U-Pb zircon age and geochemistry of the Blåfjellhatten granite, Grong-Olden Culmination, Central Norway

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U-Pb zircon dating of the Blåfjellhatten granite in the Olden Nappe, Grong-Olden Culmination, Central Norwegian Caledonides, has yielded a discordia upper intercept of 1633.2 ± 2.9 Ma, interpreted as the crystallisation age of the pluton. This precise age is comparable to an *approximate* age of emplacement, 1650 Ma, reported for the neighbouring Olden granite but contrasts with an earlier, Rb-Sr whole-rock, isochron age of 1356 ± 29 Ma for the Blåfjellhatten body. Geochemical data indicate that the Blåfjellhatten granite was derived from a fairly evolved crustal source in a continental, extensional, and probably anorogenic setting. Both the Blåfjellhatten and the Olden granite are representative of I-type granitoids (though with some A-type features) of the youngest magmatic episode of the Palaeoproterozoic, Transscandinavian Igneous Belt (TIB). The Blåfjellhatten granite thus appears to be one of the youngest plutons in the TIB domain of the Fennoscandian Shield, extending the terminal stages of TIB magmatism by some 15–20 million years.

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Introduction

Proterozoic and, in part, Archaean, felsic and mafic crystalline rocks form the fundament to the Scandinavian Caledonides. In many areas, Palaeoproterozoic and Mesoproterozoic complexes penetrate the Caledonian allochthon in tectonic windows of diverse character, though mostly in the form of Scandian antiformal stacking of basement or basement-and-cover slices. The Precambrian rocks are variably reworked by Caledonian structures and metamorphic fabrics that generally increase in intensity towards the west in Norway.

The Fennoscandian Shield is composed of several crustal segments or domains (Gaál & Gorbatschev 1987) and many are traceable beneath and into the Caledonian orogen. In the region of the Central Scandinavian Caledonides, there are two principal domains; the Transscandinavian Igneous Belt (TIB) and the Central Svecofennian Domain (CSD) including the Bothnian Basin, rocks of which have been identified in the Vestranden part of the Western Gneiss Region of coastal Central Norway (Johansson et al. 1993). In general, TIB and CSD rocks can be recognised and differentiated on bases of age and geochemistry, but such data are uncommon in the Grong-Namsos district of Mid Norway. The purpose of this paper is to present the results of a U-Pb zircon dating and geochemical investigation of a major granite body occurring in the Grong-Olden Culmination (Fig. 1), and briefly discuss its likely affiliation. This particular granite had earlier yielded a Rb-Sr whole-rock isochron age of 1356 ± 29 Ma (Fossen & Nissen 1991).

Geological setting

The Grong-Olden Culmination and its western extension into northern Vestranden provide almost 200 km of continuous exposure of the Precambrian crystalline basement across the general grain of the Caledonian orogen (Fig. 1). Within the culmination, the Olden Nappe (Asklund 1938) forms the core of the structure and is overlain by the Formofoss Nappe Complex (Roberts 1989), both these units constituting part of the Lower Allochthon of Caledonide tectonostratigraphic terminology. Olden Nappe rocks generally show only low but somewhat variable degrees of Caledonian (Scandian) deformation and very low-grade metamorphism, though locally with the development of discrete high-strain zones and mylonites (Sjöström & Talbot 1987). In contrast, Formofoss Nappe Complex lithologies were much more strongly reworked during the Scandian orogeny (Johansson 1986; Roberts 1989; Johansson et al. 1993), original granites, for example, having been largely converted into augen gneisses, and the degree of reworking increases westwards into the Vestranden district.

The rocks of the *Olden Nappe* comprise granites and porphyritic felsic, continental volcanites with subordinate microgranites, gabbro-dolerites and mafic volcanic rocks (Johansson 1980; Roberts 1997a, b). Based on geochemistry, the felsic volcanites can be classified as high-K rhyolites and trachytes, and along with minor basalts the anorogenic within-plate association is considered to have extruded in an extensional regime (Roberts 1997b). The granitic rocks include the Olden granite (Fig. 2), which has

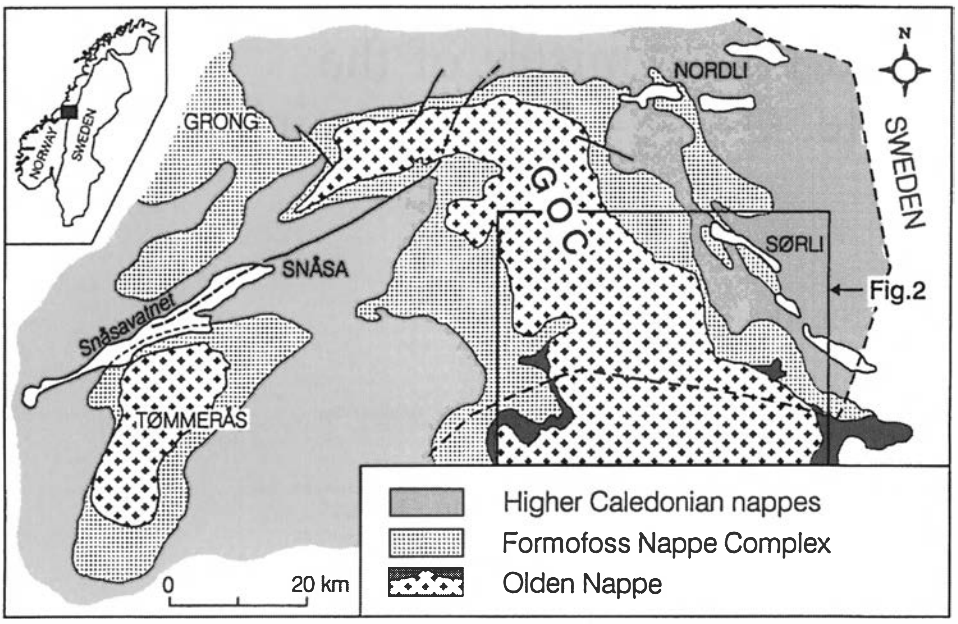

Fig. 1. Location map of the Grong-Olden Culmination, Central Scandinavian Caledonides. Details of the boxed area are shown in Fig. 2.

been shown to be a highly evolved, weakly peraluminous body, and where a geochronological investigation (U-Pb, Pb-Pb, Rb-Sr and K-Ar), although not definitive, suggests an emplacement age of ca. 1650 Ma (Klingspor & Troëng 1980; Stuckless et al. 1982; Troëng 1982). In this same study, a Scandian age of 420 Ma was obtained for local uranium mineralisation.

Another granite body, the Blåfjellhatten pluton of the present paper (Fig. 2), was the subject of a later Rb-Sr dating study by Fossen & Nissen (1991) which, as noted above, provided a whole-rock isochron age of 1356 ± 29 Ma. Based mainly on reported differences in initial Sr ratios between the Olden (0.7135 ± 0.0012) and Blåfjellhatten (0.7245 ± 0.0027) granites, and the fact that the latter body appeared undeformed at the sampling localities, Fossen & Nissen considered this ca. 1350 Ma date to represent the age of intrusion. In a more regional context, the granitic and porphyritic volcanic rocks of the Olden Nappe are considered to belong to the ca. 1.81–1.65 Ga TIB (Gorbatschev 1985), such that an apparently ca. 300 million year younger granite might be regarded as an anomaly in this situation. Fossen & Nissen (1991), however, believed that the Blåfjellhatten pluton was truly younger than the TIB granites. Of the other plutonic rocks in the Olden Nappe, subordinate amphibolitised gabbros and dolerites are considered (Johansson 1980) to correlate with the ca. 1.22 Ga Central Scandinavian Dolerite Group (Gorbatschev et al. 1979).

In its uppermost parts, the Olden Nappe also includes a thin cover of very low-grade and partly sheared and folded quartzite, phyllite and limestone of inferred Vendian to Cambrian age, lying unconformably upon the older Proterozoic, plutonic and volcanic rocks (Fig. 2). To the southeast, in Sweden, this sedimentary sequence thickens considerably and extends up into the Silurian (Gee 1975).

The rocks of the *Formofoss Nappe Complex* are

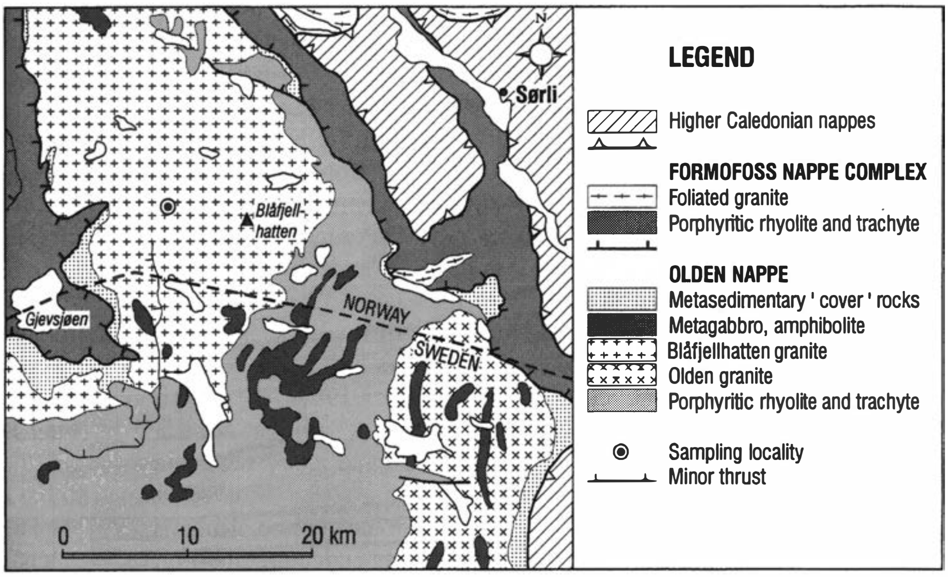

Fig. 2. Map showing the Blåfjellhatten and Olden granites, Grong-Olden Culmination, and the sampling locality.

Table 1. Major and trace element data, Blåfjellhatten granite. Major elements in wt%, trace elements in ppm.

Sample	2488	2588	2688	2788	2888	2988	5888	5988	6088	6188	6288	3088	3188
SiO_2	75.49	72.92	71.38	70.90	70.82	72.76	71.41	71.04	71.29	73.32	73.02	77.76	76.96
TiO_2	0.18	0.38	0.42	0.41	0.36	0.28	0.46	0.47	0.40	0.46	0.23	0.07	0.07
Al_2O_3	12.93	13.65	14.18	14.39	13.42	13.86	14.34	14.39	13.31	13.96	13.79	12.34	12.06
Fe_2O_3	0.58	0.66	0.78	0.75	0.64	0.41	0.56	0.71	0.63	1.01	0.20	0.00	0.00
FeO	0.76	1.33	1.39	1.62	1.50	1.28	1.64	1.54	1.50	1.38	1.56	0.67	0.77
MnO	0.04	0.06	0.06	0.06	0.06	0.04	0.06	0.07	0.06	0.07	0.05	0.01	0.02
MgO	0.12	0.25	0.30	0.35	0.26	0.19	0.36	0.32	0.30	0.32	0.47	0.15	0.04
CaO	0.50	0.88	1.02	1.09	0.94	0.71	1.01	1.17	1.05	1.15	0.83	0.16	0.55
Na_2O	3.71	3.66	3.82	3.98	3.66	3.94	4.07	3.98	3.59	3.79	4.04	3.92	3.51
K_2O	5.62	5.75	5.80	5.50	5.68	5.67	5.59	5.66	5.56	5.44	4.78	4.77	5.01
P_2O_5	0.02	0.06	0.06	0.06	0.06	0.04	0.07	0.07	0.06	0.07	0.05	<0.01	<0.01
CO_2	0.04	0.03	0.00	0.00	0.03	0.00	0.04	0.23	0.08	0.01	0.00	0.32	0.02
H_2O^+	0.22	0.41	0.39	0.48	0.40	0.45	0.38	0.41	0.36	0.41	0.35	0.35	0.37
H_2O^-	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LOI	0.20	0.24	0.16	0.24	0.18	0.17	0.16	0.17	0.13	0.07	0.22	0.21	0.39
Total	100.41	100.28	99.77	99.83	98.01	99.8	100.15	100.23	98.32	101.46	99.59	100.73	99.77
Zr	184	292	297	311	272	247	339	335	306	338	149	142	94
Y	58	63	63	68	67	65	58	73	59	71	27	88	84
Sr	26	87	100	100	83	72	91	101	98	105	101	8	8
Rb	298	271	210	208	258	236	230	238	220	203	151	420	484
Zn	25	52	44	40	56	36	65	65	57	59	37	38	17
Cu	<5	<5	<5	<5	<5	<5	6	14	18	5	<5	<5	<5
Ni	18	18	14	16	18	16	13	17	12	16	7	28	30
Cr	8	7	7	12	9	8	6	8	7	10	8	7	8
Ba	141	422	510	477	445	342	470	467	458	451	337	28	23
Nb	27	30	26	27	30	24	31	32	29	32	25	45	46
V	13	20	20	19	18	15	22	24	23	22	22	13	12
Ga	15	13	18	11	18	15	17	17	16	15	12	17	14

comparable in many respects to those in the Olden Nappe, though more strongly deformed, consisting mainly of metagranitoids and weakly metamorphosed porphyritic rhyolites and trachytes. There are additional rock-types present, however, as pointed out by Johansson (1986), and just to the west of the Grong-Olden Culmination the coarse-grained Geitfjell granite has yielded a U-Pb zircon age of $1828^{+88}/_{-65}$ Ma (Johansson et al. 1993). This granite was considered by Johansson et al. to correlate, in age and chemistry, with the late- to post-Svecofennian Bothnian Basin granites of Sweden, e.g. the granites of Revsund type. These are quite different in their geochemistry to either the Olden or the Blåfjellhatten granite.

The Blåfjellhatten granite

Petrographic features

The pale grey to grey-pink, coarse-grained granite sampled for the U-Pb analysis shows comparatively little sign of deformation or alteration. In general, the porphyritic textured granite carries perthitic microcline as the main phenocrystic mineral, ca. 40% of the mode, with quartz (ca. 30%), plagioclase (ca. 20%) and magmatic biotite (< 10%) as the other principal phenocrystic minerals. The finer-grained and relatively uniform groundmass is dominated by the same minerals and in addition there is muscovite, chlorite and epidote. Accessory mineral phases include apatite, zircon, sphene, magnetite, haematite and allanite; and one tiny grain of garnet has been found in one thin-section.

The anhedral phenocrysts of K-feldspar vary from 1 to 10 mm in size and are perthitic, with vein-, patch- and string-perthitic types present. Some of the crysts are poikilitic with many inclusions of quartz, plagioclase and biotite. The smaller groundmass grains of K-feldspar are mainly microcline. Plagioclase (albite to oligoclase) occurs as anhedral grains up to 5 mm in size with common albite-twinning, and in places bent twin lamellae. Partial sericitisation is seen in some thin-sections and the plagioclase phenocrysts contain inclusions of quartz, in places worm-like and myrmekitic. Quartz, in general, occurs as anhedral grains of varying size and these show undulose extinction. In other parts of the granite, a faint tectonic foliation may be present, defined by micas, and much of the quartz is recrystallised to a fine-grained mozaic. The biotite typically occurs in clusters and commonly together with anhedral grains of apatite, sphene and zircon. Muscovite, where present, also occurs as aggregates of bent, elongate grains. Magnetite is an important opaque component in all samples, generally <1 mm but in one case ranges to 2 mm in size.

Geochemistry

Thirteen samples of the granite were selected for major and trace element analysis. The major element concentrations

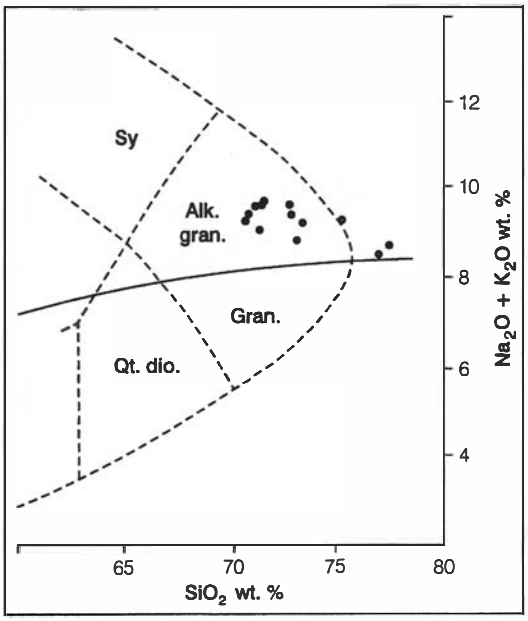

Fig. 3. The Blåfjellhatten granite samples of Table 1 plotted on part of the modified Total Alkali vs. Silica diagram of Wilson (1989), with the boundary line between alkaline (above) and subalkaline rocks indicated. Alk. Gran. – alkali granite; Gran. – granite; Qt. Dio. – Quartz diorite/granodiorite; Sy. – syenite.

of 12 of these samples have been presented earlier, but not discussed, in the Rb-Sr study of Fossen & Nissen (1991). As 2 of these 12 samples show significant deviations in some oxide and trace element contents as compared with the other 10 samples, we have considered it relevant and essential, in this particular case, to present the complete data set of major and trace element analyses (Table 1).

The major and trace elements were analysed at NGU, Trondheim, on fused glass beads and pressed powder pellets, respectively, on an automatic Philips 1450/20 XRF instrument. Ferrous iron, H_2O- and CO_2 were determined by wet chemical methods. Contents of W and Sn were below the detection limit (<10 ppm) in all samples and are not listed. Values for Cu were below the < 5 ppm limit in 9 samples, and just marginally above this limit in the others. Five of the samples have been analysed by INAA for eight rare earth elements (REE) and the elements Sc, Co, Hf, Ta, Th and U, at the University of Leuven, Belgium (analyst, Dr Jan Hertogen), with irradiation at the reactor at the University of Ghent. The 'in-house' silicate rock standards have been repeatedly calibrated against international reference rocks.

In their major element oxide contents, the Blåfjellhatten granite samples show a reasonable homogeneity (Table 1). On a total alkali oxide vs. silica (TAS) diagram modified for plutonic rocks by Wilson (1989) (Fig. 3), the analysed samples fall within the alkali granite field. In all cases, the K_2O content (averaging 5.55 wt.%) exceeds that of Na_2O, and the mean Na_2O:K_2O ratio is 0.69 which is a comparable value to that for the porphyritic volcanites. On a molar ratio Al_2O_3-alkalis-CaO diagram (not shown), the samples are weakly peraluminous, as in the case of the Olden granite (Stuckless et al. 1982) and the associated felsic volcanic rocks (Roberts 1997b); and compositionally, the high-K, alkali-calcic Blåfjellhatten body is akin to an I-type granite.

Two of the samples analysed, from the northeasternmost marginal part of the granite, show marked differences in several major oxide contents as compared with the other 11 samples (Table 1). The SiO_2 content of >77 wt.% is close to the mean silica value for the Olden granite. The indications are that, in this particular area, we may possibly be dealing with a separate granitic body and not the Blåfjellhatten *sensu stricto*, and one that appears to be more comparable with the Olden granite in terms of major element geochemistry.

Selected, comparatively immobile trace elements are known to be efficient discriminants between granites from different tectonic settings (e.g. Pearce et al. 1984; Harris et al. 1986). The Nb-Y (Fig. 4) and Rb-(Y + Nb) diagrams of Pearce et al. (1984) both show that the Blåfjellhatten samples cluster quite clearly in the field for within-plate granites, with a comparable element ratio distribution to that of the porphyritic rhyolites. Within-plate granites are equivalent to the A-type, i.e. anorogenic, granitoids (Loiselle & Wones 1979; Collins et al. 1982; Whalen et al. 1987), which are considered to be a subgroup of the I-type granites. The relatively high LIL and HFS element abundances in the Blåfjellhatten granite analyses do, in fact, favour an A-type affinity.

For further chemical subdivision of the anorogenic granitoids, the diagrams devised by Eby (1992) are useful in pointing to the likely source of the magmas. The Rb/Nb vs. Y/Nb plot, for example, shown in Fig. 5, classifies the Blåfjellhatten granite samples in the field (A2) for magmas derived by partial melting of a continental crust that had probably been through a cycle of subduction-zone magmatism (Eby 1992). Data for uranium and thorium were obtained on the same five samples as used for the REE analyses (Table 2), one of which is from the northeastern

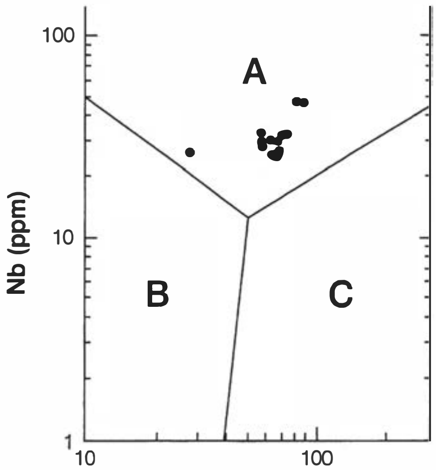

Fig. 4. Nb-Y discriminant diagram of Pearce et al. (1984) with samples plotted. A – within-plate; B – volcanic arc and syn-collisional; C – oceanic ridge.

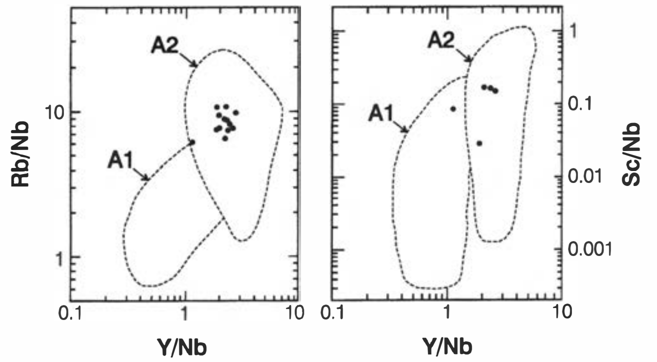

Fig. 5. Rb/Nb-Y/Nb and Sc/Nb-Y/Nb diagrams of Eby (1992) for further discrimination of within-plate granitic rocks. Field A1 – intra-plate rift and ocean-island. A2 – mainly anorogenic granites, derived by partial melting of continental crust.

Table 2. Rare-earth element and Sc, Hf, Th and U contents (ppm) of the representative samples of the Blåfjellhatten granite shown in Fig. 6.

Sample	2588	2988	5988	6288	3188
La	67.8	79.0	67.3	37.9	47.7
Ce	142	153	138	84	96
Nd	53	59	56	27	32
Sm	10.3	10.8	11.0	5.2	7.5
Eu	0.96	0.93	1.11	0.55	0.17
Tb	1.39	1.47	1.55	0.75	1.54
Yb	6.2	6.4	7.3	3.8	10.2
Lu	0.85	0.89	0.99	0.54	1.39
Hf	8.8	8.0	10.3	4.9	4.6
Th	21.5	31.9	21.8	22.2	37.5
U	8.3	8.1	7.3	9.3	18.3
Sc	5.4	3.9	5.9	3.2	1.2

granite outcrops noted above. The differences between this one sample, no. 3188, and the others are striking in terms of U and Th abundances, sample 3188 having values which are closer to those of the non-mineralised Olden granite (U, average 24 ppm; Th, average 52 ppm; Stuckless et al. 1982) than to the Blåfjellhatten *sensu stricto*. These are considerably higher values than those of the ranges for typical granitic rocks (U, 3–10 ppm; Th, 10–20 ppm).

High Ga/Al ratios, as well as high contents of Ga, are known to be especially diagnostic of A-type granites (Whalen et al. 1987). In the case of the analytical data from the Blåfjellhatten granite, the Ga abundances (Table 1) are fairly consistent and are similar to those of I-type granites *sensu stricto*. Moreover, the Ga/Al ratio, averaging 2.1, is precisely the same as that for I-type granitoids, and well below the 3.75 mean value for the A-types (Whalen et al. 1987). The Sc/Nb ratio of 1.64 is also closer to that of I-type (1.20) than of A-type (0.11) granitoids. If, however, one compares the various major and trace element mean values for the diverse granite types (not shown here, but given in Whalen et al. 1987), then the data from the Blåfjellhatten granite generally fall somewhere between those for the I- and A-types.

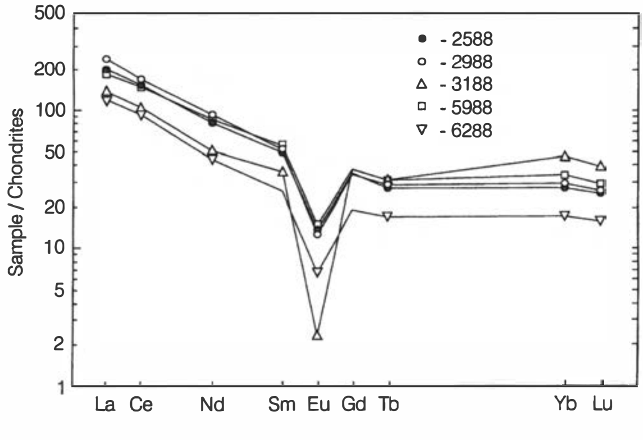

Fig. 6. Chondrite-normalised REE patterns for representative samples of the Blåfjellhatten granite. Sample 3188 is from the northeastern area of the granite, which bears chemical similarities to the Olden granite (see text). Chondrite normalisation values from Masuda et al. (1973), Nakamura (1974) and Evensen et al. (1978).

The chondrite-normalised REE patterns are characterised by quite marked LREE enrichment and pronounced, negative Eu anomalies (Fig. 6). La enrichment is from 112 to 232 times chondritic abundances and the La_N:Yb_N ratio is between 6 and 8, except for sample 3188 which is 2.9. The Eu content and chrondrite-normalised Eu value for sample 3188 are also lower than for the other four samples and are not unlike those of the Olden granite. The HREE exhibit flat or slightly convex patterns at between 15 and 30 times the chondritic values, except for higher values (40–48) for sample 3188. These REE abundances and patterns are comparable in many ways to those from the porphyritic, high-K rhyolites and trachytes from this same area, and indicate that the Blåfjellhatten body is quite typical of a crustally derived granite.

In summary, the geochemical data show that the Blåfjellhatten granite magma derived from a fairly, but not markedly evolved, crustal source in a continental, extensional and probably anorogenic setting. Certain element ratios, however, e.g. Ga/Al and Sc/Nb, point in the direction of an I-type rather than A-type granite. Although the major element data for the Olden granite are broadly comparable, there are perceptible small differences between the two granite bodies which may be a reflection of the precise character of the crustal materials in the actual source region.

U-Pb analytical methods and results

Analytical methods

Zircon concentrates from the Blåfjellhatten pluton were cleaned in successive solutions of 2N HNO_3, 2N HCl and distilled H_2O. They were then split by magnetic character using a Frantz Isodynamic Barrier separator followed by sieving to provide populations of desired size range. Four representative subpopulations were hand-sorted, and either air abraded for 6 h in a device similar to that described by Krogh (1982) or chemically leached in 48% HF in a Teflon

Table 3. Zircon analytical data.

Fraction propertiesϕ	Amount analysed (grains)	Concentration$^+$ (ppm)		Pb isotopic composition#			Radiogenic ratios@			Age and uncertainty** (Ma)		
		Pb	U	206/208	206/207	206/204	$^{206}Pb^*/^{238}U$	$^{207}Pb^*/^{235}U^*$	$^{207}Pb^*/^{206}Pb^*$	$^{206}Pb^*/^{238}U$	$^{207}Pb^*/^{235}U$	$^{207}Pb^*/^{206}Pb^*$
−250 + 150 μm, ab.	6	22.8	80.1	5.225	9.622	3,466	0.2549 (0.22%)	3.528 (0.23%)	0.10037 (0.18%)	1464.0 (± 3.2)	1533.6 (± 3.5)	1631.1 (± 2.9)
−100 + 75 μm, ab	5	23.6	79.28	5.294	9.216	1,572	0.2669 (0.27%)	3.695 (0.28%)	0.10041 (0.09%)	1525.2 (± 4.0)	1570.4 (± 4.1)	1631.7 (± 1.5)
−100 + 75 μm, 1ch.	8	18.9	63.1	5.785	9.008	1,206	0.2699 (0.31%)	3.739 (0.33%)	0.10047 (0.11%)	1540.7 (± 4.8)	1579.9 (± 5.2)	1632.7 (± 1.8)
−150 + 100 μm, 1ch	6	25.2	83.6	5.890	9.121	1,358	0.2732 (0.33%)	3.783 (0.26%)	0.10040 (0.17%)	1557.5 (± 5.1)	1589.2 (± 4.1)	1631.5 (± 2.8)

ϕ ab = zircons mechanically abraded for 6 h; 1ch = leached in 48% HF at 70°C for 24 h prior to digestion.

+ Concentration is total Pb and includes blank Pb, common Pb in zircon, and radiogenic Pb. Total procedural blanks are ~2 picograms for U and ~10 picograms for Pb. Because weights of grains are estimated and a mixed U-Pb tracer was employed, uncertainty in estimates of grain weight affects only concentration data, not calculated U-Pb or Pb/Pb ages.

Measured isotopic ratios prior to correction for mass fractionation of ~0.11% per atomic mass unit based on replicate analyses of NIST SRM 981 and 982 and adjusted for small amount of ^{206}Pb in tracer.

@ Value in parentheses is percent uncertainty in the calculated ratio, stated at the two-sigma level.

** Decay constants: $^{238}U = 1.5513\ E^{-10}/yr$; $^{235}U = 9.8485\ E^{-10}/yr$. Atom ratio $^{238}U/^{235}U = 137.88$. Uncertainty in the calculated ages is stated at the two-sigma level and estimated from combined uncertainties in calibrations of mixed 205Pb – ^{233}U – ^{235}U tracer, measurement of isotopic ratios of Pb and U, common and laboratory blank Pb isotopic ratios, Pb and U mass fractionation corrections, and reproducibility in measurement of NIST Pb and U standards.

screw-top capsule held at 70°C for 24 h. Zircon dissolution and ion-exchange procedures were comparable with those described by Krogh (1973) and Parrish et al. (1987). A mixed $^{205}Pb-^{233}U-^{235}U$ tracer was employed. Pb was loaded to W filaments and U to Re filaments and analysed on the Finnigan MAT 261 multicollector mass spectrometer at Brown University. Pb was analysed in static multicollector mode employing Faraday cup collection of masses 208, 207, 206 and 205 while simultaneously collecting mass 204 in a secondary electron multiplier. Additional analytical details are given in the footnotes to Table 3.

The zircons extracted from the sample are pale pink in colour and range in size from ca. 250 to 80 microns, and in form from squat prisms (aspect ratio 2:1) to needle-like grains (aspect ratio 5:1). The zircons are typically euhedral with sharp crystal edges and prominent terminations. The least magnetic, crack- and inclusion-free crystals within subpopulations based on size and aspect ratio were those selected for isotopic analysis.

Data and age interpretation

Four fractions were analysed. The data are presented in Table 3 and graphically displayed in Fig. 7. The U-Pb systematics exhibit normally discordant behaviour, although the degree of discordance is not related in the expected manner to grain size, i.e., the most discordant fraction is that of the largest, not smallest, grain size. However, the 207/206 ages of each of the four fractions are identical within analytical uncertainty. A discordia trajectory constructed through the data indicates an upper intercept of 1633.2 ± 2.9 Ma and a lower intercept of 30 ± 47 Ma, with a MSWD of 0.32. Such discordia are the product of simple U-Pb systematics that indicate no inheritance of older zircons and/or post-crystallisation

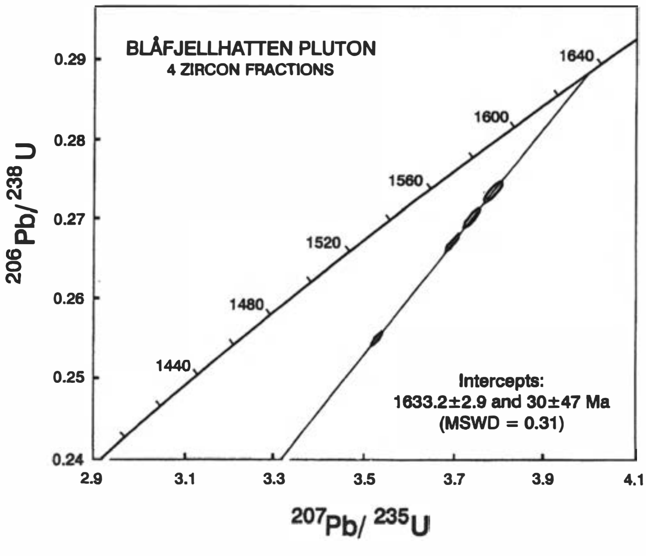

Fig. 7. U-Pb concordia diagram of zircon analyses (4 fractions) from the Blåfjellhatten granite.

thermometamorphic histories. We thus interpret the upper discordia intercept of 1633 ± 3 Ma as the emplacement age of the Blåfjellhatten granite.

Discussion

The U-Pb zircon age reported here for this granite is quite close to the suggested approximate age of intrusion of the neighbouring and geochemically comparable Olden granite. In a U-Pb study of this Olden granite, the zircon fractions analysed were strongly discordant; and on a concordia plot the upper intercept of 1570 ± 20 Ma was interpreted as the minimum age of emplacement (Stuckless et al. 1982). These authors also used Pb-Pb data from galenas and one potassium feldspar to derive a secondary isochron corresponding to an age of ca.1650 Ma for the granite. An attempt to generate a Rb-Sr isochron age, however, was less successful, but Stuckless et al. noted that four of the least disturbed samples were colinear on a strontium evolution plot and yielded an 'age' of 1640 ± 10 Ma. In an earlier Rb-Sr investigation of the Olden granite by Klingspor & Troëng (1980), most of the samples analysed were found to have been clearly disturbed by cataclasis and alteration and gave minimum-age and maximum-age reference lines corresponding to ca.1500 and 1635 Ma, respectively. The results of these two, separate studies indicated indisputably that although none of the isotopic systems investigated recorded the precise age of Olden granite, there is evidence suggesting 1650 Ma as the approximate time of emplacement.

In their Rb-Sr whole-rock investigation of the Blåfjellhatten granite, Fossen & Nissen (1991) generated a 5-point whole-rock isochron with a MSWD of 1.01 and a slope indicating an age of ca. 1350 Ma. The initial ^{87}Sr/^{86}Sr ratio of 0.7245 ± 0.0027 also differs appreciably from that of the Olden granite (0.7134 ± 0.0012). These isotopic data, and the apparently undeformed nature of their Blåfjellhatten samples, convinced Fossen & Nissen that the Blåfjellhatten granite is significantly younger than the granites of the TIB.

The analytical data now available for both the Olden and the Blåfjellhatten granite, and for the intervening porphyritic felsic volcanites, demonstrate that the two plutons and the extrusive complex have comparable geochemical signatures. The data for the porphyritic high-K rhyolites and Olden granite led Roberts (1997b) to conclude that they formed in a continental extensional setting. The new geochemical data for the Blåfjellhatten granite similarly suggest a continental and probably anorogenic, extensional regime.

We conclude that the two granites are broadly coeval, but slightly younger than the regionally extensive, porphyritic volcanites through which they intrude. The actual age relationship of the Olden and Blåfjellhatten granites is uncertain. The precise zircon age of 1633.2 ± 2.9 Ma reported here for the Blåfjellhatten granite is similar to the estimated, approximate emplacement age of 1650 Ma for the Olden granite. The Sr isotopic systematics of the Blåfjellhatten granitic rocks, and the high initial ratio, may be indicating an isotopic disturbance arising, for example, from a minor geological event, e.g., fluid percolation associated with Scandian hydrothermal activity. The ca. 1350 Ma date could therefore also be providing yet another example of a geologically meaningless, Rb-Sr whole-rock isochron (Field & Råheim 1979).

In a more regional context of the TIB, post-Svecofennian granitoids of comparable age to that of the Blåfjellhatten granite, i.e., 1.65–1.63 Ga, have been reported from northern Vestranden (summarised in Johansson et al. 1993), but these bodies have been variably and, in part, strongly reworked during the Scandian orogeny and little is known about their geochemistry. TIB rocks are also known in the Trysil–Engerdal area of SE Norway, some 300 km south of Blåfjellhatten, where both granitoids and porphyritic volcanites are represented (Heim et al. 1996). One distinctive, red-, blue- and green-coloured granite, the Trysil 'tricolor' granite, has yielded a U-Pb zircon, upper intercept age of 1673 ± 8 Ma (MSWD, 1.4), which was interpreted by Heim et al. (1996) as the crystallisation age of the granite. Rb-Sr whole-rock data for the same granite gave an isochron age of 1642 ± 35 Ma with an initial ^{87}Sr/^{86}Sr ratio of 0.70391 ± 97. Both this 'tricolor' granite and a neighbouring perthite granite show within-plate, I-type, geochemical characteristics that are similar in many respects to those of the Blåfjellhatten and Olden granites.

Larsen & Berglund (1992) subdivided the TIB of southern Sweden into three magmatic episodes (1.81–1.76, 1.71–1.69 and 1.68–1.65 Ga) with a general westward younging or crustal accretion. More recent work has indicated that the oldest (TIB-1) plutons are closer to 1.85 Ma (Persson & Wikström 1993), i.e. some 30–40 million years older than hitherto believed. In this scheme of events, the Trysil granitoids are correlated with the post-volcanic Dala and Råtan granites, representing the youngest, TIB-3 episode. The Blåfjellhatten and Olden granites are also representative of the youngest magmatic episode of TIB evolution, with the former marking what is perhaps the youngest large granite pluton so far recorded in this particular domain of the Fennoscandian Shield.

Conclusions

A U-Pb zircon analysis of the Blåfjellhatten granite in the Olden Nappe of the Grong-Olden Culmination, Central Norwegian Caledonides, has yielded an age of 1633.2 ± 2.9 Ma. The date is comparable to that reported for the neighbouring Olden granite, but contrasts with an earlier Rb-Sr isochron age of 1356 ± 29 Ma for the Blåfjellhatten body. Geochemical data indicate that the 'within-plate' Blåfjellhatten granite derived from a fairly evolved crustal source in a continental, extensional, and probably anorogenic setting. Certain element ratios, however, are pointing to an I-type rather than a true A-type granite. Both the Blåfjellhatten and the Olden granite are considered to form part of the youngest stage (TIB-3) of the 1.81–1.65 Ga Transscandinavian Igneous Belt. The precise age reported here thus makes the Blåfjellhatten granite one of the youngest plutons in the TIB, and extends the terminal stages of the latter by some 15–20 million years.

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