Proterozoic orogenic magmatism within the Western Gneiss Region, Sunnfjord, Norway

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The Askvoll group, in the westernmost part of the Western Gneiss Region, Norway, is a sequence of mylonitic and phyllonitic schists that houses metagabbroic to granitic rocks, of which the former predominate. It comprises three tectonostratigraphic units. The highest Sandvika Unit consists of phyllonites, quartz schists, marble and fragments of tholeiitic, MORB-type metagabbro. The Vikanes Unit is dominated by epidote-actinolite mylonites and minor amounts of felsic schists and phyllonites, hosting abundant lenses of calc-alkaline metagabbros and subordinate granodiorites, quartz diorites and granites. A quartz diorite has yielded a U/Pb-zircon age of 1640.5 ± 2.3 Ma, and is interpreted to date the calc-alkaline magmatism. The chemical composition of the epidote-actinolite mylonites is very similar to that of the calc-alkaline metagabbros. The Kumble Unit at the bottom contains felsic schists and garnet-amphibole mica schists with lenses of garnet-amphibolite. The calc-alkaline metagabbros and associated differentiates in the Vikanes Unit represent arc magmatism. The epidote-actinolite mylonites are genetically related to the gabbros. On the basis of the geochemical characteristics, it is proposed that the heterogeneous Askvoll group was formed by subduction-related arc magmatism. The igneous rocks of the Askvoll group correlate well with time coeval rocks in southwestern Sweden and southern Norway. These were formed during the Gothian/Kongsbergian/Labradorian orogeny (1700–1500 Ma) when subduction-related magmatism occurred along the margins of present Fennoscandia and northeastern Laurentia.

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Introduction

The Precambrian crust in Norway, Sweden and Finland shows a pattern of younging towards the southwest (Fig. 1A). The Southwest Scandinavian Domain comprises southwestern Sweden, and southern and western Norway (Fig. 1A). It consists predominantly of various gneisses ranging in age from ~1750 Ma to 830 Ma (Fig. 1B), amongst these the main part was formed during the Gothian/Kongsbergian orogeny (Demaiffe & Michot 1985; Kullerud et al. 1986; Padget 1990; Tucker et al. 1990; Park et al. 1991).

The Precambrian basement in South Norway (Fig. 1A) consists of migmatites, various Gothian/Kongsbergian ortho- and paragneisses, and Sveconorwegian syn- to post-kinematic intrusions (Gorbatschev 1985). The Western Gneiss Region (WGR) comprises the westernmost part of the South Norwegian Precambrian (Gorbatschev 1985; Milnes & Koestler 1985; cf. Fig. 1A).

According to Kullerud et al. (1986), three main tectonothermal episodes can be recognized in the WGR. The protoliths of paragneisses, followed by orthogneisses, are the oldest rocks. They were formed between 1750 and 1450 Ma (Middle Proterozoic), during the main crust-forming event. It must be commented that the paragneisses are all dated by Rb-Sr whole rock ages with considerable uncertainty. In the north central part of the WGR U-Pb dating has shown that the major crust formation was in the time interval of 1686 to 1653 Ma, which is correlative with the Transscandinavian Granite-Porphyry Belt (Tucker et al. 1990). The next tectonothermal episode occurred between 1250 and 950 Ma ago (Late Proterozoic), when various igneous rocks were intruded. During the Caledonian orogenesis the rocks were structurally and metamorphic reworked, with eclogite facies metamorphism around 420–410 Ma, and subsequent amphibolite facies metamorphism around 400–390 Ma (Griffin 1987).

The origin, age, and tectonostratigraphic appurtenance of the Askvoll group in the WGR (Fig. 2A, cf. Skjerlie 1969) have long been controversial. Skjerlie interpreted the Askvoll group to be metasupracrustal rocks of Lower Palaeozoic age, a view shared by Furnes et al. (1976), who, however, redefined the extent of the Askvoll group to the area as indicated in the present paper. Skjerlie & Pringle (1978) included the Askvoll group in the 'Vevring Complex' (which is part of the Sunnfjord nappe of Precambrian age) that was considered to have been thrusted onto the rest of the WGR during the Sveconorwegian orogeny. Swensson & Andersen (1991) interpreted parts of the Askvoll group to be allochthonous rocks emplaced during the Caledonian orogeny. They relate the mylonitic character of the rocks of the Askvoll group to extensional deformation in the post-Caledonian Kvamshesten Detachment Zone, which the Askvoll group is a part of (Swensson & Andersen 1991; Sæbø Hveding 1992).

The aim of this article is to find, with the help of geochemistry, the platetectonic setting of the igneous rocks of the Askvoll group, and a precise U-Pb age of

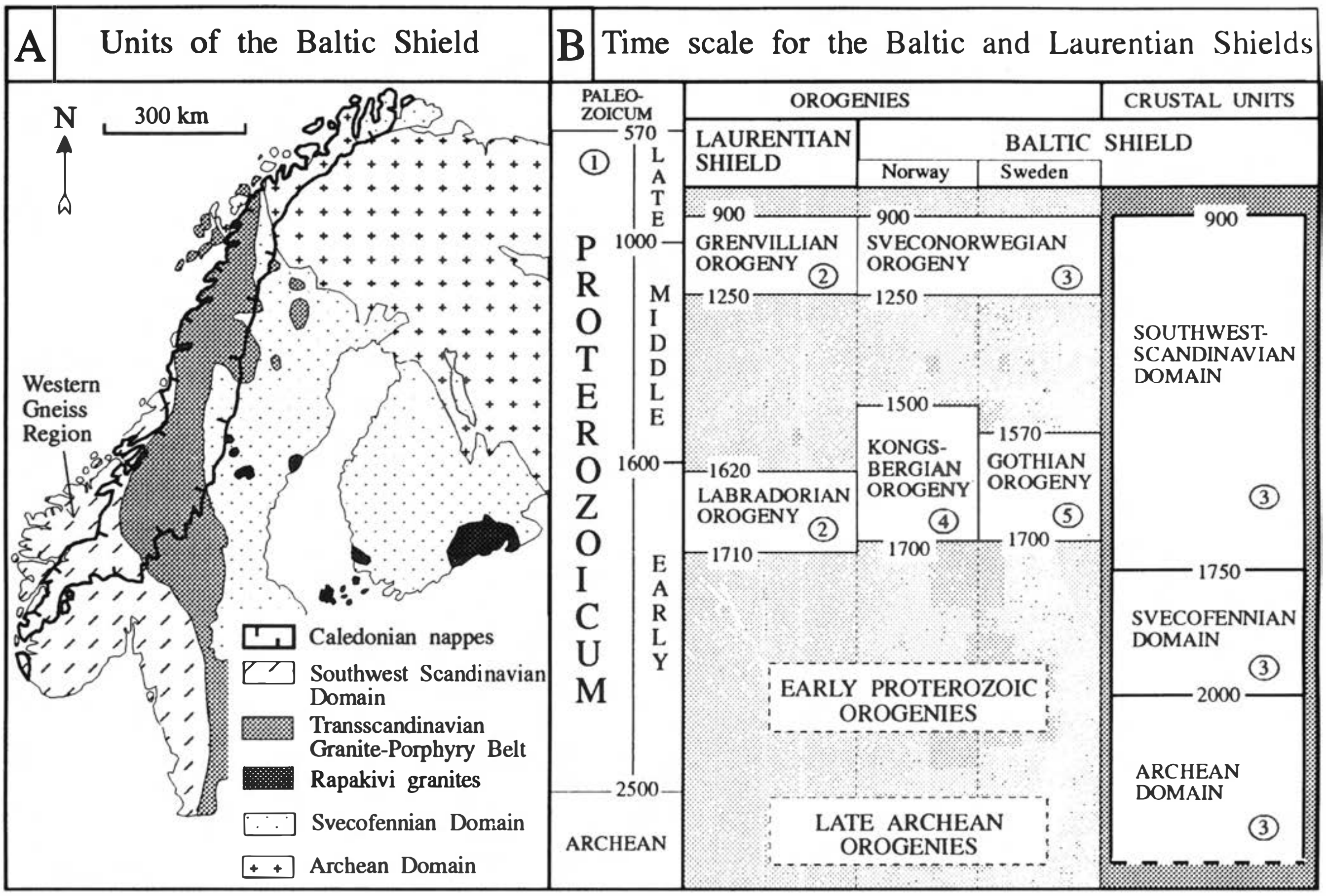


Fig. 1. A. Map (simplified after Gorbatschev 1985) showing the distribution of Precambrian and Caledonian rocks of the Baltic Shield. Subdivisions after Gaál & Gorbatschev (1987). B. Geological time-scale for the Precambrian rocks and orogenic events of the Baltic and Laurentian Shields. Numbers refer to the following references: 1. Plumb (1991); 2. Gower (1990); 3. Gaál & Gorbatschev (1987); 4. Stramer (1991); 5. Åhäll et al. (1990).

the rocks enables us to discuss the relationship between this part of the WGR and the rest of the Southwest Scandinavian Domain.

Geology, petrography and age

The rocks in the Sunnfjord Region (Fig. 2A) have been subdivided into three tectonostratigraphic units (Brekke & Solberg 1987; Andersen et al. 1990). The uppermost of these units comprises the Late Ordovician Solund–Stavfjorden ophiolite complex and its cover of metasedimentary and metavolcanic rocks (Furnes et al. 1990). The middle unit is composed of various syenitic to charnockitic orthogneisses, granites and gabbros (Kolderup 1921), overlain by pre-Silurian and Silurian metasediments (Brekke & Solberg 1987; Andersen et al. 1990). The upper and middle tectonic units are separated by an obduction melange related to the emplacement of the Ordovician ophiolite complex (Andersen et al. 1990; Alsaker & Furnes 1994).

The lower tectonic unit comprises the Proterozoic rocks of the WGR (Fig. 2A). In the Sunnfjord Region (Fig. 2A), Bryhni (1966, 1989) and Skjerlie & Pringle (1978) distinguished several complexes and groups. In simple outline this part of the WGR can be subdivided into (1) the *Askvoll group*, (2) the *Fjordane complex* of paragneisses associated with augengneisses, amphibolites, eclogites and meta-anorthosites, and (3) the *Jostedal complex* of migmatitic orthogneisses (Fig. 2A).

The Askvoll group was subdivided by Swensson & Andersen (1991) into the Gjervika, Vikanes and Kumle Units. This subdivision is largely similar to the one used here. However, we have renamed the Gjervika Unit as the Sandvika Unit, because of its larger extent than that of the original Gjervika Unit (Fig. 2B). In descending order the Askvoll group comprises: (1) *The Sandvika Unit* dominated by phyllonites, quartz schists, marble and a few metagabbroic lenses. (2) *The Vikanes Unit* is the largest of the three, and is dominated by epidote-actinolite mylonites. Throughout this unit occur abundant metagabbro and minor bodies of granodiorite, granite and quartz diorite. Felsic schists are most frequent in the lower part of the unit. The boundary between the Sandvika and the Vikanes Units is gradational, and represents a change from dominantly quartz-rich schists to chlorite-

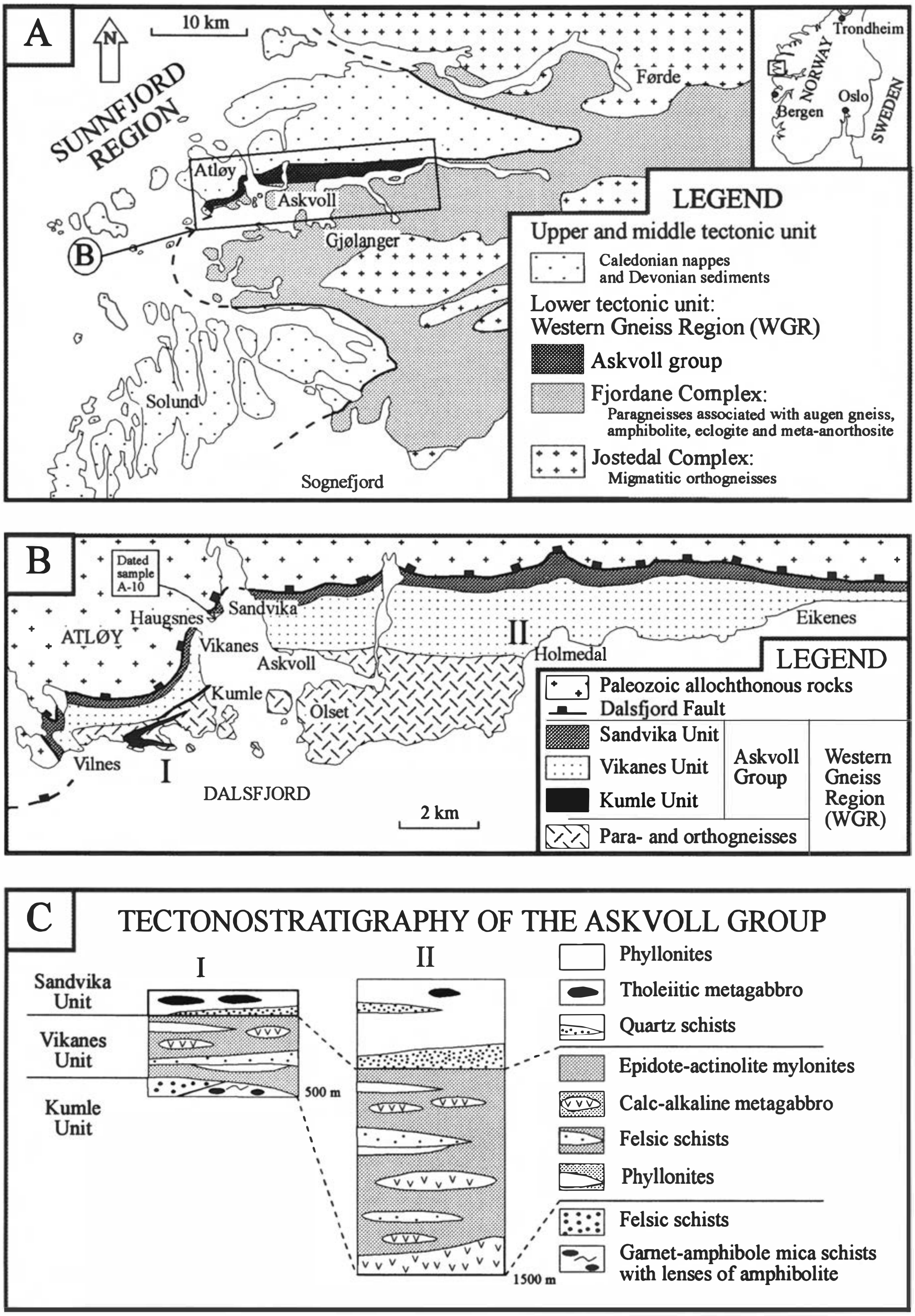


Fig. 2. A. Simplified map of the Palaeozoic and Proterozoic rocks of the Sunnfjord area (from Swensson & Andersen 1991). B. Simplified map of the Askvoll group. C. Simplified lithological/tectonostratigraphic sections (I and II) through the Askvoll group. Locations of sections are shown in Fig. 2B. At the lower right of the sections, their thicknesses (500 m and 1500 m) are indicated.

actinolite mylonites. (3) The tectono-stratigraphically lowest *Kumle Unit* outcrops only on Atløy (Fig. 2B). It consists predominantly of felsic schists, and minor occurrences of garnet-amphibole mica schist with lenses of garnet-amphibolite. Its boundaries with the Vikanes Unit and the adjacent gneisses are concordant, sharp, but tectonized.

Petrography of the Askvoll group

The lithologies of the Askvoll group are indicated in Fig. 2C. Classification of the igneous rocks and of the mylonites is according to Streckeisen (1976) and Sibson (1977), respectively.

Marble occurs in the middle to lower parts of the Sandvika Unit and alternates with phyllonite or quartz schist. The contact with the surrounding rocks is sharp or gradational. The marble layers are 1 mm to 50 cm thick, and thicker ones featuring 2–3 mm thick grey to white mylonitic laminae. In addition to dominant calcite, muscovite, opaques and K-feldspar are present.

Phyllonite is the principal rock of the Sandvika Unit, but also occurs in the epidote-actinolite mylonite of the Vikanes Unit. It comprises numerous horizons <1 to 40 m in thickness. It features mylonitic to ultramylonitic textures, the main type being made up of sericite, muscovite, albite, quartz and minor amounts of chlorite, calcite, epidote, sphene, and tourmaline. A subsidiary type consists of albite, actinolite, biotite, epidote, and minor calcite and titanite.

Felsic schists are best developed on Atløy (up to 150 m in thickness; Fig. 2C), where they are present in both the Vikanes and Kumle Units. The boundaries with the epidote-actinolite mylonite are sharp. The rock consists of alternating 0.1–3 cm thick white and grey bands, and locally contains thin layers of mica schist. The component minerals are quartz, plagioclase, muscovite, K-feldspar, epidote and minor amounts of biotite, chlorite, titanite, apatite, zircon, and opaques. Grain size is medium and the texture is defined by elongated heteroblastic crystals.

Quartz schist occurs throughout the Sandvika Unit. Commonly, it forms layers of 10–30 m thickness, but there are also thinner (0.2–2 m) layers, in alternation with phyllonite. In addition to quartz (70–80%), plagioclase, microcline and muscovite are the principal minerals. In the thickest layers, granitic bands up to 10 cm thick occur.

Epidote-actinolite mylonite is the dominant rock in the Vikanes Unit. This is a rather uniformly light grey, strongly foliated rock. It occurs in alternation with white feldspar-rich bands a few centimetres to 1 m in thickness, which contain thin stringers of only quartz or feldspar. The epidote-actinolite mylonite usually comprises porphyroclasts of 40–50% plagioclase (albite and oligoclase), 10–20% actinolite, 10–20% epidote, and minor quartz, set in a matrix of biotite and polycrystalline quartz (5–20%). The plagioclase grains, which are variably saussuritized, are usually surrounded by newly crystallized albite and oligoclase, and the rock may hence be classified as a blastomylonite.

Garnet-amphibole mica schist occurs in the Kumle Unit on Atløy (Fig. 2B), where it forms a lower 100 m in thickness. It is mylonitic, lepidoblastic, porphyroblastic and poikiloblastic. The main minerals are quartz, muscovite, plagioclase and biotite, but there is also up to 20% actinolite and 10% garnet.

Garnet-amphibolite appears as 0.1–2 m thick and up to 6 m long lenses in the garnet-amphibole mica schist. This medium-grained rock is nematoblastic, porphyroblastic and poikiloblastic in texture, and consists of hornblende and actinolite (60–75%), saussuritized plagioclase (5–10%), garnets partly retrograded to chlorite (5–20%), epidote (2–5%), and quartz (1–5%).

Metagabbro of the Sandvika Unit is most abundant on Vilnes (Fig. 2B), where it occurs as tectonic lenses up to 50 m in length. The lenses are usually much smaller (<1 m). The metagabbro is medium-grained and heterogranular, and the smaller bodies have a pervasive flaser texture. In one of the larger bodies, varitextured metagabbro, very similar to that observed in the upper part of ophiolitic gabbro (e.g. Skjerlie et al. 1989), occurs. Metabasalt dykes are found in one of the metagabbro bodies on Vilnes (Fig. 2b).

The *metagabbro* of the Vikanes Unit occurs as elipsoidal bodies in the epidote-actinolite mylonites. Most of these bodies are small (0.5–20 m thick), but some large bodies (up to 200 m thick and >4 km long) occur in the middle and eastern parts of the map area (Fig. 2B). At the boundaries to the epidote-actinolite schist, the metagabbro has a pronounced flaser texture, but in the central part of the large bodies, the primary igneous texture is well preserved. There the rock is massive without signs of layering. It is medium grained, and the subhedral to anhedral grains in some cases show a subophitic texture. The metagabbro is made of variable amounts of plagioclase and amphibole, with minor amounts of epidote, biotite, chlorite, titanite, opaques, apatite and quartz. The plagioclase (An_{25-35}) is saussuritized, and hornblende is the dominant amphibole, together with minor amounts of actinolite and tremolite.

In a few cases the metagabbro is cut by dykes (up to 1 m thick) of fine-grained, porphyritic metabasalt, consisting predominantly of actinolite (60–70%) saussuritized plagioclase (30–40%). There are also small amounts of ilmenite rimmed by leucoxene, and tine biotite grains.

Within several of the massive metagabbro bodies east of Askvoll (Fig. 2B) are inclusions of variously sized bodies of coarse-grained metapyroxenite, and, occasionally, metawehrlite. They show typical adcumulate textures, and are thought by the authors to represent segregations of earlier fractionates (e.g. Furman & Spera 1985).

Table 1a. U-Pb data for quartz diorite A 10 of the Vikanes Unit.

Sample 92010 (A 10)	Concentrations in ppm			Atomic ratios[a] and model ages in Ma				
Fraction[b]	U	Pb_{rad}	^{204}Pb	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{206}Pb}{^{238}Pb}$ Age	$\frac{^{207}Pb}{^{235}Pb}$ Age	$\frac{^{207}Pb}{^{206}Pb}$ Age
<45	238	76	0.0235	2400	0.2570	0.27493 ± 44 1566	3.8057 ± 167 1594	0.10040 ± 38 1631
45–74	226	75	0.0086	6500	0.2432	0.28678 ± 43 1625	3.9849 ± 80 1631	0.10078 ± 12 1638
74–106	272	91	0.0078	8500	0.2409	0.28824 ± 49 1633	4.0078 ± 84 1636	0.10084 ± 12 1640
>106	258	85	0.0312	2000	0.2332	0.28669 ± 54 1625	3.9862 ± 187 1631	0.10084 ± 39 1640
74–106[ab]	218	72	0.0029	18,000	0.2566	0.28427 ± 148 1613	3.9548 ± 237 1626	0.10090 ± 27 1641

[a] $^{206}Pb/^{204}Pb$ corrected for blank and mass discrimination; all other atomic ratios also corrected for initial lead. Errors are given as least significant digits at the 95% confidence level. Corrections for sample 92010: Discrimination U 0.05%/AMU Pb 0.12%/AMU. Blank U 0.1 ng Pb 0.1 ng. Common lead $^{206}Pb/^{204}Pb$ 15.9 $^{207}Pb/^{204}Pb$ 15.3 $^{208}Pb/^{204}Pb$ 35.5. (Stacey & Kramer 1975 growth curve).

[b] Size fraction in μm; ab = abraded as described by Krogh (1982).

Granodiorite: Within one of the metagabbro bodies ca. 1 km NW of Holmedal (Fig. 2B) there is a discontinuous zone (ca. 500 m long and 10 m wide) of medium-grained granodiorite consisting of plagioclase (An_{27-35}, 20–30%), mesoperthite (30–40%), quartz (20–30%), K-feldspar (1–10%), and aggregates (5%) of fine-grained biotite and epidote. Accessory minerals are zircon, titanite and apatite. The boundary between the metagabbro and the granodiorite is not exposed, but the two may be genetically related. This inference is based on a number of compositional changes in the metagabbro close to the interface with the granodiorite. Thus the amounts of K-feldspar and quartz increase, and pegmatitic veins are present.

Granite: Light orange-coloured granite occurs in lenses up to 40 m long and 1 m wide throughout the Vikanes Unit. This is a heteroblastic, medium-grained rock that consists of K-feldspar (40–60%), plagioclase (20–30%), quartz (20–25%), and accessory muscovite (1%), titanite, epidote, zircon, and oxides.

Quartz diorite: Lenses of quartz diorite have only been observed in a few places, and most abundantly on Haugsnes (UTM 876 086) on Atløy (Fig. 2B), where the sample used for age determination was collected. The rock is light grey, heteroblastic medium grained. It consists of albite (60–70%), microcline and perthites (5–10%), quartz (20–35%), and 2–3% of tiny grains of biotite, epidote, zircon, and irregular aggregates of titanite.

U/Pb geochronology

Approximately 50 kg quartz diorite from the Vikanes Unit (locality at Haugsnes UTM 876 086, Fig. 2B) was sampled for zircon U/Pb dating. The zircons vary from euhedral prisms to subrounded crystals that are predominantly transparent and light brown in colour. The concentration of zircons followed standard procedures for the separation of heavy minerals, and was carried out at the Geology Department of the University of Bergen. The zircons were split into several size fractions, of which one was abraded in accordance with the method of Krogh (1982). Subsequent sample preparation and mass spectrometry were carried out in the 'Laboratoriet för isotopgeologi' at the Naturhistoriska Riksmuseet, Stockholm.

The chemical preparation was done using standard methods including ion exchange separation of U and Pb by HBr and HCl. Analytical results and particulars are presented in Table 1a. The Pb/U and Pb/Pb ratios were estimated according to Ludwig (1991a), and discordia line intercepts were calculated according to Ludwig (1991b).

The regression line through all data points is plotted in Fig. 3. It has an upper concordia intercept at 1640.5 ± 2.3 Ma, with a MSWD value of 0.63. Since the analysed fractions are close to concordant, the lower intercept has a large uncertainty (254 ± 225 Ma). The abraded zircon fraction is no more concordant than the other fractions, and does not deviate from the discordia line. This indicates that the zircon population is homogeneous without significant amounts of older cores or younger overgrowths.

One crystal from the 106–150 μm size fraction was mounted directly in a Re filament, and its Pb isotopic composition was analysed in three steps at increasing temperatures. Essentially, the technique described by Kober (1987) was followed. The measured Pb isotope ratios and the calculated $^{207}Pb/^{206}Pb$ ages are given in Table 1b. The above conclusion that the zircon population is homogeneous is supported by the results from the

Table 1b. Analytical data for Kober analysis of one ca. 150 μm zircon crystal from sample 92010 (UTM 876 086).

Heating step	Temp. °C	Atomic ratios $^{206}Pb/^{204}Pb$	Atomic ratios $^{207}Pb/^{206}Pb^{a,b}$	Age (Ma) $^{207}Pb/^{206}Pb^{b}$
1	1380	6200	0.10143 ± 180	1650 ± 34
2	1450	19,900	0.10163 ± 79	1654 ± 15
3	1500	25,900	0.10150 ± 91	1652 ± 13

[a] Corrected for initial Pb. [b] Errors given as 1 sigma.

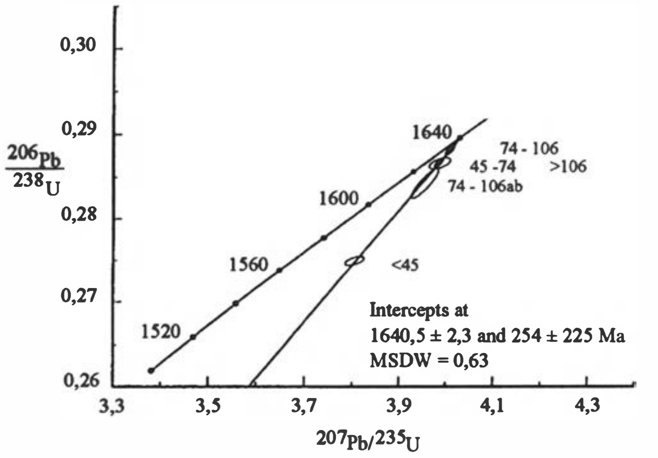


Fig. 3. Concordia diagram showing data of zircon fractions from quartz diorite A 10 from the Vikanes Unit. Fraction sizes in μm; ab = abraded fraction.

Kober analysis. Within error limits the three analysed steps all give similar $^{207}Pb/^{206}Pb$-ages of ca. 1650–1655 Ma (Table 1b). The Kober ages, which are all less precise than the conventional upper intercept age, are thus on the average slightly older, but within error not significantly different from the upper intercept age (Table 1b). We therefore interpret the age of 1640.5 ± 2.3 Ma as the crystallization age of the quartz diorite.

Geochemistry

Analytical methods

Geochemical analyses were carried out by X-ray fluorescence (XRF) at the Department of Geology, University of Bergen. The major and trace elements were analysed on glass beads and pressed powder pellets, respectively, according to the method of Norrish & Hutton (1969). International standards with the recommended values of Govindaraju (1984) were used for the calibration.

Alteration effects and selection of elements

The rocks of the Askvoll group have undergone amphibolite facies, and subsequently, greenschist facies metamorphism. We must therefore assess whether geochemistries of the igneous and volcaniclastic rocks were affected by the metamorphic processes. Previously, it has been well established that Ti, V, Zr, Y, Nb, Cr and Ni remain more or less unchanged in magmatic rocks during greenschist facies metamorphism (e.g. Cann 1970; Coish 1977; Shervais 1982). For the amphibolite facies metamorphism of magmatic rocks, it has been shown that the extent of element mobility is largely controlled by the availability of fluids to be flushed through the system (Weaver & Tarney 1981; Nicollet & Andriambololona 1980). The work of these writers on basaltic rocks indicates that Ti, V, Zr, Hf, Nb, P, the middle to heavy RE elements, Ni, Cr, Co, Cu, Zn, Fe, Mn and Mg are not affected particularly. Hence we employed Nb, P, Zr, Ti, Y, Cr and V to assess the tectonic environment of the magmatic rocks, specifically using the diagrams Zr/TiO_2-Nb/Y (Winchester & Floyd 1977), V-Ti/1000 (Shervais 1982), and Cr-Y and Ti-Zr (Pearce 1982).

The Askvoll group

Geochemical data from the preserved lenses of metagabbro in the phyllonites of the Sandvika Unit are shown in Table 2. In Fig. 4, the major oxides and selected trace elements have been plotted versus MgO (Bowen diagram). With decreasing MgO there is a pronounced increase in TiO_2, Y and Zr, a slight increase in $Fe_2O_3^t$ and P_2O_5, a decrease in Al_2O_3, CaO, Ni and Cr, whereas SiO_2 remains constant. The geochemical data of a metabasalt dyke associated with the metagabbro fit with the trends defined by the metagabbros. While it remains controversial whether the metagabbros represent liquid compositions, the reasonably smooth trends for most elements suggest that cumulative effects hardly play a major role. These obtained geochemical trends are typical for tholeiitic rocks. For comparison, the trends defined by the tholeiitic metabasalts of the Solund–Stavfjord Ophiolite Complex (Skjerlie et al. 1989) have been superimposed on the diagrams of Fig. 4. In Fig. 5 the data have been plotted in various discrimination diagrams, where they all plot in the MORB fields.

The relict protoliths in the mylonites of the Vikanes Unit comprise metagabbro, quartz diorite, granodiorite and granite. Representative analyses are shown in Table 3. The major and selected trace elements are also plotted in the Bowen diagram (see Fig. 6). With decreasing MgO content there is an increase in SiO_2, Na_2O, Y, Zr and Nb, whereas TiO_2, $Fe_2O_3^t$, CaO, Ni and Cr decrease. Al_2O_3 shows a slightly upward-convex trend, with the highest values at 4 to 6% MgO. Also, P_2O_5 shows highest values at a MgO content of around 4 to 6% MgO, but drops rapidly with decreasing MgO. The SiO_2, TiO_2, Al_2O_3 and CaO vs. MgO diagrams show smooth trends, and we therefore suggest that the samples represent liquid compositions. The trends defined by these data are typically calc-alkaline, which is well

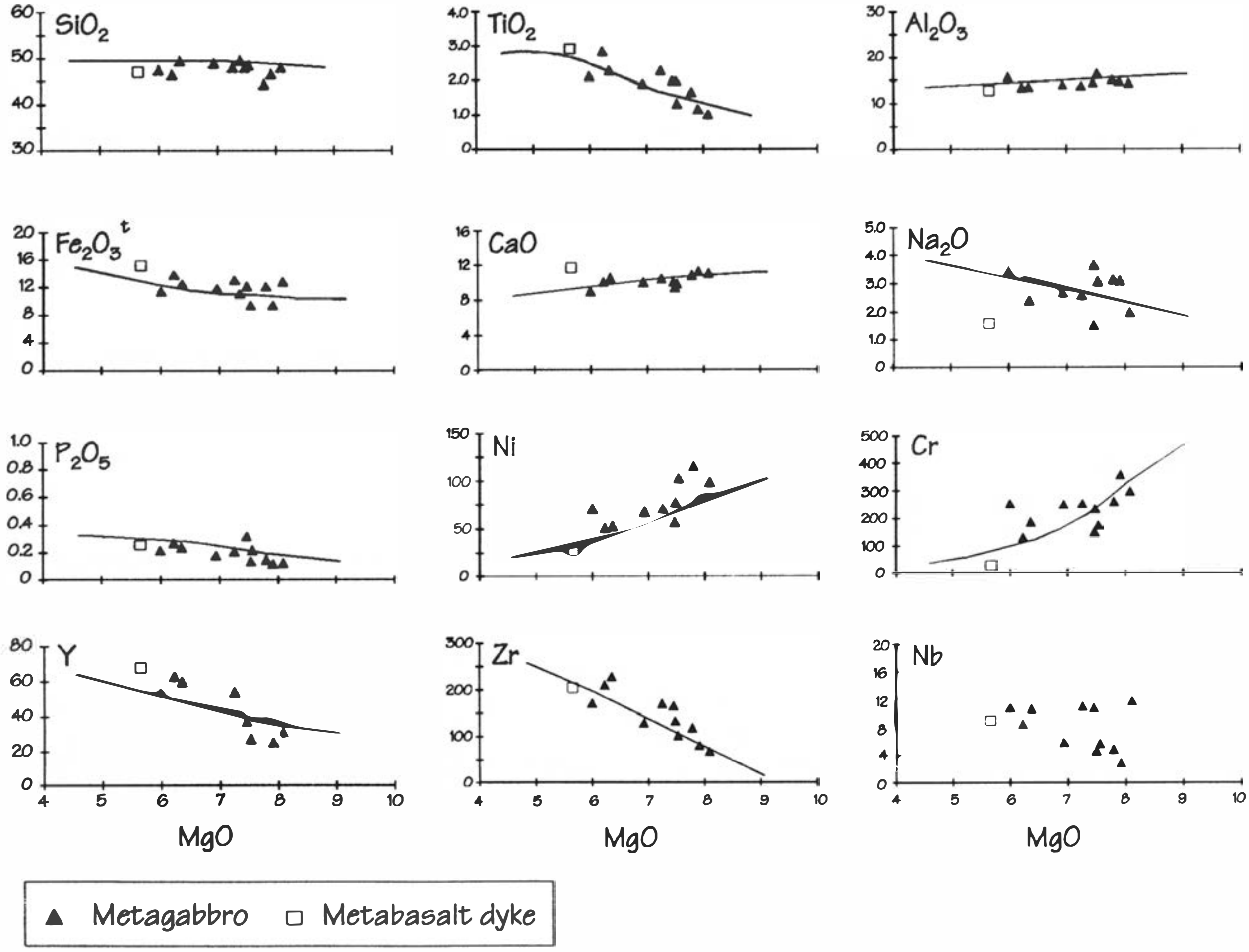


Fig. 4. Bowen diagram of metagabbro and a metabasalt dyke from the Sandvika Unit of the Askvoll group. The superimposed solid line in all diagrams represents the trend defined by tholeiitic metabasalts of the Upper Ordovician Solund–Stavfjord Ophiolite Complex in the Sunnfjord region (Skjerlie et al. 1989).

demonstrated by the similarly shown trends defined by volcanic rocks from the Sunda arc (Stoltz et al. 1990). The arc character of the metagabbro and associated differentiates is shown by the various trace element diagrams of Fig. 7. Even though Sr and, in particular, Ba are mobile elements during metamorphic processes, it is nevertheless worth mentioning the high Sr and Ba contents of these rocks (Table 3), which average 1041 ppm and 1104 ppm, respectively. This is another feature typical of calc-alkaline rocks (e.g. Saunders et al. 1979). A few metabasalt dykes occur in the Vikanes Unit, where they cut the metagabbro but they have concordant borders with epidote-actinolite mylonite of the Vikanes Unit. Their geochemistry is shown in Figs. 6 and 7, and from these diagrams they seem not to be related to the metagabbros. In particular, they have a much higher content of TiO_2, Y, Zr and Nb than the calc-alkaline metagabbros, and are thus more akin to alkaline basalts.

The chemistry of the epidote-actinolite mylonites of the Vikanes Unit is shown in various discrimination diagrams (Fig. 8), and representative analyses are presented in Table 4. About half of the analyses plot within or very close to the field defined by the Vikanes metagabbro. The other half is characterized by higher Zr/TiO_2 ratios, Zr and Y content, and lower V and Cr content. These are more akin to the composition of the granodiorites. Also, the Sr and Ba content of these mylonites is very high, similar to that of the plutonic rocks with which they are associated (Table 4). Based on these geochemical characteristics the epidote-actinolite mylonites can be genetically related to the described calc-alkaline plutonic rocks and may represent their volcaniclastic equivalents. However, regarding the mylonitic texture of these rocks, it cannot be excluded that they represent sheared metagabbros.

Discussion

An arc model for the Askvoll group

Each of the tectonostratigraphic units of the Askvoll group contains characteristic metamorphic rocks of magmatic origin, and presumably supracrustal rocks. Thus

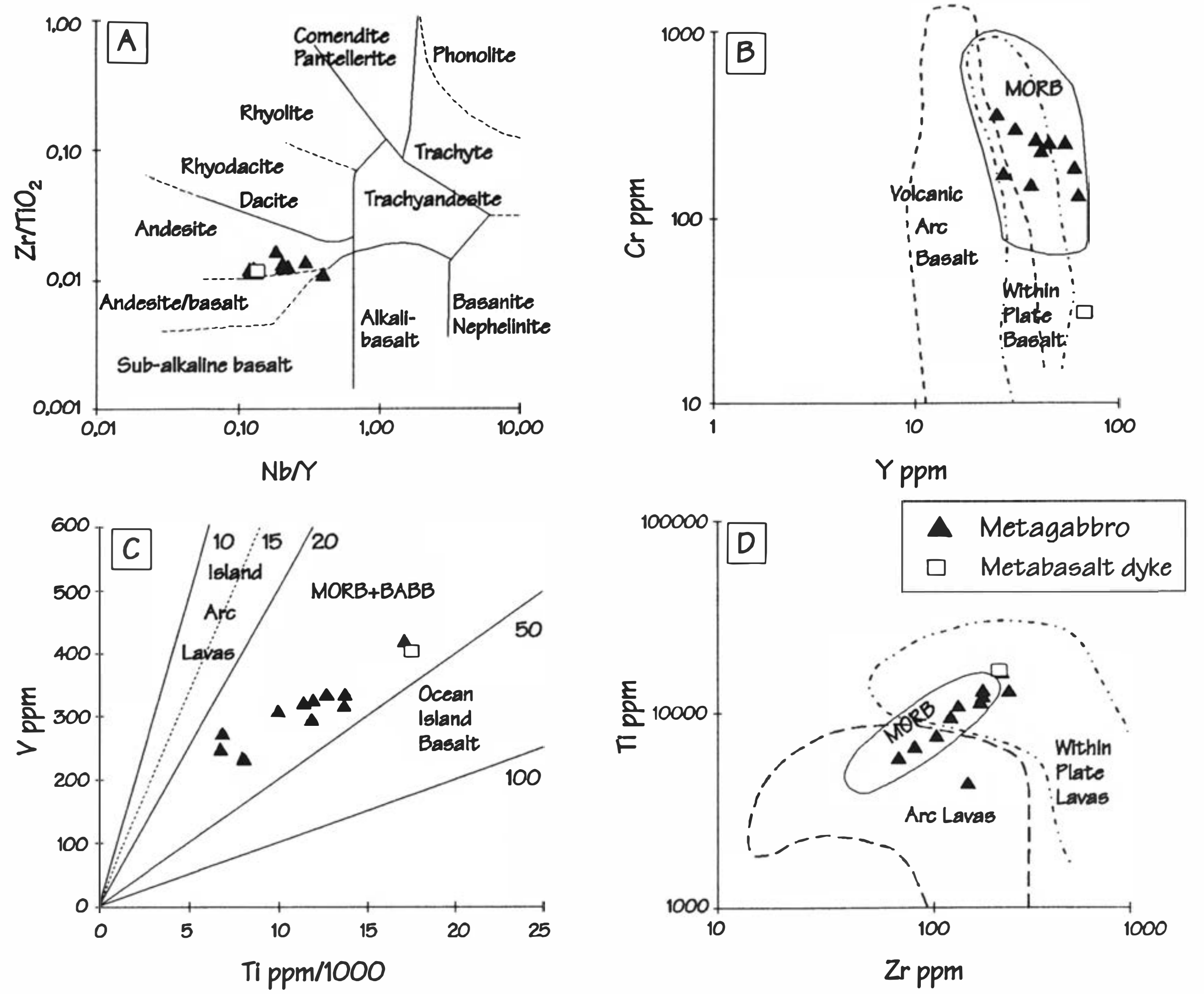


Fig. 5. Metagabbro and a metabasalt dyke from the Sandvika Unit of the Askvoll group, plotted in various discrimination diagrams. A: Zr/TiO_2–Nb/Y (Winchester & Floyd 1977); B: Cr–Y and D: Ti–Zr (Pearce 1982); C: V–Ti (Shervais 1982). BABB: Back-arc basin basalt; Morb: Mid-ocean ridge basalt.

the uppermost Sandvika Unit carries fragments of tholeiitic, MORB-type metagabbro set in a matrix of phyllonites and quartz schists, while the Vikanes Unit contains calc-alkaline intrusives ranging from predominant metagabbros to granites in composition, and epidote-actinolite mylonites and felsic schists. The lowermost Kumle Unit is characterised mainly by felsic schists.

The calc-alkaline character of the magmatic rocks of the Vikanes Unit implies arc magmatism at a continental margin. The minor amounts of MORB-type magmatic rocks of the Sandvika Unit could represent either part of an accretionary prism, into which fragments of oceanic crust were tectonically emplaced (cf. Karig & Sharmàn 1975), or intrusions of tholeiitic magma within a back-arc basin (e.g. Hawkins 1977; Saunders et al. 1979).

It is difficult to determine the protoliths of the mylonitic and phyllonitic rocks and associated schists, since all primary texture and mineralogy have been obliterated. The chemistry of the mylonites of the Vikanes Unit indicates an origin in a tectonic setting dominated by arc-related magmatism, similar to the calc-alkaline rocks that occur as lenses in the mylonites. It is therefore possible that the epidote-amphibole mylonites either represent sheared metagabbros, or they represent volcanic equivalents to these. However, either of the two alternatives satisfies the tectonic model of the Askvoll group as an arc type.

Regional correlations and conclusions

The effects of the Early- to Middle-Proterozoic subduction in Scandinavia, known as the Gothian orogeny in southwestern Sweden and the Kongsbergian orogeny in southern Norway, can be traced westward to the Laurentian margin where similar events are grouped as the Labradorian orogeny (Fig. 9). The Askvoll group constitutes only a small portion of the westernmost WGR, and the adjacent heterogeneous gneisses have not yet been subject to systematic geochemical and petrological inves-

Table 2. Representative analyses of metagabbro and a metabasalt dyke from the Sandvika Unit.

		UTM	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum	V	Cr	Ni	Rb	Sr	Y	Zr	Nb	Ba
A6	Metagabbro	876 087	48.15	1.02	14.42	12.81	0.24	8.08	11.06	1.97	0.18	0.13	2.30	100.36	263	299	99	5	114	31	68	12	25
A67	Metagabbro	834 054	48.11	1.99	14.46	12.16	0.18	7.46	10.11	1.50	0.72	0.32	2.59	99.61	325	151	57	25	247	37	167	11	83
A60	Metagabbro	838 048	49.14	1.90	14.08	11.64	0.20	6.93	10.05	2.66	0.40	0.18	2.33	99.50	321	252	68	9	143	45	131	6	74
A5	Metagabbro	875 087	49.60	2.28	13.52	12.46	0.19	6.35	10.59	2.39	0.22	0.24	2.85	100.71	316	187	53	4	218	60	229	11	57
A3	Metagabbro	875 087	47.57	2.12	15.76	11.31	0.14	5.99	9.05	3.43	0.29	0.22	3.38	99.25	334	254	71	3	295	54	172	11	71
A61	Dyke	838 048	47.19	2.92	12.84	15.39	0.22	5.65	11.75	1.56	0.38	0.26	1.63	99.79	403	31	27	10	132	68	206	9	25

LOI = loss on ignition.

Table 3. Representative analyses of plutonic rocks from the Vikanes Unit.

		UTM	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum	V	Cr	Ni	Rb	Sr	Y	Zr	Nb	Ba
C133	Metagabbro	926 086	45.10	0.76	14.19	12.69	0.19	10.19	13.24	1.25	0.40	0.06	1.48	99.55	281	177	100	4	1137	12	30	n.d.	342
B125	Metagabbro	888 084	45.22	0.71	14.62	12.83	0.23	9.51	12.81	1.76	0.37	0.07	1.40	99.51	267	148	86	n.d.	1035	11	31	n.d.	198
A77	Metagabbro	840 053	41.08	1.01	16.29	16.15	0.16	8.67	10.16	1.78	0.79	0.13	2.34	98.56	340	54	88	13	944	15	72	6	632
D182	Metagabbro	987 090	48 31	0.82	16.45	10.07	0.16	7.39	11.78	3.25	0.74	0.31	0.82	100.08	258	148	49	n.d.	1091	37	47	12	398
C150	Metagabbro	959 085	46.18	1.08	20.18	9.15	0.13	6.42	10.63	3.06	1.20	0.09	1.01	99.11	280	39	73	7	1895	14	39	6	1462
C159	Metagabbro	950 090	50.27	0.78	17.28	9.93	0.20	5.51	8.77	3.94	0.86	0.27	0.70	98.64	189	57	34	8	1021	21	49	7	632
B116	Metagabbro	888 088	49.91	0.83	18.34	9.79	0.18	5.08	8.61	3.79	0.93	0.42	1.02	98.80	221	39	33	10	1631	17	31	4	1038
B128	Metagabbro	889 083	52.85	0.71	18.91	8.02	0.14	4.13	6.63	4.21	2.05	0.30	0.65	98.62	166	47	30	21	1334	12	41	4	2217
A18	Metagabbro	870 080	52.74	0.65	20.16	7.04	0.15	3.53	7.30	4.39	1.96	0.29	0.90	99.12	125	29	22	29	1622	20	104	6	2293
C155	Granodiorite	951 093	56 32	0.79	17.77	6.76	0.16	3.29	5.57	4.64	3.09	0.30	0.99	99.68	130	25	18	35	992	23	239	8	2590
C154	Granodiorite	953 092	60.18	0.68	18.02	5.13	0.12	2.13	4.27	4.64	3.96	0.23	0.86	100.23	101	16	12	53	727	22	268	10	1772
B85	Quartz diorite	897 086	60.41	0.60	19.67	3.32	0.08	1.55	3.67	7.77	0.38	0.13	1.13	98.72	80	11	13	n.d.	1696	5	99	n.d.	1543
C166	Quartz diorite	963 100	65.53	0.30	16.76	2.84	0.06	0.87	2.70	7.87	1.16	0.11	1.03	99.24	30	8	7	20	537	19	261	7	1362
A10	Quartz diorite	876 086	66.73	0.54	17.52	1.13	0.04	0.52	2.09	8.77	0.15	0.06	1.22	98.76	34	9	8	n.d.	270	10	797	5	104
C165	Granite	963 100	74.14	0.13	13.44	1.07	0.02	0.08	0.40	4.23	6.64	0.01	0.08	98.95	n.d.	7	7	54	100	25	215	22	621

LOI = loss on ignition

Table 4. Representative analyses of epidote-actinolite mylonites from the Vikanes Unit.

	UTM	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum	V	Cr	Ni	Rb	Sr	Y	Zr	Nb	Ba
A12	875 086	51.99	0.70	17.78	8.74	0.19	4.70	8.30	2.79	2.74	0.36	0.80	99.28	181	67	29	49	1136	20	46	n.d.	1575
B84	901 087	54.43	0.66	18.81	7.14	0.14	3.78	7.25	4.43	1.35	0.34	1.47	99.80	155	25	27	4	1910	10	62	5	1938
B115	888 088	53.44	0.72	18.45	7.92	0.15	3.83	6.54	4.26	2.59	0.33	0.50	98.72	157	23	20	24	1403	12	89	4	2339
D183	998 091	48 69	0.93	18.69	9.25	0.18	5.19	8.30	3.88	1.80	0.39	1.53	98.84	207	58	39	35	1722	24	107	8	1574
A74	839 075	53.26	0.82	18.54	8.46	0.19	3.41	6.42	4.15	2.55	0.37	1.41	99.58	168	12	9	37	963	23	109	6	1574
C131	923 098	54.71	0.75	16.96	7.59	0.17	4.35	5.92	3.98	3.44	0.38	1.32	99.57	152	74	28	88	725	26	141	8	1618
A32	847 063	57.07	0.73	17.99	6.72	0.16	2.97	5.64	4.62	2.47	0.30	1.24	99.92	123	18	14	43	1022	25	168	9	2129
C152	956 094	54.06	1.22	14.17	11.28	0.18	5.83	6.80	2.17	0.97	0.19	2.32	100.85	185	240	80	24	277	31	149	8	496
C172	967 090	59.52	0.79	16.51	6.43	0.15	3.30	3.34	5.39	2.76	0.30	1.29	99.78	122	40	27	40	632	25	266	10	2048
B90	913 089	55.04	1.30	14.57	11.36	0.19	5.33	6.15	2.82	1.91	0.15	1.29	100.11	184	155	63	53	378	38	263	12	834
A21	872 075	60.69	1.24	15.64	6.74	0.09	4.06	3.22	4.91	0.96	0.23	2.35	100.12	123	26	12	26	277	50	636	41	306

LOI = loss on ignition.

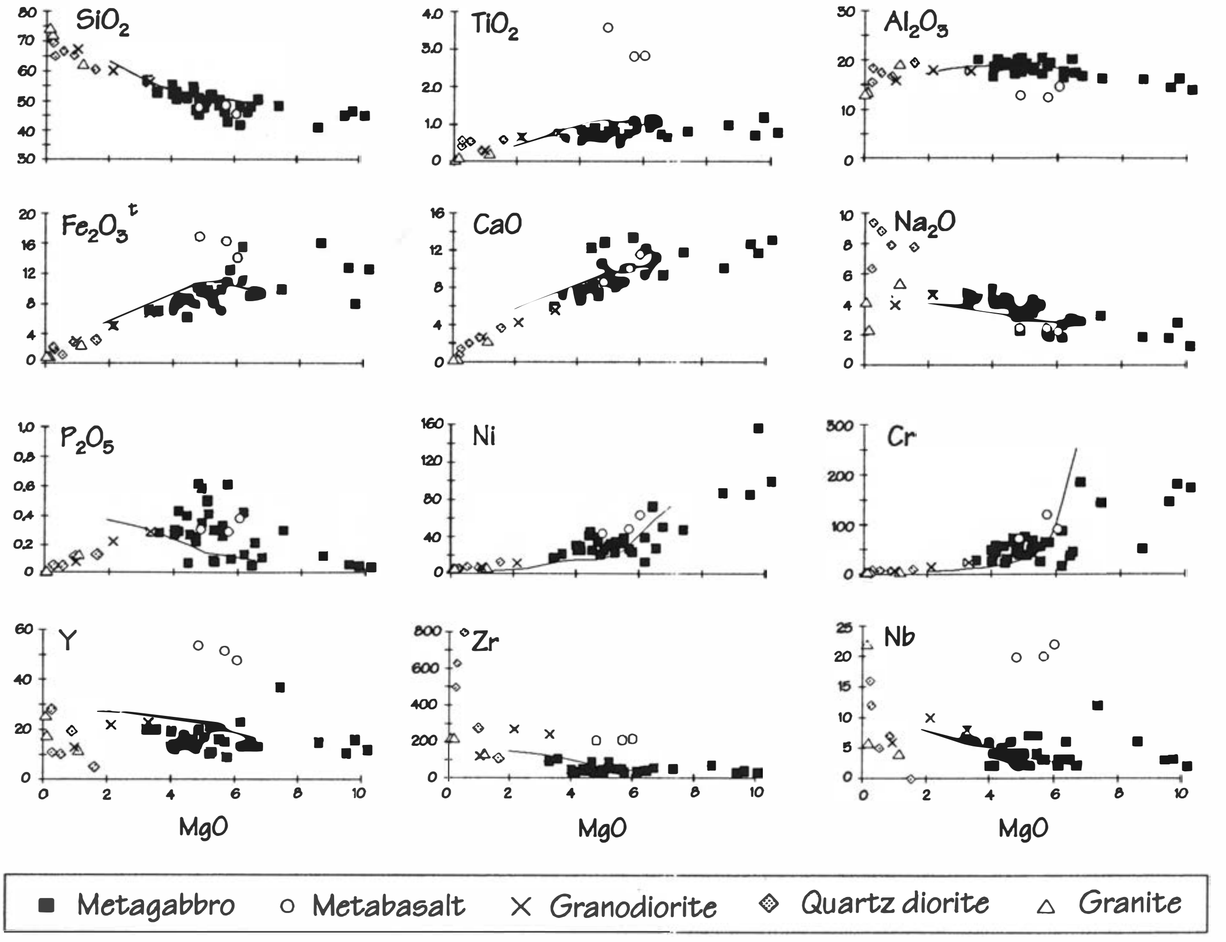
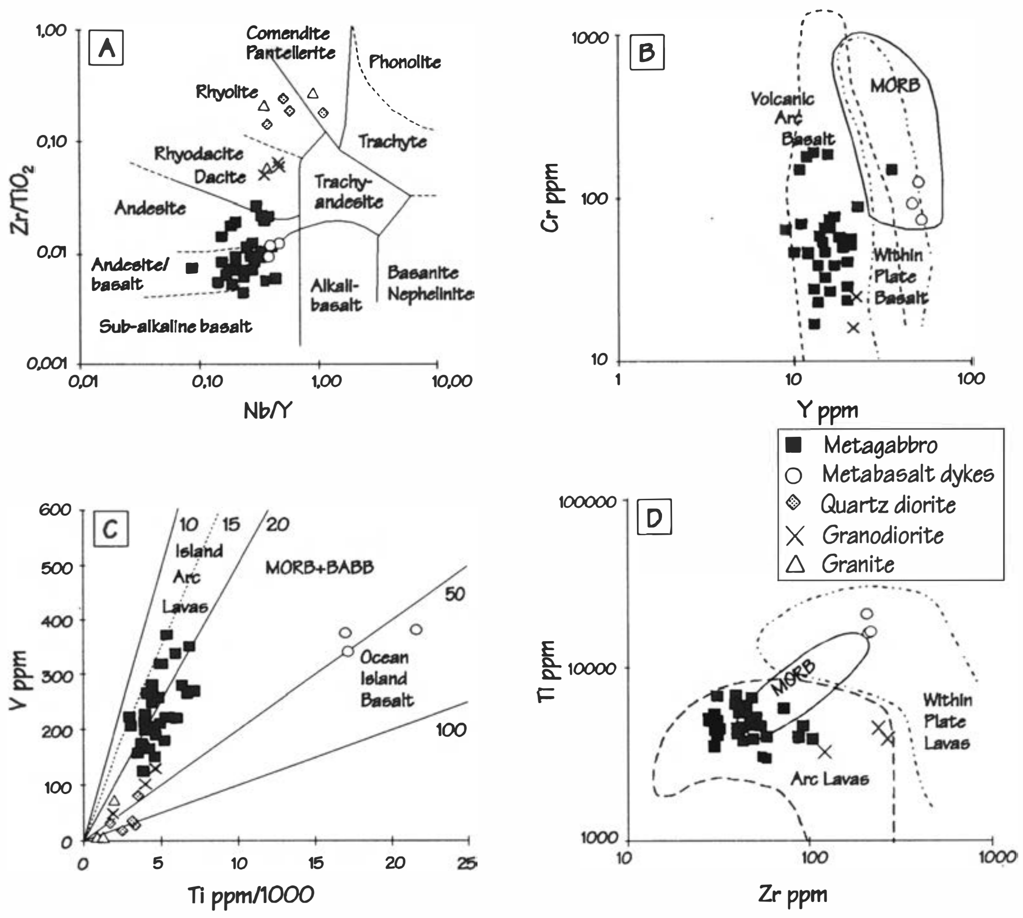


Fig. 6. Bowen diagram of the plutonic rocks from the Vikanes Unit. The superimposed solid lines represent the trends defined by volcanic rocks from the Sunda arc (data from Stolz 1990).

tigation. Reconnaissance studies of rocks in the Olset area (Fig. 2B) show banded gneisses with granitic to dioritic composition, together with lenses of amphibolites, and in the southeastern parts eclogitic lenses occur. At the southern side of the Dalsfjord (Figs. 2A and B), large areas are composed of amphibolites that represent retrograded eclogites (Andersen et al. 1994). Within this area at Gjølanger (Fig. 2B), the garnet-amphibolites and coronites are interpreted as representing a large differentiated basic intrusion metamorphosed *in situ* to eclogite (Griffin & Mørk 1981). This indicates that mafic magmatic rocks also occur elsewhere in this part of the Western Gneiss Region. However, these rocks have been subjected to eclogite facies metamorphism in the Caledonian orogeny.

Age determinations that have been performed on various rocks from the Sunnfjord area and elsewhere in the WGR indicate a major crust-forming period of intrusion (gabbro to granite), between ca. 1700 and 1500 Ma (Kullerud et al. 1986; Tucker et al. 1990). During the later Sveconorwegian orogeny there were granitic intrusions in the Sunnfjord area, and elsewhere in WGR there were also intrusions of diorites, dolerites and pegmatites (Kullerud et al. 1986). Regarding the Gothic orogeny, similar plutonic rock association, and the long periods of magmatism are well known from, e.g., the Andean continental arc (e.g. Drake et al. 1982). Thus it is possible that the rocks represented by the Askvoll group have been part of a similar continental arc system. The western Swedish part of the Southwest Scandinavian Domain is characterized by early Gothian island arc volcanism and sedimentation, soon followed by granitoid intrusions (Åhäll & Daly 1989) and interpreted to represent a result of subduction of oceanic crust at a continental margin (Pharaoh & Brewer 1990). The careful mapping, detailed geochemical study, and a radiometric dating of the heterogeneous rocks of the Askvoll group, allow us to propose a similar tectonic model for these rocks. The study of the Askvoll group thus supports the Proterozoic plate tectonic model of large-scale subduction-related magmatism along the margins of Baltica and Laurentia (Fig. 9).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Zr/TiO2
Nb/Y
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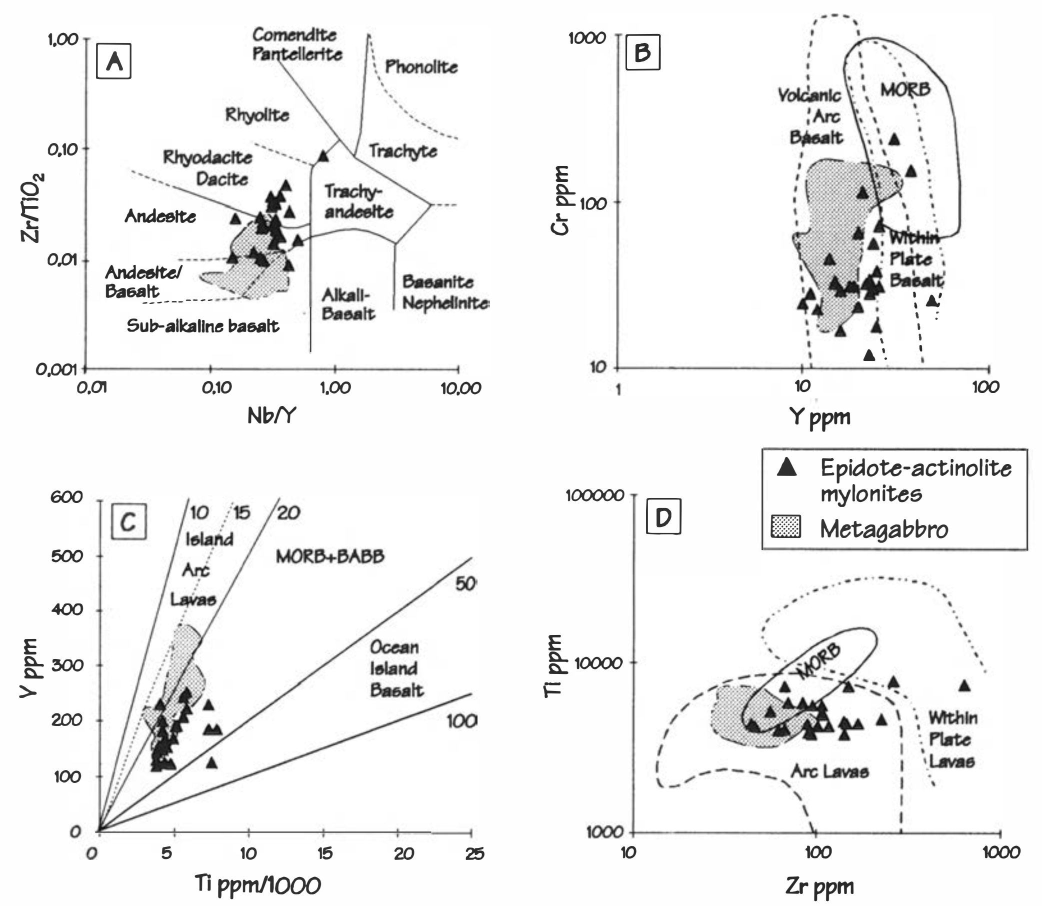
Phonolite
Rhyolite
Trachyte
Rhyodacite
Dacite
Trachy-andesite
Andesite
Andesite/basalt
Alkali-basalt
Basanite Nephelinite
Sub-alkaline basalt
B
Cr ppm
Y ppm
Volcanic Arc Basalt
MORB
Within Plate Basalt
C
V ppm
Ti ppm/1000
Island Arc Lavas
MORB+BABB
Ocean Island Basalt
D
Ti ppm
Zr ppm
MORB
Within Plate Lavas
Arc Lavas
Metagabbro
Metabasalt dykes
Quartz diorite
Granodiorite
Granite

Fig. 7.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Nb/Y
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Phonolite
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Dacite
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Andesite/Basalt
Alkali-Basalt
Basanite Nephelinite
Sub-alkaline basalt
B
Cr ppm
Y ppm
Volcanic Arc Basalt
MORB
Within Plate Basalt
C
V ppm
Ti ppm/1000
Island Arc Lavas
MORB+BABB
Ocean Island Basalt
D
Ti ppm
Zr ppm
MORB
Within Plate Lavas
Arc Lavas
Epidote-actinolite mylonites
Metagabbro

Fig. 8.

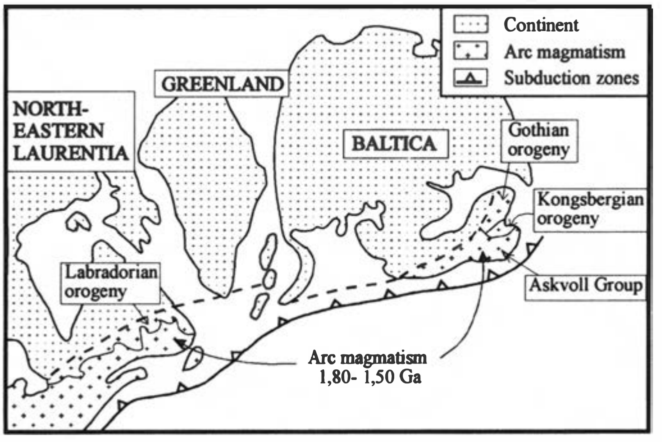

Fig. 9. Plate tectonic model for the Askvoll group, placed in a regional context. The regional picture is after Park et al. (1991), Park (1992) and Gower (1992).

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References

Åhäll, K.-I. & Daly, J. S. 1989: Age, tectonic setting and provenance of Östfold–Marstrand belt supracrustals. Westward crustal growth of the Baltic Shield at 1760 Ma. *Precambrian Research 45*, 45–61.

Åhäll, K.-I., Daly, J. S. & Schöberg, H. 1990: Geochronological constraints on mid-Proterozoic magmatism in the Östfold–Marstrand belt; implications for crustal evolution in southwest Sweden. *In* Gowers, C. F., Rivers, T. & Ryan, B. (eds.): Mid-Proterozoic geology of the southern margin of proto Laurentia–Baltica. *Geological Association of Canada, Special Paper 38*, 97–115.

Alsaker, E. & Furnes, H. 1994: Geochemistry of the Sunnfjord Melange: sediment mixing from different sources during obduction of the Solund–Stavfjord Ophiolite Complex, Norwegian Caledonides. *Geological Magazine 13*, 105–121.

Andersen, T. B., Osmundsen, P. T. & Jolivet, L. 1994: Deep crustal fabrics and a model for the extensional collapse of the southwest Norwegian Caledonides. *Journal of Structural Geology 16*(9), 1191–1203.

Andersen, T. B., Skjerlie, K. P. & Furnes, H. 1990: The Sunnfjord Melange, evidence of Silurian ophiolite accretion in the West Norwegian Caledonides. *Journal of the Geological Society London 147*, 59–68.

Brekke, H. & Solberg, P. O. 1987: The geology on Atløy, Sunnfjord, western Norway. *Norges geologiske undersøkelse 410*, 73–94.

Bryhni, I. 1966: Reconnaissance studies of gneisses, ultrabasites, eclogites and anorthosites in outer Nordfjord, western Norway. *Norges geologiske undersøkelse 241*, 1–68.

Bryhni, I. 1989: Status of the supracrustal rocks in the Western Gneiss Region, S. Norway. *In* Gayer, R. A. (ed.): *The Caledonian Geology of Scandinavia*, 221–228.

Cann, J. R. 1970: Rb, Sr, Y, Zr and Nb in some ocean floor basaltic rocks. *Earth Planetary Science Letters 10*, 7–11.

Coish, R. A. 1977: Ocean floor metamorphism in the Betts Cove Ophiolite, Newfoundland. *Contributions to Mineralogy and Petrology 60*, 255–270.

Demaiffe D. & Michot, J. 1985: Isotope geochronology of the Proterozoic crustal segment of southern Norway: A review. *In* Tobi, A. C. & Touret J. L. R. (eds.): *The Deep Proterozoic Crust in the North Atlantic Provinces*, 411–433. D. Reidel Publ. Comp., Dordrecht.

Drake, R. E., Vergara, M., Munizaga, F. & Vicente, J. C. 1982: Geochronology of Mesozoic–Cenozoic magmatism in central Chile, Lat. 31°–36 °S. *Earth Science Reviews 18*, 353–363.

Furman, T. & Spera, F. J. 1985: Co-mingling of acid and basic magma with implications for the origin of mafic I-type xenoliths: Field and petrochemical relations of an unusual dike complex at Eagle Lake Sequoia National Park, California, U.S.A. *Journal of Volcanology and Geothermal Research 24*, 151–178.

Furnes, H., Skjerlie, K. P., Pedersen, R. B., Andersen, T. B., Stillman, C. J., Suthren, R. J., Tysseland, M. & Garmann, L. B. 1990: The Solund–Stavfjord Ophiolite Complex and associated rocks, west Norwegian Caledonides: geology, geochemistry and tectonic environment. *Geological Magazine 127*, 209–224.

Furnes, H., Skjerlie, F. J. & Tysseland, M. 1976: Plate tectonic model based on greenstone geochemistry in the Late Precambrian– Lower Palaeozoic sequence in the Solund–Stavfjorden areas, west Norway. *Norsk Geologisk Tidsskrift 56*, 161–186.

Gaál, G. & Gorbatschev, R. 1987: An outline of Precambrian evolution of the Baltic Shield. *Precambrian Research 35*, 15–52.

Gorbatschev, R. 1985: Precambrian basement of the Scandinavian Caledonides. *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen – Scandinavia and Related Areas*, 197–212. J. Wiley and Sons Ltd., Chichester.

Govindaraju, K. 1984: 1984 compilation of working values and sample description for 170 international reference samples of mainly silicate rocks and minerals. *Geostandards Newsletter 8*, 1–91.

Gower, C. F. 1990: Mid-Proterozoic evolution of the eastern Grenville Province, Canada. *Geologiska Föreningens i Stockholm Förhandlingar 112*, 127–139.

Gower, C. F. 1992: Stages in the evolution of the southern margin of mid-Proterozoic Laurentia–Baltica. *Geologiska Föreningens i Stockholm Förhandlingar 114*, 455–457.

Griffin, W. L. 1987: 'On the eclogites of Norway' – 65 years later. *Min. Mag., 51*, 333–343.

Griffin, W. L. & Mørk, M. B. E. 1981: Guidebook, Excursion B1, *Excursions in the Scandinavian Caledonides*. Mineralogisk-Geologisk Museum, Oslo. 91 pp.

Hawkins, J. W. 1977: Petrologic and geochemical characteristics of marginal basin basalts. *In* Talwani, M. & W. C. Pitman (eds.): *Island Arcs, Deep Sea Trenches, and Back-Arc Basins*, 355–365. American Geophysical Union.

Karig, D. E. & Sharman, G. F. 1975: Subduction and accretion in trenches. *Geological Society American Bulletin 86*, 377–389.

Kober, B. 1987: Single-zircon evaporation combined with Pb^+ emitter bedding for 207Pb/206Pb – age investigations using thermal ion mass spectrometry, and implications to zirconology. *Contributions to Mineralogy and Petrology 96*, 63–71.

Kolderup, N. H. 1921: Der Mangeritsyenit und umgebende Gesteine zwischen Dalsfjord und Stavfjord in Søndfjord im westlichen Norwegen. *Bergen Museum Aarbok, Naturvitenskapelig Række nr. 1*, 222 pp.

Krogh, T. E. 1982: Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique. *Geochimica et Cosmochimica Acta 46*, 637–649.

Kullerud, L., Tørudbakken, B. & Ilebekk, S. 1986: A compilation of radiometric age determinations from the Western Gneiss Region, South Norway. *Norges geologiske undersøkelse 406*, 17–42.

Ludwig, K. R. 1991a: PBDAT. A computer Program for Processing Pb-U-Th Isotope Data. USGS Open-file Report 88-542.

Ludwig, K. R. 1991b: ISOPLOT. A Plotting and Regression Program for Radiogenic-Isotope Data. USGS Open-file Report 88–542.

Milnes, A. G. & Koestler, A. G. 1985: Geological structure of Jotunheimen, southern Norway (Sognefjell–Valdres cross-section). *In* Gee, D. G. & Sturt, B. A. (eds.): *The Caledonide Orogen – Scandinavia and Related Areas*, 457–474. J. Wiley and Sons Ltd., Chichester.

Nicollet, C. & Andriambololona, D. R. 1980: Distribution of transition elements in crustal metabasic rocks. *Chemical Geology 28*, 79–90.

Norrish, K. & Hutton, T. T. 1969: An accurate X-ray spectroscopic method for analysis of a wide range of geological samples. *Geochimica et Cosmochimica Acta 33*, 431–453.

Padget, P. 1990: Tectonic and lithostratigraphic relations in the Bamble Sector, south Norway: an interpretative view. *In* Govers, C. F., Rivers, T. & Ryan, B. (eds.): Mid-Proterozoic geology of the southern margin of proto Laurentia–Baltica. *Geological Association of Canada, Special Paper 38*, 307–316.

Park, R. G. 1992: Plate kinematic history of Baltica during the Middle to Late Proterozoic: A model. *Geology 20*, 725–728.

Park, R. G., Åhäll, K.-I. & Boland, M. P. 1991: The Sveconorwegian shear-zone network of SW Sweden in relation to mid-Proterozoic plate movements. *Precambrian Research 49*, 245–260.

Fig. 7. Plutonic rocks from the Vikanes Unit of the Askvoll group, plotted in various discrimination diagrams. For further information: see Fig. 5.

Fig. 8. Epidote-actinolite mylonites of the Vikanes Unit of the Askvoll group, plotted in various discrimination diagrams. The shaded area defines the field defined by the metagabbro of the Vikanes Unit. For further information: see Fig. 5.

Pearce, J. A. 1982: Trace element characteristics of lavas from destructive plate boundaries. *In* Thorpe, R. S. (ed.): *Andesites: Orogenic Andersites and Related Rocks*, 525–548. J. Wiley and Sons Ltd., Chichester.

Pharaoh, T. C. & Brewer, T. S. 1990: Spatial and temporal diversity of early Proterozoic volcanic sequences – comparisons between the Baltic and Laurentian shields. *Precambrian Research 47*, 169–189.

Plumb, K. A. 1991: New Precambrian time scale. *Episodes 14*, 139–140.

Saunders, A. D., Tarney, J., Stern, C. R. & Dalziel, I. W. D. 1979: Geochemistry of Mesozoic marginal basin floor igneous rocks from southern Chile. *Geological Society of America Bulletin 90*, 237–258.

Shervais, J. W. 1982: Ti-V plots and the petrogenesis of modern and ophiolitic lava. *Earth Planetary Science Letters 59*, 101–118.

Sibson, R. H. 1977: Fault rocks and fault mechanisms. *Journal of Geological Society London 133*, 191–213.

Skjerlie, F. J. 1969: The pre-Devonian rocks in the Askvoll–Gaular area and adjacent districts, western Norway. *Norges geologiske undersøkelser 258*, 325–359.

Skjerlie, F. J. & Pringle, I. R. 1978: A Rb/Sr whole-rock isochron date from the lowermost gneiss complex of the Gaular area, west Norway, and its regional implications. *Norsk Geologisk Tidsskrift 58*, 259–265.

Skjerlie, K. P., Furnes, H. & Johansen, R. J. 1989: Magmatic development and tectonomagmatic models for the Solund–Stavfjord Ophiolite Complex, West Norwegian Caledonides. *Lithos 23*, 137–151.

Stacey, J. S. & Kramer, J. D. 1975: Approximation of terrestrial lead isotope evolution by a two-stage model. *Earth and Planetary Science Letters 26*, 207–221.Stramer, I. C. 1991: The Proterozoic evolution of the Bamble Sector shear belt, southern Norway: correlations across southern Scandinavia and the Grenvillian controversy. *Precambrian Research 49*, 107–139.

Stoltz, A. G., Varne, R., Davies, G. R., Wheller, G. E. & Folden, J. D. 1990: Magma source components in an arc-continent collision zone: the Flores-Lembata sector, Sunda arc, Indonesia. *Contributions to Mineralogy and Petrology 105*, 585–601.

Streckeisen, A. 1976: To each plutonic rock its proper name. *Earth-Science Reviews 12*, 1–33.

Swensson, E. & Andersen, T. B. 1991: Contact relationships between the Askvoll group and the basement of the Western Gneiss Region (WGR), Sunnfjord, Western Norway. *Norsk Geologisk Tidsskrift 71*, 15–27.

Sæbø Hveding, B. 1992: En strukturgeologisk undersøkelse av mylonittsonen under Dalsfjordforkastningen i Atløy-Askvollområdet, Sunnfjord. Unpublished Cand. Scient. thesis, University of Oslo. 124 pp.

Tucker, R. D., Krogh, T. E. & Råheim, A. 1990: Proterozoic evolution and age-province boundaries in the central part of the Western Gneiss Region, Norway: Results of U-Pb dating of accessory minerals from Trondheimsfjord to Geiranger. *In* Gowers, C. F., Rivers, T. & Ryan, B. (eds.): Mid-Proterozoic Geology of the southern margin of proto Laurentia–Baltica. *Geological Association of Canada, Special Paper 38*, 149–173.

Weaver, B. L. & Tarney, J. 1981: Chemical changes during dyke metamorphism in high-grade basement terrains. *Nature 289*, 47–49.

Winchester, J. A. & Floyd, P. A. 1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology 20*, 325–343.