Ma (Skår 1998). Five single zircons from the quartzite east of Kvamsøy (Fig. 2) have yielded only Svecofennian Pb/Pb ages older than 1770 Ma (D.G. Gee, pers. comm. 1997). This would imply that the quartzites represent remnants of a pre-Gothian basement.

Sveconorwegian rocks

Sveconorwegian dykes of granitic, syenitic and monzonitic composition are common in the Kvamsøy area (Skår 1998). The dykes are usually 0.5-10 m wide, but up to 300 m-wide granitic dykes occur to the north of the Kvamsøy area (Fig. 2). At Sele, composite dykes composed of mingled basic to intermediate and acidic rocks are common. At Målsnes, monzonitic dykes dominate, but monzonitic and granitic dykes are observed throughout the Kvamsøy area; and only some few examples are illustrated in Fig. 2. Sveconorwegian pegmatites and aplites are common, and at many localities they are closely associated with the dykes (Skår 1998).

Geochemistry

Analytical techniques

All chemical analyses were performed at the Geological Institute, University of Bergen. The major and trace elements were analysed on glass beads and pressed powder pellets, respectively (Norrish & Hutton 1969), using an automatic XRF spectrometer. International standards with the recommended values of Govindaraju (1984) were used for calibration. FeO was determined by titration with potassium dichromate. REE analyses were done by INAA (instrumental neutron activation analysis) using high-resolution planar and coaxial germanium detectors after high-flux irradiation with thermal neutrons in the Jeep II reactor, Kjeller, Norway. The analyses are presented in Tables 2 and 3.

All Sm-Nd and Rb-Sr analyses were carried out at the University of Bergen. The isotopes were measured on a Finnigan 262 mass-spectrometer. The chemical processing was carried out in a clean-room environment with HEPA-filtered air supply and positive pressure, and the reagents were purified in two-bottle Teflon stills. Samples were dissolved in a mixture of HF and HNO_3. Sr and Rb were separated by specific extraction chromatography using the method described by Pin et al. (1994). Sr was loaded on a double filament and analysed in static mode. Repeated measurements of the NBS 987 Sr standard have yielded an average of 0.710251 ± 19 (2σ) (n = 27); the accepted value is 0.710240. The REE were separated by specific extraction chromatography using the method described by Pin et al. (1994). Sm and Nd were subsequently separated using a modified version of the method described by Richard et al. (1976). Sm and Nd were loaded on a double filament and analysed in static mode. Nd isotopic ratios were corrected for mass fractionation using a $^{146}Nd/^{144}Nd$ ratio of 0.7219. Sm and Nd concentrations were determined using a mixed $^{150}Nd/^{149}Sm$ spike. Repeated measurements of the J. M. Nd-standard yielded an average $^{143}Nd/^{144}Nd$ ratio of 0.511113 ± 15 (2σ) (n = 62).

Table 2. Major and trace element concentrations of representative Gothian rocks from the Kvamsøy area.
Major element concentration in weight percent; LOI = Loss on ignition; trace elements in ppm; -- = not determined.

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
ØS-96-264	Monzonite	Målsnes	57.47	1.63	16.50	3.21	3.24	0.24	1.54	3.70	3.68	6.46	0.67	0.24	98.58
ØS-96-222	Syenite	Målsnes	60.17	1.10	17.94	2.19	2.02	0.14	1.22	2.40	4.58	6.34	0.38	0.47	98.95
ØS-96-33	Syenite	Målsnes	60.27	0.83	18.48	1.72	2.45	0.14	1.27	2.64	4.18	6.43	0.41	0.58	99.40
ØS-96-34	Syenite	Målsnes	60.27	0.82	18.40	1.79	2.20	0.13	1.24	2.99	4.68	5.56	0.31	0.49	98.88
ØS-96-265	Syenite	Målsnes	60.95	1.30	17.45	1.57	3.06	0.13	1.21	1.91	4.78	6.42	0.46	0.25	99.49
ØS-96-35	Syenite	Målsnes	61.05	1.02	18.65	1.18	2.66	0.07	1.08	2.08	5.09	5.73	0.40	0.80	99.80
ØS-96-50	Syenite	Målsnes	62.06	1.04	18.44	2.31	1.33	0.09	0.71	1.92	5.02	6.58	0.34	0.82	100.65
ØS-96-45	Syenite	Målsnes	62.37	0.83	18.32	1.46	2.12	0.09	0.82	2.16	4.90	5.87	0.31	0.42	99.66
ØS-95-183	Syenite	Målsnes	62.43	0.85	18.59	1.61	1.96	0.11	0.91	2.20	5.12	5.54	0.31	0.74	100.35
ØS-96-49	Syenite	Målsnes	62.59	0.88	18.65	0.79	2.20	0.07	0.95	2.33	5.53	5.11	0.31	0.95	100.37
ØS-96-47	Syenite	Målsnes	62.72	0.90	18.32	1.21	2.38	0.11	0.91	2.14	5.14	5.32	0.31	0.74	100.19
ØS-96-46	Syenite	Målsnes	62.73	0.83	18.98	0.87	2.66	0.09	0.85	2.09	5.09	6.05	0.30	0.48	101.01
ØS-95-188	Syenite	Målsnes	62.85	1.15	17.44	1.03	3.28	0.12	0.95	1.91	4.97	6.07	0.45	0.30	100.51
ØS-96-48	Syenite	Målsnes	62.85	0.98	17.80	1.84	1.91	0.11	0.99	2.14	4.75	5.69	0.34	0.92	100.32
ØS-96-44	Syenite	Målsnes	62.94	0.84	18.75	0.98	2.48	0.08	0.82	2.10	5.14	5.91	0.31	0.48	100.83
ØS-96-51	Syenite	Målsnes	63.07	0.79	18.54	1.58	1.90	0.09	0.78	2.17	4.77	6.26	0.33	0.25	100.53

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-95-135	Monzogabbro	Saurdal	46.79	1.48	13.50	4.63	7.45	0.22	9.10	9.38	2.83	2.34	0.37	1.04	99.13
ØS-95-133b	Monzogabbro	Saurdal	46.81	1.72	14.15	5.12	7.13	0.19	8.95	9.83	3.68	2.27	0.41	0.74	100.99
ØS-95-133a	Monzogabbro	Saurdal	49.06	0.87	20.61	4.25	3.85	0.14	4.06	6.91	4.33	1.97	0.52	1.95	98.52
ØS-96-215	Quartz syenite	Saurdal	60.67	1.07	17.26	2.30	2.74	0.18	1.82	3.52	4.42	4.72	0.46	0.55	99.71
ØS-96-217	Quartz syenite	Saurdal	62.33	1.05	16.45	2.33	2.30	0.12	1.59	3.02	3.99	5.23	0.47	0.50	99.38
ØS-96-218	Quartz syenite	Saurdal	62.46	1.03	16.79	1.89	2.56	0.13	1.54	2.84	4.17	5.61	0.42	0.53	99.97
ØS-95-139	Quartz syenite	Saurdal	63.96	0.76	15.90	0.97	2.77	0.10	1.01	2.20	4.03	5.80	0.31	0.48	98.28
ØS-96-221	Quartz syenite	Saurdal	64.48	0.72	17.56	1.53	1.48	0.08	0.80	2.05	4.97	5.63	0.20	0.40	99.90
ØS-96-216	Quartz syenite	Saurdal	64.62	0.89	16.24	1.70	2.41	0.12	1.42	2.49	4.61	5.51	0.36	0.77	101.14
ØS-95-138	Quartz syenite	Saurdal	65.46	0.64	16.25	0.83	2.27	0.08	0.86	1.95	3.66	5.66	0.25	0.79	98.70
ØS-95-137	Quartz syenite	Saurdal	65.92	0.74	16.65	1.06	2.34	0.11	1.09	2.60	4.18	5.19	0.28	0.30	100.46

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-96-42	Granite	Målsnes	72.50	0.39	13.09	1.10	1.12	0.07	0.22	0.79	3.62	5.84	0.07	0.21	99.02
ØS-96-40	Granite	Målsnes	72.69	0.36	13.35	1.22	0.94	0.06	0.27	0.80	4.13	5.27	0.05	0.22	99.35
ØS-96-38	Granite	Målsnes	73.03	0.40	13.04	0.33	1.62	0.06	0.30	0.49	3.85	5.47	0.06	0.83	99.47
ØS-96-43	Granite	Målsnes	73.17	0.40	12.79	1.20	0.97	0.07	0.25	0.80	3.52	5.65	0.07	0.24	99.14
ØS-95-119	Granite	Målsnes	73.27	0.34	12.94	1.09	0.97	0.07	0.19	0.69	2.65	5.91	0.04	0.83	99.00
ØS-96-39	Granite	Målsnes	73.51	0.34	12.80	0.52	1.48	0.06	0.24	0.48	3.70	5.40	0.06	0.71	99.30
ØS-96-41	Granite	Målsnes	73.84	0.40	13.13	1.13	1.08	0.05	0.29	0.70	3.46	5.87	0.06	0.06	100.07
ØS-96-116	Granite	Målsnes	74.89	0.42	12.71	1.32	0.97	0.08	0.24	0.80	3.48	5.53	0.06	0.06	100.56

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-96-54	Granodiorite	Målsnes	64.46	0.51	16.59	2.39	1.33	0.07	1.72	3.86	4.54	2.97	0.24	1.05	99.73
ØS-96-267	Granodiorite	Målsnes	64.73	0.38	18.34	1.45	1.15	0.07	0.81	2.50	6.39	3.92	0.13	0.55	100.42
ØS-96-266	Granodiorite	Målsnes	67.66	0.26	16.47	0.86	1.01	0.05	0.77	2.35	5.82	2.89	0.14	0.57	98.85
ØS-95-153	Granodiorite	Målsnes	67.96	0.31	16.33	1.52	0.65	0.06	0.84	2.57	5.13	3.01	0.12	1.01	99.51
ØS-95-120	Granodiorite	Målsnes	68.99	0.29	15.81	0.83	0.97	0.04	0.64	2.61	4.86	2.65	0.11	0.30	98.10
ØS-96-55	Granodiorite	Målsnes	69.28	0.32	15.60	1.57	0.76	0.05	0.87	2.22	4.85	3.12	0.13	1.08	99.85
ØS-96-52	Granodiorite	Målsnes	69.42	0.35	16.29	1.36	1.04	0.05	1.01	2.35	5.13	3.09	0.15	0.65	100.89
ØS-95-154	Granodiorite	Målsnes	69.55	0.28	14.71	0.78	1.04	0.05	0.69	2.53	4.51	2.49	0.10	0.57	97.30
ØS-95-155	Granodiorite	Målsnes	69.64	0.27	14.90	1.05	0.68	0.05	0.63	2.52	4.18	2.84	0.11	0.73	97.60
ØS-96-53	Granodiorite	Målsnes	70.01	0.27	15.61	1.01	0.65	0.04	0.56	1.93	4.40	4.81	0.09	0.78	100.16
ØS-95-156	Granodiorite	Målsnes	71.20	0.24	15.41	0.94	0.76	0.04	0.61	1.87	4.13	3.21	0.08	0.78	99.27

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-96-263	Monzogabbro	Sagenes	46.36	2.45	16.84	3.85	8.56	0.18	6.86	7.68	3.21	2.13	0.51	0.60	99.23
ØS-96-261	Monzogabbro	Sagenes	46.42	2.70	16.44	3.95	8.96	0.19	5.52	7.46	5.04	1.71	0.56	0.45	99.40
ØS-96-262	Monzogabbro	Sagenes	46.57	2.17	16.02	4.75	8.39	0.24	5.54	7.48	1.87	3.79	0.41	0.91	98.14
ØS-96-37	Granodiorite	Sagenes	64.97	0.75	15.06	1.88	3.06	0.08	2.20	3.82	3.51	3.44	0.20	0.92	99.89
ØS-96-259	Granodiorite	Sagenes	65.18	0.53	16.85	1.29	2.45	0.08	1.54	2.76	4.08	3.91	0.19	0.98	99.84
ØS-96-66	Granodiorite	Sagenes	66.67	0.57	14.92	1.75	3.03	0.09	2.03	3.86	3.41	3.76	0.17	0.70	100.96
ØS-96-36	Granodiorite	Sagenes	66.94	0.61	14.85	2.36	2.02	0.07	1.84	3.51	3.57	3.51	0.17	0.70	100.15
ØS-96-67	Granodiorite	Sagenes	66.97	0.63	14.99	1.23	3.06	0.07	1.79	3.62	3.61	3.52	0.17	0.48	100.14
ØS-94-72	Granodiorite	Sagenes	69.53	0.40	14.14	1.61	1.76	0.05	0.90	2.00	4.56	3.04	0.11	0.71	98.81

Table 2. (continued).

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-94-187	Monzo-gabbro	Leikanger	48.75	1.50	15.08	5.28	9.58	0.25	6.08	8.11	3.22	1.56	0.44	0.53	100.38
ØS-96-19	Quartz syenite	Leikanger	66.32	0.78	15.97	1.55	1.55	0.12	0.75	1.73	4.00	6.20	0.24	0.58	99.79
ØS-96-11	Quartz syenite	Leikanger	68.11	0.76	15.22	1.74	1.55	0.14	0.57	1.31	4.05	6.35	0.18	0.32	100.30
ØS-96-10	Quartz syenite	Leikanger	68.27	0.78	14.91	1.76	1.58	0.14	0.54	1.33	3.89	6.23	0.18	0.44	100.05
ØS-96-13	Quartz syenite	Leikanger	68.29	0.81	14.91	1.23	1.69	0.14	0.58	1.32	3.93	6.39	0.17	0.37	99.83
ØS-94-186	Quartz syenite	Leikanger	68.67	0.61	14.70	1.12	1.37	0.12	0.44	1.04	4.04	6.45	0.13	0.22	98.91
ØS-96-14	Quartz syenite	Leikanger	69.41	0.70	14.54	1.62	1.37	0.09	0.53	1.58	3.23	6.86	0.16	0.33	100.42
ØS-96-12	Quartz syenite	Leikanger	69.52	0.74	14.81	1.77	1.26	0.13	0.51	1.20	3.79	6.66	0.15	0.26	100.80
ØS-96-16	Quartz syenite	Leikanger	70.41	0.43	14.60	1.56	1.69	0.04	0.65	0.73	4.28	4.79	0.13	0.69	100.00
ØS-96-189a	Quartz syenite	Leikanger	70.62	0.60	14.22	1.36	1.12	0.04	0.60	0.69	3.48	7.39	0.08	0.31	100.51
ØS-96-189b	Quartz syenite	Leikanger	70.74	0.63	14.07	1.23	1.15	0.10	0.54	0.71	3.87	7.18	0.09	0.38	100.69
ØS-96-18	Quartz syenite	Leikanger	70.97	0.66	14.14	1.61	1.08	0.12	0.39	0.88	3.97	6.10	0.12	0.31	100.35
ØS-96-17	Quartz syenite	Leikanger	71.36	0.59	14.00	1.65	1.15	0.12	0.37	0.72	3.93	6.16	0.08	0.31	100.44

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-96-255	Monzonite	Sele	47.95	0.78	18.70	3.43	5.29	0.19	4.85	8.03	3.99	4.00	0.55	1.15	98.91
ØS-96-254	Monzonite	Sele	49.35	0.84	18.98	4.05	5.26	0.23	3.53	6.15	4.63	3.59	0.51	0.89	98.01
ØS-96-239	Monzonite	Sele	50.14	1.52	17.92	3.75	4.90	0.22	3.42	7.31	4.32	3.02	1.62	0.86	99.00
ØS-96-256	Monzonite	Sele	50.85	0.85	18.28	3.30	4.57	0.31	4.40	5.90	2.40	6.30	0.45	1.33	98.94
ØS-96-253	Monzonite	Sele	52.24	1.45	15.42	4.44	5.58	0.28	3.25	5.39	4.96	3.91	1.18	0.46	98.56
ØS-96-227	Syenite	Sele	62.25	0.95	17.31	1.74	2.05	0.20	0.90	1.81	4.64	6.62	0.26	0.52	99.25
ØS-96-226	Syenite	Sele	63.66	0.87	16.87	1.70	1.76	0.16	0.91	1.83	4.52	7.04	0.23	0.48	100.03
ØS-95-198	Syenite	Sele	64.51	0.67	17.77	0.97	2.16	0.11	0.62	1.52	4.07	8.21	0.18	0.38	101.16
ØS-96-117	Syenite	Sele	64.60	0.88	17.38	1.35	2.05	0.17	0.75	1.50	4.74	6.61	0.25	0.50	100.78
ØS-96-228	Syenite	Sele	64.83	0.84	16.78	1.72	1.66	0.16	0.80	1.44	5.02	6.91	0.24	0.35	100.75
ØS-96-272	Syenite	Sele	66.66	0.74	15.64	1.38	1.69	0.13	0.72	1.41	4.81	6.54	0.21	0.28	100.21
ØS-96-271	Syenite	Sele	67.34	0.75	15.37	1.41	1.51	0.10	0.74	1.47	4.34	6.07	0.18	0.35	99.63
ØS-96-274	Granite	Sele	76.51	0.10	11.50	0.76	0.40	0.02	0.11	0.29	3.55	5.38	0.03	0.13	98.78
ØS-96-229	Granite	Sele	77.08	0.07	12.25	0.28	0.39	0.01	0.29	0.62	3.64	5.29	0.04	0.28	100.24
ØS-96-225	Granite	Sele	77.59	0.10	12.26	0.31	0.40	0.02	0.14	0.48	4.33	5.04	0.01	0.25	100.93
ØS-96-231	Granite	Sele	77.96	0.10	12.26	0.48	0.32	0.01	0.23	0.22	4.17	5.14	0.02	0.25	101.16
ØS-96-273	Granite	Sele	77.96	0.13	11.43	0.61	0.47	0.03	0.18	0.34	3.22	5.64	0.02	0.20	100.23
ØS-96-230	Granite	Sele	78.20	0.07	11.80	0.14	0.47	0.01	0.12	0.40	4.19	4.46	0.01	0.32	100.19
ØS-96-118	Granite	Sele	79.07	0.07	11.64	0.25	0.32	0.01	0.05	0.33	3.52	4.96	0.01	0.26	100.49

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-96-206	Granite	Lindane	75.88	0.18	13.16	0.69	0.50	0.04	0.23	0.68	4.20	4.93	0.04	0.37	100.90
ØS-96-201	Granite	Lindane	75.96	0.16	12.59	1.14	0.68	0.04	0.11	0.42	3.92	5.48	0.03	0.25	100.78
ØS-96-198	Granite	Lindane	76.50	0.20	12.12	0.53	0.76	0.04	0.23	0.49	3.73	5.27	0.04	0.17	100.08
ØS-96-203	Granite	Lindane	76.90	0.22	12.20	0.97	0.50	0.05	0.25	0.58	3.51	5.21	0.03	0.44	100.86
ØS-96-199	Granite	Lindane	76.98	0.24	12.02	0.86	0.61	0.04	0.23	0.32	3.92	5.18	0.03	0.28	100.71

Sample	Rock	Locality	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
ØS-96-208	Metagabbro	Lindane	44.96	1.83	12.97	6.95	10.33	0.30	8.85	9.13	1.86	0.46	1.01	0.42	99.07
ØS-95-196	Metagabbro	Lindane	45.26	1.91	13.60	14.50	2.83	0.25	6.97	9.11	2.36	0.59	0.98	0.72	99.08
ØS-96-205	Metagabbro	Lindane	45.80	2.52	17.59	4.62	9.22	0.34	4.14	8.25	3.57	0.70	1.71	0.60	99.06
ØS-96-202	Metagabbro	Lindane	46.03	2.03	18.04	5.53	7.89	0.26	4.29	8.78	3.12	0.70	1.58	0.75	99.00
ØS-96-204	Metagabbro	Lindane	46.99	2.29	17.04	4.95	8.93	0.28	4.68	8.66	3.20	0.60	1.72	0.38	99.72
ØS-96-209	Metagabbro	Lindane	47.04	1.58	15.43	5.40	8.57	0.24	7.25	9.00	2.32	0.70	0.79	0.63	98.95
ØS-94-67	Metagabbro	Lindane	47.99	1.45	15.67	11.74	2.09	0.22	6.20	9.44	2.87	0.54	0.78	0.66	99.65
ØS-96-207	Metagabbro	Lindane	48.66	1.46	19.76	4.18	5.87	0.20	3.74	9.11	3.48	1.04	1.14	0.90	99.54

Table 2. (continued).

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-96-264	Monzonite	Målsnes	95	5	10	6	4	103	76	370	69	301	18	2764	49	72	57
ØS-96-222	Syenite	Målsnes	58	5	6	5	8	68	107	382	31	87	11	3756	28	28	28
ØS-96-33	Syenite	Målsnes	58	8	7	5	10	73	101	413	25	60	7	4451	30	23	26
ØS-96-34	Syenite	Målsnes	56	16	7	6	9	66	63	277	19	44	7	4963	13	6	15
ØS-96-265	Syenite	Målsnes	54	5	6	6	3	63	57	163	25	49	7	1275	23	38	22
ØS-96-35	Syenite	Målsnes	68	7	6	5	10	60	65	392	21	71	8	4043	22	25	27
ØS-96-50	Syenite	Målsnes	57	3	5	5	4	39	68	316	20	74	8	4903	26	23	23
ØS-96-45	Syenite	Målsnes	50	8	5	6	5	48	57	389	19	76	7	4393	35	37	31
ØS-95-183	Syenite	Målsnes	56	3	6	6	7	57	60	440	20	122	7	4475	14	16	20
ØS-96-49	Syenite	Målsnes	58	--	5	5	7	60	50	376	19	74	8	3642	26	26	26
ØS-96-47	Syenite	Målsnes	55	4	5	5	7	55	54	406	27	62	11	4023	22	26	28
ØS-96-46	Syenite	Målsnes	56	10	5	5	6	49	66	375	18	66	8	4413	19	14	18
ØS-95-188	Syenite	Målsnes	58	3	6	6	14	59	92	144	26	56	9	1766	19	32	25
ØS-96-48	Syenite	Målsnes	58	3	6	5	10	60	60	387	20	79	8	4243	20	20	23
ØS-96-44	Syenite	Målsnes	55	3	5	5	5	51	78	375	18	58	8	4116	14	12	18
ØS-96-51	Syenite	Målsnes	47	3	5	5	7	41	81	345	21	59	8	4507	22	14	19

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-95-135	Monzogabbro	Saurdal	284	445	42	172	9	120	103	657	23	94	9	545	18	32	20
ØS-95-133b	Monzogabbro	Saurdal	292	373	42	151	11	111	82	549	23	93	8	621	19	31	24
ØS-95-133a	Monzogabbro	Saurdal	117	4	25	9	18	128	64	1132	25	105	6	791	12	43	28
ØS-96-215	Quartz syenite	Saurdal	96	--	10	7	5	104	137	707	40	367	26	1797	125	145	53
ØS-96-217	Quartz syenite	Saurdal	86	--	7	6	19	90	130	703	30	319	20	2313	117	139	55
ØS-96-218	Quartz syenite	Saurdal	85	3	7	6	7	93	150	716	22	355	22	2344	136	124	42
ØS-95-139	Quartz syenite	Saurdal	73	5	6	6	7	62	153	677	24	315	23	2513	29	107	46
ØS-96-221	Quartz syenite	Saurdal	46	5	4	6	6	64	101	445	24	375	9	2613	35	45	23
ØS-96-216	Quartz syenite	Saurdal	79	7	7	5	5	84	140	657	25	299	16	2164	106	109	38
ØS-95-138	Quartz syenite	Saurdal	63	10	5	6	23	60	138	666	19	286	14	2646	19	77	36
ØS-95-137	Quartz syenite	Saurdal	62	3	6	6	4	60	123	731	22	257	18	2477	79	89	42

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-96-42	Granite	Målsnes	15	4	--	5	5	67	153	77	67	314	22	541	81	96	55
ØS-96-40	Granite	Målsnes	16	7	--	5	9	37	121	88	66	329	27	561	75	105	55
ØS-96-38	Granite	Målsnes	17	6	4	5	5	52	151	87	63	331	23	607	76	109	55
ØS-96-43	Granite	Målsnes	14	10	2	5	6	64	153	74	68	314	24	563	86	117	55
ØS-95-119	Granite	Målsnes	16	10	2	5	5	36	121	195	62	323	22	713	83	159	77
ØS-96-39	Granite	Målsnes	16	4	4	5	5	38	134	92	51	280	20	572	96	128	55
ØS-96-41	Granite	Målsnes	16	4	--	5	4	47	127	187	65	290	26	832	62	93	47
ØS-96-116	Granite	Målsnes	15	4	1	5	5	65	150	71	60	328	22	666	74	106	49

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-96-54	Granodiorite	Målsnes	76	16	9	13	19	81	88	1284	16	156	10	1577	26	44	25
ØS-96-267	Granodiorite	Målsnes	36	5	5	7	4	48	61	99	15	139	6	1367	17	28	19
ØS-96-266	Granodiorite	Målsnes	34	8	4	7	13	45	43	1050	9	97	4	1537	7	19	11
ØS-95-153	Granodiorite	Målsnes	42	11	4	7	9	56	70	1031	11	122	9	1368	18	49	24
ØS-95-120	Granodiorite	Målsnes	37	7	3	7	5	49	60	1207	5	127	6	1279	18	36	18
ØS-96-55	Granodiorite	Målsnes	43	13	3	7	36	43	80	980	7	127	5	1775	33	35	22
ØS-96-52	Granodiorite	Målsnes	44	9	4	7	6	61	74	1165	7	157	7	1513	29	49	25
ØS-95-154	Granodiorite	Målsnes	36	9	3	7	7	50	53	1060	13	126	7	986	11	28	16
ØS-95-155	Granodiorite	Målsnes	38	6	4	7	5	50	56	1115	7	110	6	1277	13	22	12
ØS-96-53	Granodiorite	Målsnes	31	6	--	6	5	35	90	1027	7	110	5	2624	24	10	15
ØS-95-156	Granodiorite	Målsnes	29	8	3	7	6	49	72	882	10	107	7	1289	20	27	14

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-96-263	Monzogabbro	Sagenes	243	38	36	82	34	104	47	707	29	114	8	599	18	19	17
ØS-96-261	Monzogabbro	Sagenes	254	37	36	61	27	118	45	713	34	117	9	639	17	32	24
ØS-96-262	Monzogabbro	Sagenes	259	104	33	59	90	142	204	359	39	128	7	392	20	23	17
ØS-96-37	Granodiorite	Sagenes	91	43	13	21	16	77	121	418	34	199	14	795	36	58	34
ØS-96-259	Granodiorite	Sagenes	48	10	7	8	6	83	132	391	15	190	15	800	12	41	19
ØS-96-66	Granodiorite	Sagenes	81	38	12	16	14	66	119	371	33	181	13	756	27	43	27
ØS-96-36	Granodiorite	Sagenes	77	31	11	16	16	64	120	382	26	169	12	846	29	44	27
ØS-96-67	Granodiorite	Sagenes	76	33	11	17	14	62	121	381	22	180	10	737	39	65	33
ØS-94-72	Granodiorite	Sagenes	37	18	6	8	12	38	88	453	20	160	7	866	30	70	25

Table 2. (continued).

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-94-187	Monzogabbro	Leikanger	225	34	40	67	40	132	60	503	44	99	6	764	19	35	25
ØS-96-19	Quartz syenite	Leikanger	34	4	4	5	7	113	246	208	62	447	32	2036	118	152	69
ØS-96-11	Quartz syenite	Leikanger	34	--	3	5	3	109	166	135	83	632	48	1273	154	216	96
ØS-96-10	Quartz syenite	Leikanger	34	3	3	5	4	107	159	138	87	639	52	1293	146	202	94
ØS-96-13	Quartz syenite	Leikanger	33	--	3	5	4	106	166	133	95	689	51	1266	182	267	103
ØS-94-186	Quartz syenite	Leikanger	22	7	1	5	4	88	181	132	69	498	42	1072	98	229	111
ØS-96-14	Quartz syenite	Leikanger	40	--	3	5	3	47	174	317	121	526	60	2057	132	174	84
ØS-96-12	Quartz syenite	Leikanger	26	--	3	5	3	109	185	120	83	598	47	1171	164	214	90
ØS-96-16	Quartz syenite	Leikanger	25	--	4	5	15	88	137	228	33	501	14	2119	408	573	200
ØS-96-189a	Quartz syenite	Leikanger	20	4	2	6	4	57	191	101	96	554	55	670	161	233	102
ØS-96-189b	Quartz syenite	Leikanger	22	4	--	6	6	97	186	66	88	555	39	514	160	234	96
ØS-96-18	Quartz syenite	Leikanger	26	--	2	5	7	97	165	70	82	623	46	683	176	245	97
ØS-96-17	Quartz syenite	Leikanger	23	--	2	5	7	107	160	53	79	586	41	409	137	199	83

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-96-255	Monzonite	Sele	171	29	29	28	8	135	116	1406	19	124	7	1270	37	32	28
ØS-96-254	Monzonite	Sele	150	9	23	10	12	130	134	1371	19	115	6	1361	19	29	18
ØS-96-239	Monzonite	Sele	169	6	24	13	5	166	128	843	54	315	21	1988	57	94	48
ØS-96-256	Monzonite	Sele	141	31	19	26	5	183	178	280	39	220	11	1077	65	72	38
ØS-96-253	Monzonite	Sele	196	6	20	15	30	177	104	638	55	296	16	1921	48	86	50
ØS-96-227	Syenite	Sele	50	--	5	6	6	113	121	198	61	646	29	1591	167	243	107
ØS-96-226	Syenite	Sele	44	--	5	5	13	117	130	358	55	549	29	1742	163	198	93
ØS-95-198	Syenite	Sele	46	14	5	11	18	55	112	335	27	281	15	1399	46	64	39
ØS-96-117	Syenite	Sele	47	--	4	5	6	88	120	185	55	560	24	1567	190	304	144
ØS-96-228	Syenite	Sele	43	--	4	5	4	98	122	214	52	511	24	1667	157	205	97
ØS-96-272	Syenite	Sele	34	2	3	5	4	92	104	150	62	486	26	1164	87	140	72
ØS-96-271	Syenite	Sele	41	4	3	7	9	70	94	209	54	488	25	1376	104	160	72
ØS-96-274	Granite	Sele	7	7	--	5	4	6	75	107	2	102	3	916	9	20	6
ØS-96-229	Granite	Sele	5	3	--	5	5	11	87	209	6	28	3	1126	5	--	--
ØS-96-225	Granite	Sele	4	5	--	4	3	11	127	102	3	35	2	331	10	15	3
ØS-96-231	Granite	Sele	5	6	--	4	6	8	93	111	2	39	3	623	--	7	--
ØS-96-273	Granite	Sele	5	7	--	5	6	8	82	66	13	49	6	477	18	31	13
ØS-96-230	Granite	Sele	4	5	--	4	9	5	71	143	--	22	--	782	--	--	--
ØS-96-118	Granite	Sele	4	9	--	4	5	3	74	123	3	54	--	774	7	6	2

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-96-206	Granite	Lindane	7	8	--	5	9	33	101	150	20	157	6	575	23	38	22
ØS-96-201	Granite	Lindane	3	3	--	5	10	23	134	66	12	240	3	289	29	52	26
ØS-96-198	Granite	Lindane	8	5	--	5	6	27	129	51	28	109	11	423	23	43	22
ØS-96-203	Granite	Lindane	7	5	--	5	4	34	129	64	33	148	12	380	32	52	29
ØS-96-199	Granite	Lindane	10	10	--	5	6	25	114	54	28	174	10	435	30	54	31

Sample	Rock	Locality	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
ØS-96-208	Metagabbro	Lindane	274	32	50	94	92	216	4	524	48	60	7	355	23	51	26
ØS-95-196	Metagabbro	Lindane	360	60	49	95	104	184	7	584	43	62	7	404	21	41	27
ØS-96-205	Metagabbro	Lindane	204	5	35	13	105	264	5	851	101	66	15	1126	48	93	72
ØS-96-202	Metagabbro	Lindane	223	18	39	18	66	214	8	894	66	89	11	795	37	80	50
ØS-96-204	Metagabbro	Lindane	240	16	41	36	135	248	3	784	82	79	14	793	54	98	59
ØS-96-209	Metagabbro	Lindane	251	52	45	77	92	174	17	655	37	52	7	428	13	42	29
ØS-94-67	Metagabbro	Lindane	221	52	47	67	63	151	6	660	31	51	7	481	20	43	30
ØS-96-207	Metagabbro	Lindane	178	12	33	14	26	161	27	939	41	51	6	617	8	43	32

Table 3. Rare-earth element concentrations of representative Gothian rocks from the Kvamsøy area. Concentration in in ppm; -- = not determined.

Sample	Rock	Locality	La	Ce	Nd	Sm	Eu	Gd	Tb	Ho	Tm	Yb	Lu	Sc	Hf	Ta	Th	U
ØS-96-45	Syenite	Målsnes	35.0	37.0	31.0	10.9	3.7	4.9	--	1.1	--	2.3	--	12.5	2.4	0.5	0.8	1.2
ØS-95-119	Granite	Målsnes	83.0	159.0	77.0	13.7	1.7	--	--	--	--	9.5	1.7	7.8	12.0	1.8	17.4	1.6
ØS-95-120	Granodiorite	Målsnes	17.6	36.0	17.9	--	0.9	2.8	--	0.2	--	0.4	--	2.3	4.7	0.1	4.0	1.3
ØS-95-154	Granodiorite	Målsnes	11.1	27.5	15.7	2.6	0.7	1.7	--	0.3	--	0.9	0.2	3.5	3.8	0.2	2.3	1.0
ØS-95-153	Granodiorite	Målsnes	17.5	49.0	23.7	3.4	1.1	4.0	--	0.7	--	1.7	0.3	5.3	4.2	0.3	4.7	0.9
ØS-94-72	Granodiorite	Sagenes	30.0	70.0	24.4	4.5	1.3	--	--	--	--	1.8	0.3	6.8	4.8	0.6	21.2	--
ØS-96-36	Granodiorite	Sagenes	28.5	44.0	26.9	5.4	0.9	--	--	--	0.4	3.1	0.6	8.4	5.2	2.3	--	1.7
ØS-94-186	Quartz syenite	Leikanger	98.0	229.0	111.0	18.7	3.4	--	3.2	--	--	10.3	1.7	8.0	15.6	2.1	6.4	2.3
ØS-96-118	Granite	Sele	7.4	5.9	1.6	0.6	0.8	--	--	0.2	--	--	0.04	0.7	3.1	0.01	--	1.3
ØS-96-117	Quartz syenite	Sele	190.0	304.0	144.0	19.9	3.7	13.8	-	2.8	--	6.3	1.0	14.4	13.9	1.8	--	1.7

Major and trace element data

The samples selected for geochemical analyses are from localities in the Kvamsøy area (Fig. 2), and from one locality at Leikanger (Fig. 1), where the protoliths are best preserved. The original extent of the intrusions in the Kvamsøy area is difficult to evaluate, because the deformation has overprinted their contact relationships. Thus, the analysed samples of the protoliths may not represent all the lithological variations of the original intrusions. However, a wide spectrum of both acidic and basic igneous rocks are present. According to the classification of Debon & Le Fort (1982), the rocks define essentially four major groups, i.e., (1) gabbro, quartz gabbro and monzogabbro, (2) granodiorite, (3) granite and (4) syenite (Fig. 3a).

In the log ($CaO/Na_2O + K_2O$) vs. SiO_2 diagram of Peacock (1931), the granodioritic rocks are calc-alkaline (Fig. 3c). Further, according to the classification of Peccerillo & Taylor (1976), they belong to both the medium- and the high-K calc-alkaline series, with K_2O ranging from 2.5 to 4.8 % (Fig. 4). The granodioritic rocks from Sagenes are metaluminous, while the group from Målsnes has A/CNK ratios equal to 1.0, and thus straddle the per-/metaluminous boundary (Fig. 3b). All the other igneous rocks (the granites, quartz syenites, syenites, monzogabbros and gabbros) are alkalic-calcic (Fig. 3c). The individual protoliths in the Målsnes area are mostly metaluminous, but some samples are slightly peraluminous, while the protoliths from Sele and Leikanger are dominantly metaluminous (Fig. 3b).

The individual rock assemblages have small ranges in silica contents (Fig. 4). In spite of this, the rocks define rather smooth trends, but with variable element concentrations for the individual protoliths (Fig. 4). With increasing SiO_2, all the acidic rocks show a decrease in their contents of TiO_2, Al_2O_3, $Fe_2O_3^t$, MgO, P_2O_5, CaO, and V. There is also a general decrease in the concentration of Ba with increasing SiO_2, while the quartz syenite at Saurdal shows an increase. With respect to Na_2O and K_2O, there is an increase in the concentrations for the mafic rocks and a decrease for the more acidic varieties. Na_2O shows an increase for rocks containing up to ca. 62% SiO_2, and a decrease towards more silica-rich values. The K_2O content of the calc-alkaline granodiorites is markedly lower than that of the other rocks (Fig. 4). The quartz syenite at Saurdal and Leikanger displays increasing K_2O concentrations with increasing SiO_2, while the opposite is the case for all other acidic rocks.

The abundances of Zr, Rb, Nb, Nd and Y define distinct groups for some of the rocks (Fig. 4). For example, the syenitic rocks exhibit highly variable values of Zr (45-120 ppm at Målsnes, 260-370 ppm at Saurdal, 500-650 ppm at Sele)(Fig. 4). Another characteristic feature of the syenite at Målsnes is the very high concentration of Ba, 3600-5000 ppm for most of the rocks and 2800 ppm for a monzonitic enclave. At the western margin of the syenite, near the contact to the granodiorite, two samples have lower Ba concentrations (1300 and 1800 ppm), suggesting chemical interaction between the syenite and the granodiorite at the margin (Fig. 4). The granodiorites at Målsnes contain high Sr concentrations (900-1200 ppm), 2-3 times higher than the granodiorites at Sagenes (370-450 ppm).

Eleven samples have been analysed for rare earth elements (REE) (Table 3). Three samples of the granodiorites from Målsnes show LREE enrichment, with La/Lu ratios of 6-27 and no Eu anomalies (Fig. 5a). Two granodiorites from Sagenes show a pattern similar to the most REE-enriched granodiorites at Målsnes. All the granodiorites characteristically define a U-shaped pattern with relative depletion of MREEs. The granite sample at Målsnes and the quartz syenite at Leikanger (ØS-95-119 and ØS-94-186) have significantly higher REE concentrations than the granodiorites, La/Lu ratios of 5-6, and pronounced negative Eu anomalies (Fig. 5a). The quartz syenite from Sele (ØS-96-117) displays a pattern enriched in LREE, similar to the granite from Målsnes and quartz syenite from Leikanger, but it has a slightly higher REE concentration and a higher La/Lu ratio (20) (Fig. 5a and b). The syenite from Målsnes (ØS-96-45) has about the same REE pattern as the granodiorites from Sagenes, but it contains significantly higher contents of Nd, Sm and Eu (Fig. 5a and b). The granite from Sele (ØS-96-118), which is associated with the quartz syenite (ØS-96-117), has a very different REE pattern compared to the latter (Fig. 5b). The granite has the lowest REE concentration of all the analysed Gothian rocks (La/Lu ratio 19), and it shows a marked positive Eu anomaly.

The granodiorites have been plotted in primitive mantle-normalised spider diagrams (Fig. 6a). Those at Målsnes and Sagenes show weakly decreasing ratios towards the right in the diagrams, and negative anomalies for Th, U, Nb, Ta and Ti (Fig. 6a). The main difference between them is the positive Sr anomaly for the granodiorites at Målsnes, and their patterns are very similar to a gabbro at Saurdal (ØS-94-176), which occurs within the granodiorite at Målsnes (Figs. 2 and 6a). The granite at Målsnes and the quartz syenites at Leikanger and Sele have higher ratios than the granodiorites, and negative anomalies for U, Nb, Ta, Ti, Sr and P (Fig. 6b). The syenite at Målsnes and granite at Sele show a similar general decrease towards the right of the diagram, and also negative anomalies for Th, U, Ta and Nb. However, some anomalies are specific to these rocks (Fig. 6c). The syenite at Målsnes thus shows a pronounced negative anomaly for Ce and positive anomalies for P and Sm, and the granite at Sele exhibits positive anomalies for Hf and Zr.

The granitic and syenitic rocks are plotted in the Rb/Y+Nb discrimination diagram from Pearce et al. (1984) (Fig. 7). The granodiorites, together with the quartz syenite from Saurdal, the syenite from Målsnes and the granites from Linde and Sele, plot in the field of volcanic arc granites (VAG). The quartz syenite at Sele, and the granites from Saurdal and Leikanger plot in the field of within-plate granites (WPG).

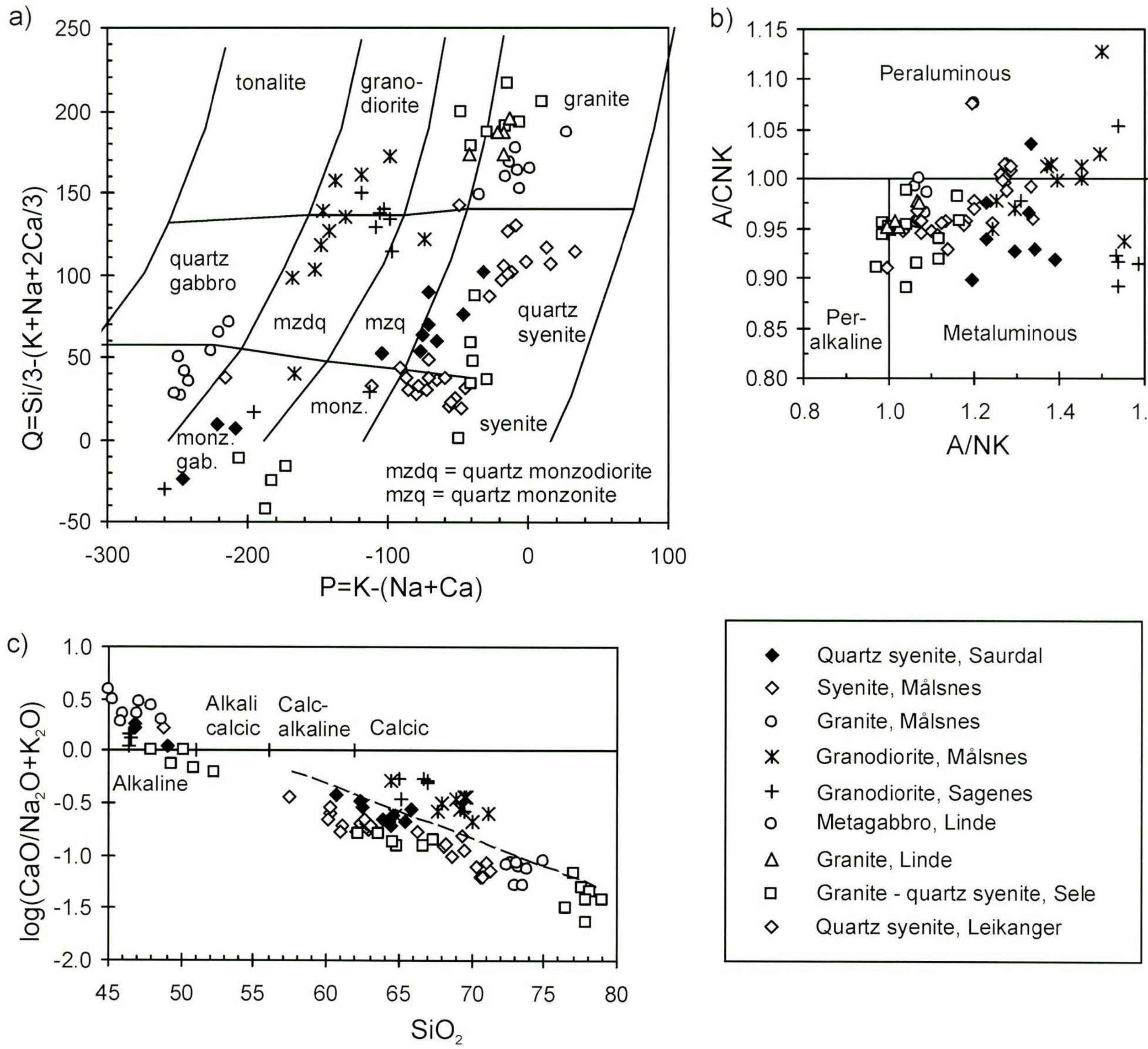
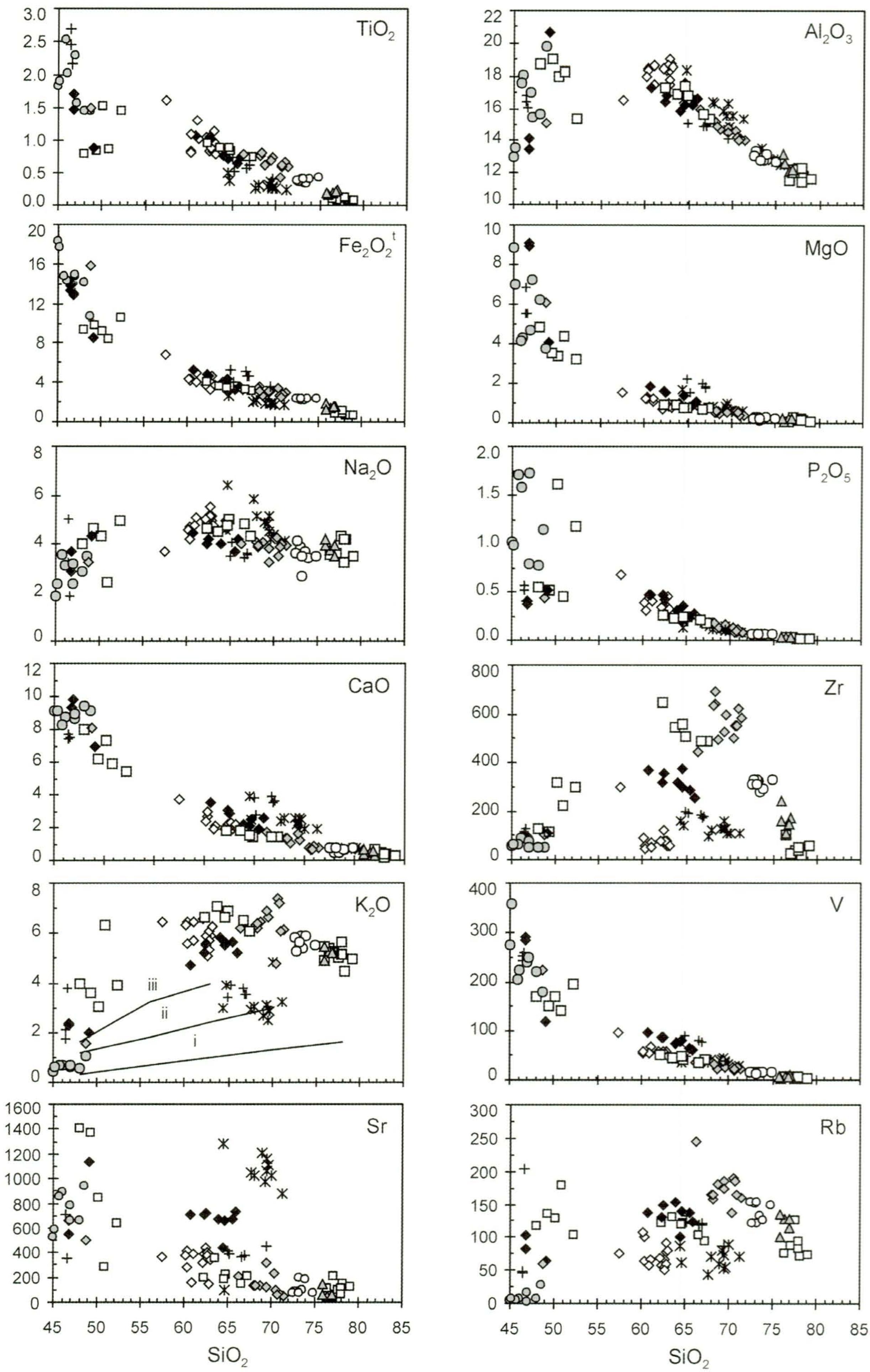


Fig. 3. (a) Classification of the Gothian rocks according to Debon & Le Fort (1982). Units are in gram-atoms x 10^3 of each 100 g of rock. Q is proportional to the content of quartz. Decreasing P means decreasing K-feldspar and increasing plagioclase. The mafic rocks have been given the same symbol as the granitoid with which they are associated.

(b) Plot of alumina-saturation index (A/CNK) versus inverse agpaitic index (A/NK) for the Gothian rocks. Boundaries according to Shand (1947). (A, C, N and K are molar contents of Al_2O_3, CaO, N_2O and K_2O).

(c) Classification diagram of Peacock (1931). The granodiorites display calc-alkaline trends, whereas all other rocks define alkalic-calcic and alkaline trends. The dividing line between the calc-alkaline and alkali-calcic fields is from Brown (1981).


TiO2
Al2O3
Fe2O3t
MgO
Na2O
P2O5
CaO
Zr
K2O
iii
ii
i
V
Sr
Rb
SiO2
SiO2

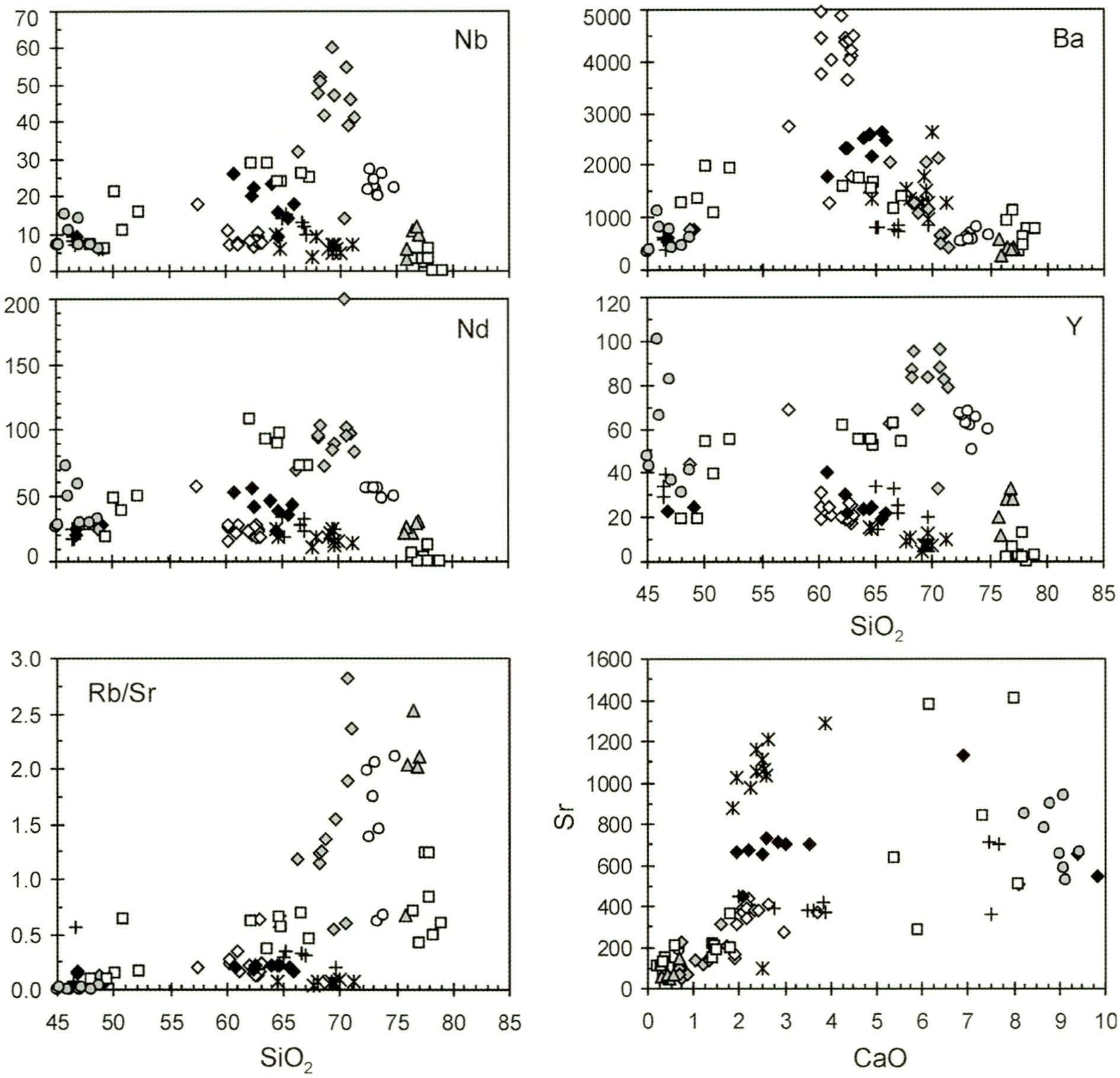


Fig. 4. Major- and trace-element concentrations for the Gothian rocks in the Kvamsøy area plotted in Harker diagrams. The lines in the K_2O-SiO_2 diagram mark the division between: (I) the calc-alkaline series, (II) the high-K calc-alkaline series and (III) the shoshonitic series according to the classification of Peccerillo & Taylor (1976). All data symbols are as in Fig. 3.

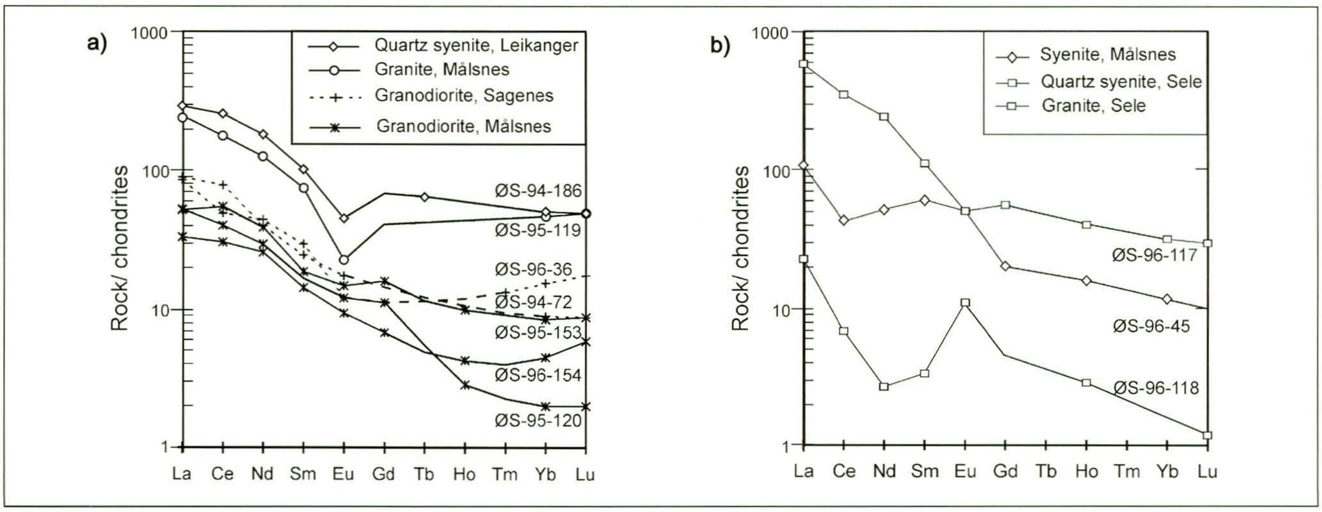


Fig. 5. Chondrite-normalised rare-earth element analyses for selected samples of the Gothian felsic rocks. Normalising values are from Haskin et al. (1968).

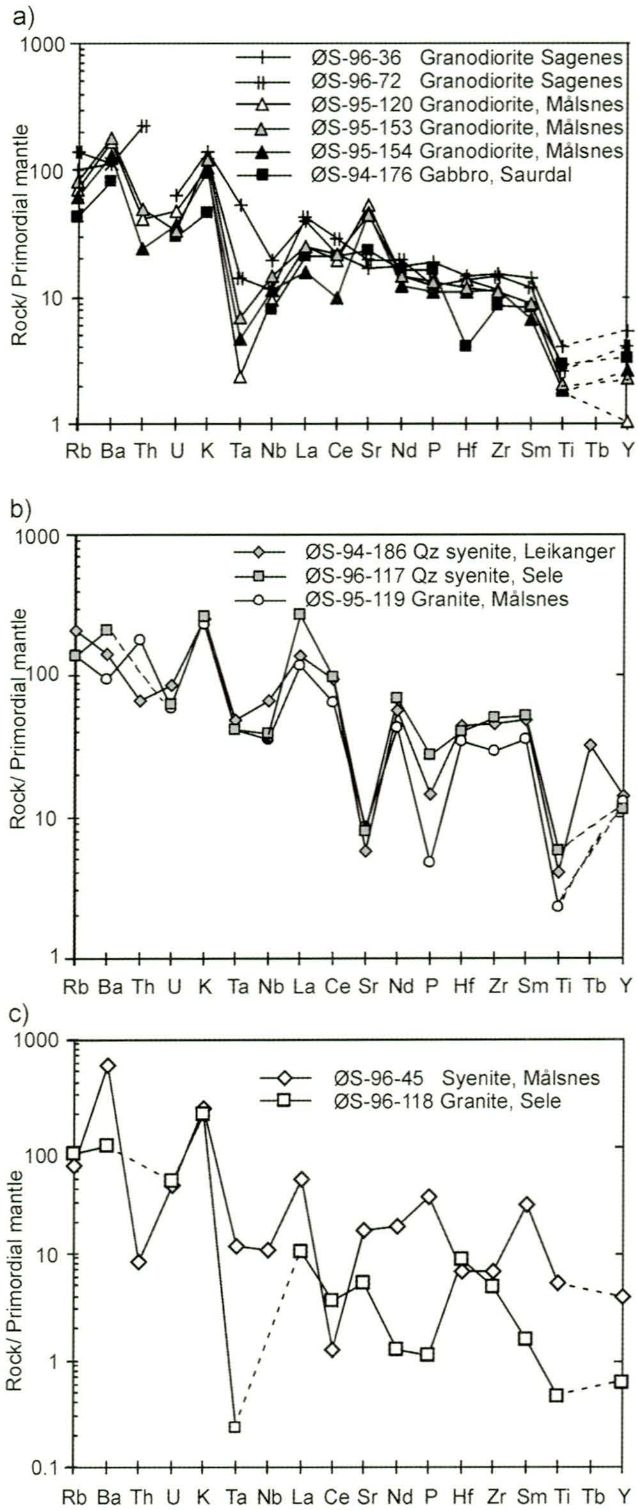


Fig. 6. Primitive mantle-normalised incompatible element abundances for selected samples from the Kvamsøy area. Normalising values are from Wood (1979). (a) Granodiorites from Sagenes and Målsnes compared with a gabbro at Saurdal. (b) Granites and quartz syenites from Leikanger, Målsnes and Sele. (c) Syenite from Målsnes and granite from Sele.

Sm-Nd and Rb-Sr isotope data

Sm-Nd and Rb-Sr isotope analysis of 11 whole-rock samples from the Kvamsøy area are presented in Table 4 and Fig. 8. Initial ε_{Nd} values are all positive in the range 1.2-3.9, and initial ε_{Sr} values are between −93 and +49 (Sri = 0.69607-0,706002) (Table 4, Fig. 8). The Nd model age (T_{DM}) is assumed to reflect the average time during which the material of a rock sample has been resident in the continental crust, i.e., the mantle separation age. However, the model age is largely dependent on which mantle evolutionary curve that is used. By using the curve of DePaolo (1981), the Gothian rock samples from the Kvamsøy area have T_{DM} ages from 1654 to 1837 Ma with an average of 1.76 Ga (Fig. 2, Table 4). The mantle evolutionary curve of Mearns (1986) gives lower T_{DM} ages with an average of 1640 Ma, similar to the U-Pb age. The emplacement ages of the oldest rocks in the WGC are about 1750 Ma, obtained by Rb-Sr whole-rock isochrons (Kullerud et al. 1986), while the oldest precise U-Pb zircon age from the WGC is 1686 ± 2 Ma (Tucker et al. 1990). This indicates that T_{DM} ages from the Kvamsøy area are not very different from the dated rocks of the WGC. The agreement between T_{DM} ages from the Kvamsøy area and the dated rocks of the WGC suggest that these T_{DM} ages date the time of significant crustal formation in the WGC.

Discussion

Tectonic setting

The quartzites in the Kvamsøy area are important when trying to establish a tectonic setting of the Gothian rocks. The occurrence of only Svecofennian zircons older than 1770 Ma in a quartzite suggests it may represent a metasediment that has been deposited prior to the Gothian orogeny. The presence of a Svecofennian quartzite would imply that the Gothian rocks were intruded into a crust situated relatively close to exposed Svecofennian rocks. Pre-Gothian rocks (>1750 Ma) are not documented from the area of the WGC covered by Fig. 1. However, in the Rogaland-Vestagder sector (Fig. 1, inset map), a 1.65 Ga granite contains Archaean zircons (Birkeland et al. 1997), suggesting that pre-Gothian crust is represented in the Southwest Scandinavian Domain. In southern Scandinavia, the Svecofennian rocks are exposed east of the Trans-Scandinavian Granite-Porphyry Belt (Fig. 1, inset map).

The Sm-Nd and Rb-Sr isotope data of the Gothian igneous rocks place some constraints on their sources. Positive initial ε_{Nd} values mainly in the range 2-4 (Fig. 8) suggest either a large input of juvenile mantle-derived melts at the time that the igneous rocks were formed, or a short crustal residence time for the source rocks. This is supported by the negative and low initial ε_{Sr} values of the rocks (Fig. 8). Positive initial ε_{Sr} values of some samples are most likely due to later mobility of the Rb-Sr system during the Sveconorwegian or Caledonian orogenies. The felsic and intermediate rocks have some common general characteristics: they are generally metaluminous, calc-alkaline to alkali-calcic (Fig. 3b,c),

Table 4. Rb-Sr and Sm-Nd isotopic relations for the rocks from the Kvamsøy area, WGC.

Sample	Type	Locality	Rb^a (ppm)	Sr^a (ppm)	$^{87}Rb/^{86}Sr^b$	$^{87}Sr/^{86}Sr_0{}^b$	±b	$^{87}Sr/^{87}Sr$	$eSr_T{}^e$	Sm^a (ppm)	Nd^a (ppm)	$^{147}Sm/^{144}Nd^b$	$^{143}Nd/^{144}Nd_0{}^b$	$\pm^b$	$^{143}Nd/^{144}Nd_T{}^c$	eNd^e	$T_{DM}{}^d$ (Ma)	$T_{SCAN}{}^e$ (MA)
ØS-94-186	Quartz syenite	Leikanger	175	136	3.7581	0.69607	± 13	0.73578	-92.5	18.2	107.7	0.10196	0.511686	± 5	0.51108	1.2	1851	1731
ØS-95-119	Granite	Målsnes	122	179	1.9791	0.70076	± 183	0.72168	-25.7	13.5	76.9	0.10653	0.511804	± 6	0.51118	2.6	1761	1643
ØS-95-120	Granodiorite	Målsnes	57	1119	0.1474	0.70282	± 18	0.70438	3.6	2.4	16.9	0.08555	0.511643	± 8	0.51114	3.9	1665	1569
ØS-95-154	Granodiorite	Målsnes	50	971	0.1479	0.70263	± 12	0.70420	1.0	2.3	13.4	0.10525	0.511765	± 7	0.51114	2.1	1795	1676
ØS-95-196	Metagabbro	Sele	9	551	0.0490	0.70286	± 13	0.70338	4.2	7.1	33.5	0.12830	0.512034	± 7	0.51128	2.5	1798	1652
ØS-96-36	Granodiorite	Sagenes	129	372	1.0080	0.69922	± 10	0.70987	-47.6	5.7	29.5	0.11657	0.511915	± 7	0.51123	2.7	1768	1640
ØS-96-37	Granodiorite	Sagenes	124	393	0.9128	0.70019	± 12	0.70984	-33.8	8.3	42.9	0.11662	0.511922	± 7	0.51123	2.8	1758	1630
ØS-96-38	Granite	Målsnes	142	85	4.8950	0.70500	± 15	0.75673	34.6	13.0	70.4	0.11187	0.511848	± 7	0.51119	2.4	1787	1662
ØS-96-45	Syenite	Målsnes	55	359	0.4117	0.70197	± 30	0.70633	-8.4	7.9	44.5	0.10781	0.511874	± 8	0.51124	3.7	1681	1567

a) Rb, Sr, Sm and Nd concentrations were determined by isotopic dilution techniques.
b) All ratios relative to $^{86}Sr/^{88}Sr = 0.1194$ and $^{144}Nd/^{146}Nd = 0.7219$. Error is given as 2 standard deviations of the mean in the last digits for each mass spectrometer run.
c) Epsilon Sr and Nd, $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ values for T are calculated by using the following chondritic uniform reservoir ratios. UR: $^{87}Rb/^{86}Sr_{UR} = 0.0827$; $^{87}Sr/^{86}Sr_{UR}$ at 0 = 0.7045 (DePaolo & Wasserburg 1976); CHUR: $^{147}Sm/^{144}Nd_{CHUR} = 0.1967$; $^{143}Nd/^{144}Nd_{CHUR}$ at 0 = 0.512638 (Wasserburg et al.1981).
d) Nd model ages (T_{DM}) are relative to the depleted mantle reservoir (DM) of DePaolo (1981).
e) Nd model ages (T_{SCAN} are relative to the depleted mantle evolution of Mearns et al. (1986).

contain biotite ± hornblende as the dominant mafic minerals and have negative anomalies for Ta and Nb (Fig. 6). This is characteristic for rocks formed from subduction-related magma generated in mature continental arcs (Brown et al. 1984). This interpretation is supported by the discrimination diagram of Pearce et al. (1984) in which the majority of the rocks show volcanic arc signatures, while some show within-plate characteristics (Fig. 7). Taken together, the combined data for the igneous rocks suggest their generation in an active continental margin. Alternatively, the data are consistent with a collision or post-collision setting during a subsequent orogenic period, by remobilisation of young magmatic source rocks generated at an active continental margin.

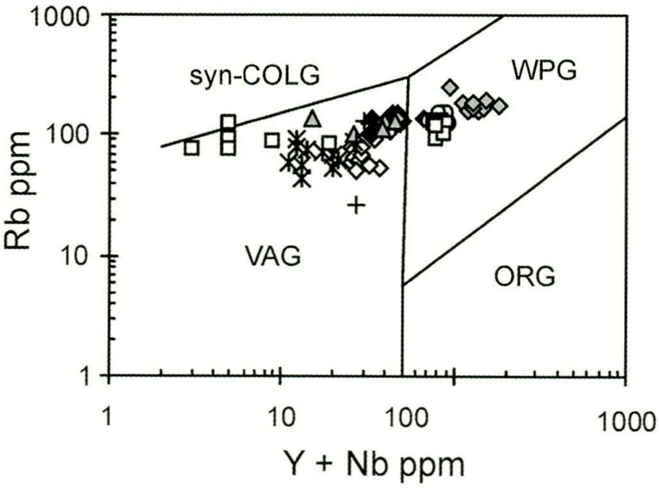


Fig. 7. Gothian rocks from the Kvamsøy area. Chemical discrimination diagram from Pearce et al. (1984). Syn-COLG = syn-collision granites, WPG = within plate granites, VAG = volcanic arc granites, ORG = ocean ridge granites. All data symbols are as in Fig. 3.

Petrogenesis and source rocks

Granodiorites

The granodiorites have been studied at Sagenes and Målsnes. Comparing their major and trace elements, it is seen that the granodiorite at Målsnes has higher concentrations of Al_2O_3, Na_2O, Sr and Ba than the granodiorites at Sagenes in the west (Fig. 4), suggesting that the two studied granodiorites were not comagmatic. The general geochemistry of the granodiorites places some constraints on the petrogenesis of the rocks. The granodiorites have U-shaped REE patterns, typical for calc-alkaline magmas from which amphibole has fractionated (Schnetzler & Philpotts 1970). Their high LREE/HREE ratios and lack of negative Eu anomaly (Fig. 5a) are consistent with generation from a mafic source containing garnet and minor plagioclase (Henderson 1984). Low Rb/Sr ratios (Fig. 4) and lack of negative Eu anomalies (Fig. 5a) suggest that plagioclase was not a major fractionating phase in the formation of the rocks. These features argue against the possibility that the granodiorites formed by crystal fractionation from a basaltic magma. With increasing SiO_2 contents of the granodiorites, there is a decrease in HREE (Fig. 5a), indicative of a garnet-bearing residual phase. Thus, the granodiorites could represent melts derived from a garnet-bearing source rock of basaltic or more evolved composition. The high Sr concentrations of the granodiorites (Fig. 4) are also consistent with a mafic source, because plagioclase most likely is a residual phase during partial melting in the crust, and thus retaining Sr in the source (Halliday et al. 1985).

If the source is composed of a mafic rock in a subduction zone environment, it may represent either 1) the subducting oceanic crust or 2) the lower continental crust.

(1) Melting of basaltic rocks in the subducting oceanic crust has been suggested for dacites containing high Sr and low HREE (e.g. Defant et al. 1991). Most authors, however,

suggest that the contribution from the subducted oceanic crust is in the form of hydrous fluids and partial melts that migrate upwards into the asthenospheric mantle wedge, and initiate parental melting of the asthenospheric mantle or the subcontinental lithosphere above the subduction zone (Wilson 1989).

(2) Melting of young basaltic rocks in the lower crust has been suggested for the generation of several of the magmatic arcs of western South America, e.g., the Lima Segment of the Coastal Batholith of Peru (Pitcher 1993). There, basaltic magma, derived from the mantle above the subduction zone, underplated the crust, and a partial remelting of these basalts generated tonalitic and granodioritic magma (Pitcher 1993).

A similar model may apply to the weakly fractionated, Sr-rich granodioritic rocks. Thus, remelting of basaltic rocks containing garnet in the lower crust may explain the generation of the granodiorites.

Granites and syenites

The major element concentrations of the various granitic and syenitic rocks are rather similar, but large differences exist for trace elements such as Zr, Rb, Nb, Nd and Y (Fig. 4). The differences in trace element contents may be due to generation from different sources, variable degrees of partial melting, fractional crystallisation, magma mixing and crustal contamination (Wilson 1989). Given the limited data sets from this reconnaissance study, only possible relationships between the rocks and candidates for their sources will be discussed.

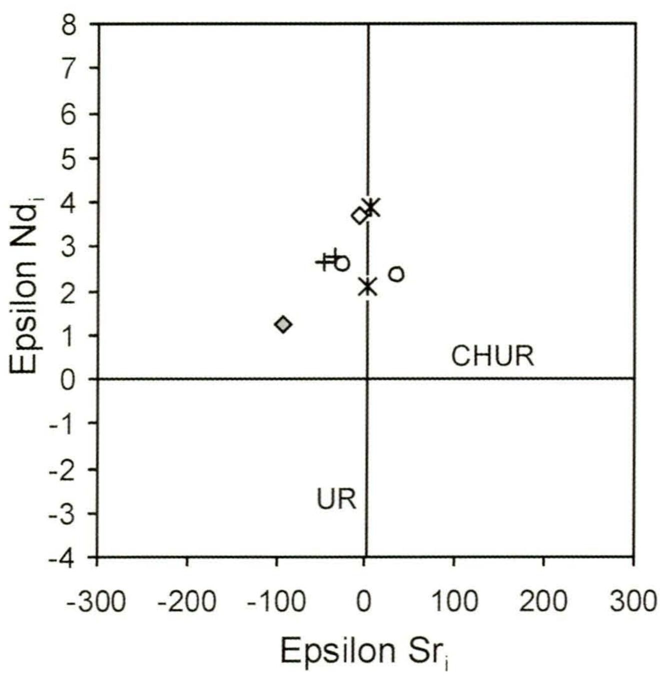


Fig. 8. Epsilon Sri – Epsilon Ndi for the Gothian rocks in the Kvamsøy area. All data symbols are as in Fig. 3.

At **Målsnes** the **syenite** defines a concordant boundary to the adjacent granodiorite. However, the concentrations of K_2O, CaO, Sr and Ba reveal that these two rock suites are not comagmatic (Fig. 4). Due to the high contents of Zr, Nb, Nd and Y for the **granite** at **Målsnes,** any genetic relationship with the adjacent granodiorite is excluded (Fig. 4).

The high concentrations of Sr and Zr of the **quartz syenite** at **Saurdal** preclude a genetic relationship with any of the other studied rock suites (Fig. 4). In the western part of the Kvamsøy area, at **Sele,** the mingling between the **granites, quartz syenites and mafic dykes** shows that these rocks were emplaced at the same time. However, the lack of intermediate rock compositions does not favour a common parental magma (Fig. 4). More likely, the granite, quartz syenite and mafic dykes at Sele had their own parental magma derived from different magma sources. The **granites** at **Linde and Sele** are quartz-rich granites with element concentrations that could be related to each other, but their highly different Rb/Sr ratios suggest that they are not comagmatic (Fig. 4).

Several factors are important when considering sources for the granites and syenites. The metaluminous to weakly peraluminous character of the rocks is consistent with reactions involving amphibole-induced dehydration melting (Patiño Douce et al. 1990). The granites and syenites are K-rich, suggesting a K-rich source without biotite in the residue, or alternatively a minor melt fraction from a mafic source (Conrad et al. 1988). Experimental work has shown that metaluminous high-K type rocks can be derived as partial melts of mafic to intermediate, transitional to high-K calc-alkaline, meta-igneous rocks (Roberts & Clemens 1993). Sr-rich melts usually imply melting at high pressure in the lower crust where plagioclase stability is suppressed (Patiño Douce & Beard 1996).

The **quartz syenites** at **Leikanger** (Fig. 1), and **Sele** (Fig. 2), and the **granite** at **Målsnes** display a depletion of HREE and negative Eu anomalies (Figs. 5a,b). These features are consistent with garnet and plagioclase in the melting residue or as fractionating phases. Likewise, their high Rb/Sr ratios indicate that they represent the most fractionated of all of the studied rocks (Fig. 4). The positive Eu anomaly of one sample of the **syenite** at **Målsnes** (ØS-96-45) may be a result of plagioclase accumulation, or from removal of hornblende (Henderson 1984). The **granite** at **Sele** contains the lowest REE concentrations of the studied rocks in the Kvamsøy area, and it displays a positive Eu anomaly (Fig. 5b). The Eu anomaly could represent accumulated feldspar, or alternatively it could represent crystallisation of hornblende (Henderson 1984).

Granites and syenites generated in both arc-type and within-plate settings may have been generated by two contrasting processes: 1) Differentiation by fractional crystallisation from mafic, mantle-derived melts, or 2) partial melting of rocks in the continental crust.

(1) Due to the lack of intermediate rocks between the granites and syenites, and the associated gabbroic rocks, it is not likely that they had parental magmas in common with those of the studied gabbroic rocks. Likewise, the large differences in concentrations of elements like K_2O, Zr, Nb, Nd and Y between the granites, syenites and the granodiorites also suggest that they are unlikely to have had common parental magmas. It implies that if the granites and syenites were formed by fractional crystallisation of a parental magma, this must have been from other magmas than those that generated the gabbroic or granodioritic rocks in the Kvamsøy area.

(2) Partial melting of mafic or intermediate rocks in the crust will form melts of variable compositions depending on the nature of the source rock and the P-T conditions. Subsequent differentiation of the melts, magma mixing and contamination will lead to rocks showing a wide range of compositions. In the Cordilleran plutonic rocks in Peru, the evolved rocks such as granites and syenites are interpreted to be related to crystal fractionation of tonalitic and granodioritic melts, derived from melting of basaltic rocks generated from mantle-derived melts that underplated the continental crust (Atherton 1990). Such a process could have generated the granites and syenites in the Kvamsøy area. Alternatively, they could have formed by melting of previously emplaced tonalites, as suggested by Weaver et al. (1990) for the granodioritic series of the Patagonian batholith in southern Chile.

From the data available it is difficult to distinguish between these two alternatives for the granites and syenites in the Kvamsøy area. Partial melting of basaltic or tonalitic rocks previously emplaced in the crust may represent the most likely alternative. Large differences in trace element concentrations probably represent several episodes of magma genesis, and/or variable involvement of contrasting sources during generation of the melts.

Correlation between the WGC and southwestern Sweden

Early in the Gothian orogeny (1.69-1.65 Ga), calc-alkaline juvenile crust was developed in western areas of southern Sweden, contemporaneous with alkali-calcic magmatism in the Trans-Scandinavian Granite-Porphyry Belt to the east, consistent with an eastward subduction zone (Åhäll & Gower 1997). To the west, renewed calc-alkaline magmatism occurred between 1.62 and 1.59 Ga, and was followed by late-orogenic granites and mafic-felsic intrusions at 1.56-1.55 Ga (Åhäll & Gower 1997). A direct correlation between the Gothian magmatism of the WGC and southern Sweden is difficult because of the sparse geochemical data for the dated rocks in the WGC. Coeval with the 1.69-1.65 Ga calc-alkaline magmatism in Sweden, granitic intrusions were emplaced into the northern parts of the WGC (Table 1, Fig. 1). These intrusions are interpreted to be equivalent to those of the Trans-Scandinavian Granite-Porphyry Belt in Sweden (Tucker et al. 1990); however, no geochemical data are published on these rocks. The 1631 ± 9 Ma calc-alkaline rocks presented in this paper and the 1641 ± 2 Ma calc-alkaline rocks in the Askvoll area (Fig. 1)(Skår et al. 1994) apparently represent an episode of calc-alkaline magmatism that is not recorded in southern Sweden. However, the 1.64-1.62 Ga ages of the magmatism in the Sognefjord area overlaps in time with the 1.62 Ga magmatism in southern Sweden (Åhäll & Gower 1997). Only three U-Pb zircon dates have been published on the post-Gothian and pre-Sveconorwegian rocks from the WGC (Table 1). These ages, of 1520 ± 20 Ma, 1508 ± 10 Ma and 1462 ± 2 Ma, correlate well with distinct episodes of anorogenic post-Gothian and pre-Sveconorwegian magmatism in the Southwest Scandinavian Domain (Fig. 1) between 1.50 and 1.20 Ga (Åhäll & Connelly 1998).

Summary and conclusions

A wide variety of rocks have been studied in the Kvamsøy area, representing a portion of the southern part of the WGC in Norway. The granitic, syenitic, granodioritic and gabbroic rocks represent protoliths to the gneisses and Sveconorwegian gneiss-migmatites that form the majority of the rocks in the Kvamsøy area, as well as other areas in the southern parts of the WGC. The main conclusions of this study are:

- The Gothian rocks in the Kvamsøy area are interpreted to have been formed in the interval 1.64-1.62 Ga, based on the available U-Pb isochron ages and Nd model ages.
- Quartzites in the Kvamsøy area are interpreted to represent remnants of a pre-Gothian basement that were intruded by the Gothian plutons.
- Sm-Nd and Rb-Sr isotope data indicate that the source rocks had a short residual time in the crust, or there were only minor contributions from the pre-Gothian basement rocks.
- The granodioritic, granitic and syenitic rocks are medium-grained, biotite- and amphibole-bearing and predominantly metaluminous.
- The granodioritic rocks are calc-alkaline to high-K calc-alkaline, and show 'volcanic-arc' signatures. The granitic and syenitic rocks are alkali-calcic and plot in the fields of both 'volcanic-arc' and 'within-plate' in geochemical discrimination diagrams,
- The data are consistent with a tectonic setting at an active continental margin, or with remobilisation of young magmatic rocks generated in such a setting, in a collision or post-collision scenario.
- The granodioritic rocks were most likely generated by partial melting of underplated, mantle-derived, basaltic rocks, while the granitic and syenitic rocks can alternatively have been generated by melting of more evolved tonalitic rocks.

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