Timing and tectonic significance of Sveconorwegian A-type granitic magmatism in Telemark, southern Norway: New results from laser-ablation ICPMS U-Pb dating of zircon

TOM ANDERSEN, STUART GRAHAM & ARTHUR G. SYLVESTER

Andersen, T., Graham, S. & Sylvester, A.G. 2007: Timing and tectonic significance of Sveconorwegian A-type granitic magmatism in Telemark, southern Norway: New results from laser-ablation ICPMS U-Pb dating of zircon. *Norges geologiske undersøkelse Bulletin 447*, 17-31.

The ages of six Sveconorwegian A-type granites without penetrative deformational fabric and an intrusive rhyolite porphyry from Telemark, southern Norway, have been determined by laser ablation inductively coupled plasma source mass spectrometry (LAM-ICPMS) on magmatic zircons. The emplacement ages span ca. 250 Ma: Åmannsbu (rhyolite porphyry) at 1168 ± 27 Ma, Fjellstadfjell at 1151 ± 9 Ma, Venås at 1157 ± 7 Ma, Otternes at 1023 ± 24 Ma, Torsdalsfjell at 990 ± 14 Ma, Vehuskjerringa at 932 ± 4 Ma and Tørdal at 918 ± 7 Ma. Inherited zircons in the granites include xenocrysts derived from Sveconorwegian rocks, ca. 1500 Ma Rjukan Group metarhyolite and / or slightly younger intrusive rocks, and rare but significant zircons derived from Paleoproterozoic protosources corresponding in age to intrusions of the Transscandinavian Igneous Belt. The zircon U-Pb ages obtained in this study confirm the early start and long duration of A-type granitic magmatism in Telemark, suggesting that this magmatism must be related to several tectonic events, and support the existence of Paleoproterozoic rocks at depth in southern Norway.

Tom Andersen, Department of Geosciences, University of Oslo, PO Box 1047 Blindern, N-0316 Oslo, Norway. E-mail: tom.andersen@geo.uio.no
Stuart Graham, Department of Geosciences, University of Oslo, PO Box 1047 Blindern, N-0316 Oslo, Norway. Present address: Rio Tinto OTX, 1 Research Avenue, Bundoora 3083, Victoria, Australia.
Arthur G. Sylvester, Department of Earth Science, University of California, Santa Barbara, CA 93106-9630, USA.

Introduction

Sveconorwegian A-type granites without penetrative deformational fabric are widespread in southern Norway, from the Båhus-Flå granite belt (Killeen & Heier 1975) in the east to Rogaland in the west (Fig. 1). Because the emplacement of these granites postdates the youngest Sveconorwegian deformation event(s) in the region, they are tectonic markers and potential indicators of the nature and composition of the lower crust after the last tectonometamorphic event that affected southwestern Fennoscandia (e.g., Andersson et al. 1996, Andersen et al. 2001, Vander Auwera et al. 2003). Based on their undeformed nature and on Rb-Sr isochron ages, these granites have generally been assumed to have intruded in late Sveconorwegian time (ca. 950-890 Ma, see compilation by Andersson et al. 1996). If the granites were really emplaced within a short time span at the end of the Sveconorwegian orogeny, then the magmatism may have been related to a common and region-wide cause, such as a major event of postorogenic extension or lithospheric delamination (Andersson et al.1996, Vanden Auwera et al. 2003).

For some of the intrusions, late Sveconorwegian ages have been confirmed by more reliable dating methods (e.g., Båhus: 922 Ma, Eliasson & Schöberg 1991; Flå 928 Ma, Nordgulen et al. 1997; Herefoss 926 Ma, Andersen 1997). The dating of some intrusions in the Telemark and Hardangervidda-Rogaland blocks to ages older than 1000 Ma (e.g., Gunnarstul: 1133 Ma, Rosskreppfjord: 1036 Ma, Andersen et al. 2002a), however, indicates that although the granitic magmatism may have culminated close to 930 Ma, it must have started considerably earlier: at ca. 1040 Ma in Rogaland and and before ca. 1130 Ma in Telemark. The quality of some of the early Sveconorwegian U-Pb ages of granites from Telemark, however, is less than optimal: One intrusion (Bandak) studied by Andersen et al. (2002a) has a massive inheritance of ca. 1500 Ma zircons; hence, it is possible that other early Sveconorwegian ages were also affected by unresolved inheritance. To gain further insight into the timing of Sveconorwegian A-type magmatism in southwestern Fennoscandia, seven intrusions whose ages have been unknown or poorly constrained have been dated by U-Pb on zircon, using laser ablation, inductively coupled plasma source mass spectrometry (LAM-ICPMS).

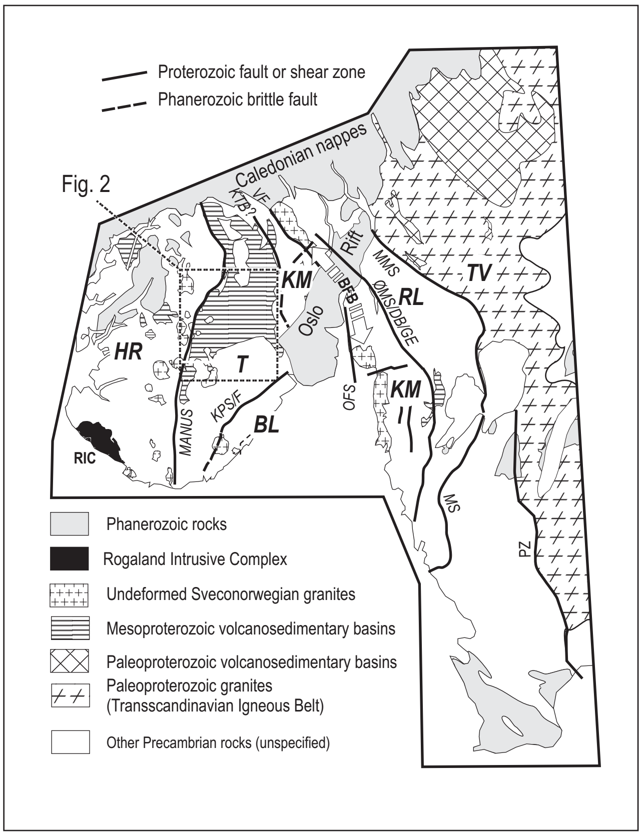

Fig. 1. Simplified geologic map of southwestern Fennoscandia, after Koistinen et al. (2001). Regional units (blocks): HR: Hardangervidda-Rogaland, T: Telemark, BL: Bamble-Lillesand, KM: Kongsberg-Marstrand, RL: Randsfjord-Lygnern, TV: Trysil-Vättern (Andersen 2005). Shear zones: MANUS: Mandal-Ustaoset line, KPS/F: Kristiansand-Porsgrunn shear zone and brittle fault. KTB: 'Kongsberg-Telemark boundary' (brittle fault). VF: Vardefjell shear zone. OFS: Oslofjord Shear zone. ØM/DB/GE: Ørje mylonite zone / Dalsland Boundary Thrust / Götaälv shear zone system. MMS: Mjøsa-Magnor shear zone. MS: Mylonite Zone. PZ: Protogine Zone. BFB: Båhus-Flå granite belt. RIC: Rogaland intrusive complex.

Geologic setting

The Fennoscandian (or Baltic) Shield consists of an Archean core in the northeast (Finland, N Sweden, NW Russia) and progressively younger Proterozoic crustal domains southwestward (Fig. 1). The Southwest Scandinavian Domain (SSD; Gaàl & Gorbatschev 1987) is separated from the older parts of the shield by a belt of 1.85-1.65 Ga granitic intrusions known as the Transscandinavian Igneous Belt (TIB, Högdahl et al. 2004). The SSD consists of reworked TIB granitoids (Söderlund et al. 2002), early Mesoproterozoic subduction-related metaigneous rocks (Brewer et al. 1998, Andersen et al. 2004a), younger Mesoproterozoic metasedimentary and anorogenic metavolcanic rocks (Bingen et al. 2001, Laajoki et al. 2002), and several generations of mafic and felsic intrusions (Killeen & Heier 1975, Bingen & van Breemen 1998, Andersen et al. 2001, Andersen 2005 and references therein).

Southwestern Fennoscandia has been strongly affected by metamorphism and ductile deformation in Sveconorwegian time (1.25-0.90 Ga), and by Paleozoic rifting and brittle faulting, resulting in a mosaic of crustal blocks, which may or may not have tectonostratigraphic terrane status (Andersen 2005 and references therein). In the present paper, the non-genetic regional nomenclature of Andersen (2005) is used (Fig. 1). The *Telemark block* in central southern Norway is separated from the *Hardangervidda-Rogaland block* in the west by a shear zone of early Sveconorwegian or older age, known as the Mandal-Ustaoset line (Sigmond 1986). On its east side, the Telemark block is separated from the *Kongsberg-Marstrand block*, which consists mainly of 1700-1500 Ma calc-alkaline meta-igneous rocks and coeval metasedimentary rocks, and younger intrusions, by Precambrian shear zones and Phanerozoic brittle faults. To the south, upper-amphibolite to granulite facies rocks of the *Bamble-Lillesand block* were thrust over lower-amphibolite facies gneisses of the Telemark block at ca. 1070 Ma (Mulch 2003). In the north, the Precambrian basement of the Telemark block is covered by Caledonian nappes.

Relatively well-preserved, ca. 1.50 Ga metarhyolite (Rjukan Group) and 1.50-1.15 Ga quartzite and conglomerate (Vindeggen group) are exposed in central Telemark, flanked to the east and west by several ca. 1.16-1.12 Ga Sveconorwegian supracrustal sequences comprising metarhyolite, metabasalt and metasedimentary rocks (Fig. 2; Dons 1960, Dons & Jorde 1978, Menuge & Brewer 1996, Nordgulen 1999, Laajoki et al. 2002, Bingen et al. 2003, 2005).

The southern part of the Telemark block is dominated by granitic gneisses, at least some of which are early Sveconorwegian granitoids (ca. 1210 Ma), possibly formed in a supra-subduction zone setting (e.g., Smalley & Field 1985, Heaman & Smalley 1994, Andersen et al. 2007). The Hardangervidda-Rogaland block has pre-Sveconorwegian metasupracrustal rocks, granitic gneisses, and Sveconorwegian metasupracrustal rocks and intrusions (Sigmond 1998, Sigmond et al. 2000, Bingen et al. 2005).

Counting ca. 1210 Ma calc-alkaline granitic gneisses in southern and southeastern Telemark as a separate group of intrusions (Heaman & Smalley 1994, Andersen et al. 2007), five distinct groups of Sveconorwegian granites are recognized in the Hardangervidda-Rogaland, Telemark and Bamble-Lillesand blocks. The ca. 1160-1150 (1120) Ma A-type Gjerstad suite (Bingen & van Breemen 1998) is in the Bamble-Lillesand block and in the southern part of the Telemark block. The ca. 1050 Ma Feda suite intrusions in the Hardangervidda-Rogaland block have high-K calc-alkaline compositions, whereas the ca.1030 Ma Fennefoss augen gneiss in southwestern Telemark is transitional between orogenic and anorogenic compositions (Bingen & van Breemen 1998). Sveconorwegian A-type granites postdating the final ductile deformation event occur in the Hardangervidda-Rogaland, Telemark, Bamble-Lillesand and Kongsberg-Marstrand blocks (Fig. 1, 2). In general, these intrusions are alkali-calcic, ferroan and high-K in composition, with clear A-type trace element signatures (Vanden Auwera et al. 2003).

Andersen et al. (2001) identified two main groups of A-

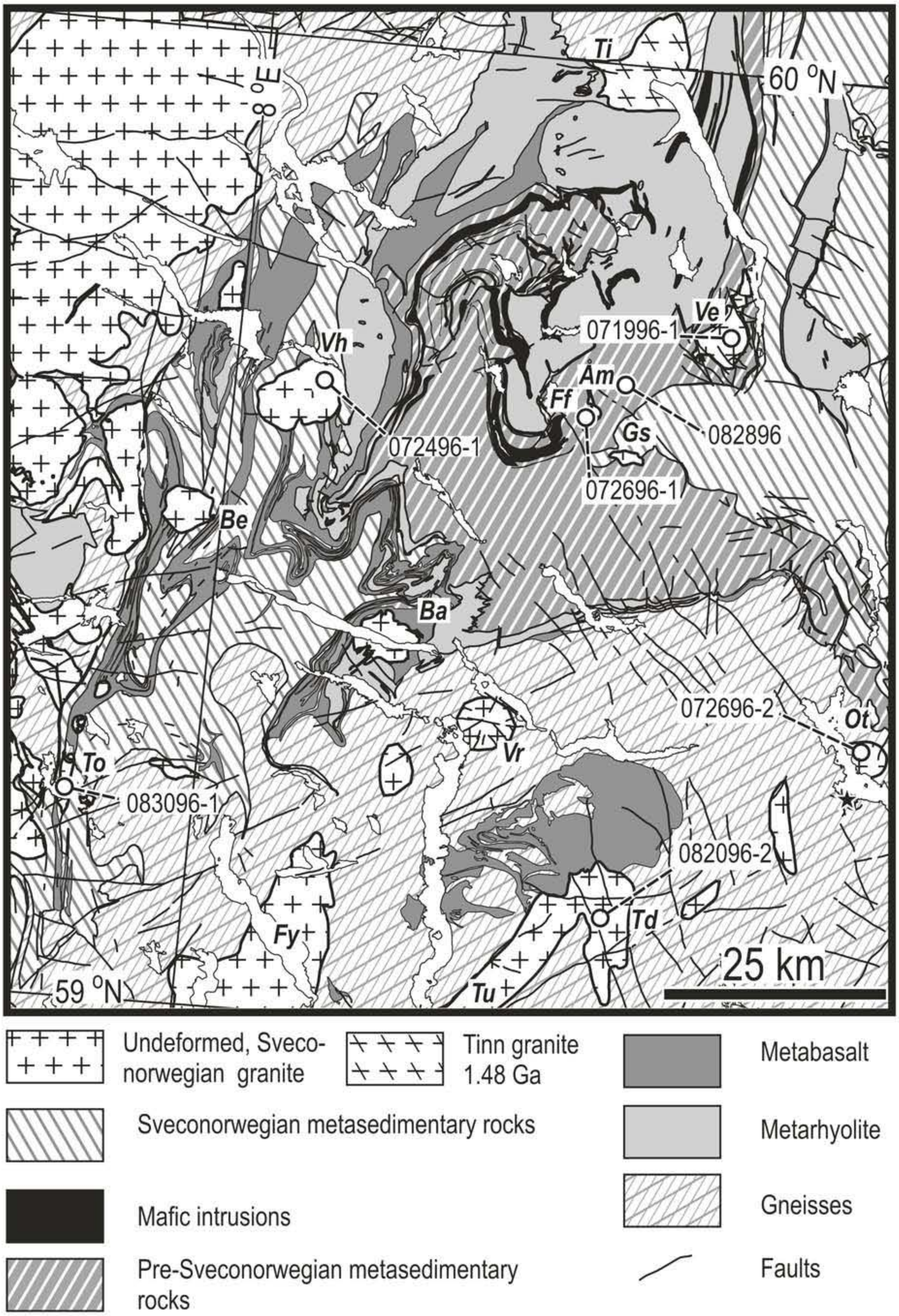

Fig. 2. Simplified geological map of central Telemark (see Fig. 1 for location). The geology is based on digital map data from Norges Geologiske Undersøkelse (file name: berggrunn_n250_1_arcims214407885.zip, download date: 12.02.2007), which incorporate published data from Dons & Jorde (1978), Sigmond (1975, 1998) and Nordgulen (1999). In the southern part, the distribution of underformed granite is based on Sigmond et al. (1984) and Bergstøl & Juve (1988). No distinctions are made between metavolcanic rocks of Sveconorwegian and pre-Sveconorwegian age. Intrusions identified by two-letter codes: Ti: Tinn, Ve: Venås, Åm: Åmannsbu, Ff: Fjellstadfjell, Gs: Gunnarstul, Ot: Otternes, Td: Tørdal, Tu: Treungen, Fy: Fyresvatn, Vr: Vrådal, Ba: Bandak, To: Torsdalsfjell, Be: Bessefjell, Vh: Vehuskjerringa. Star: Fen alkaline and carbonatite complex, ca. 580 Ma.

type granites in the region with contrasting Rb/Sr ratios and Sr isotopic characteristics:

- *Group 1* granites, are characterized by Sr > 150 ppm, $^{87}Rb/^{86}Sr < 5$ and $^{87}Sr/^{86}Sr_{0.93Ga} < 0.710$.
- *Group 2*, with Sr < 150 ppm, $^{87}Rb/^{86}Sr > 5$ and $^{87}Sr/^{86}Sr_{0.93Ga} > 0.710$.

Granites of both groups have $\varepsilon_{Nd} < 0$ at 0.93 Ga. Group 1 granites are widespread in southern Norway, whereas Group 2 intrusions are restricted to the northern and central part of the Telemark block, where they co-exist with Group 1 intrusions (Fig. 2).

The Group 2 granites in central Telemark intruded metavolcanic rocks and/or quartzite; the Otternes and Tørdal Group 2 granites, however, intruded granitic gneiss (Fig. 2). Group 1 granites are within metasupracrustal country rocks (Vehuskjerringa, Fig. 2) and in granitic gneisses (e.g., Vrådal, Fig. 2). Detailed geologic maps are available for the Venås (Carter 1962), Vrådal (Sylvester 1964, 1998), Bandak (Nilsen 1981) and Bessefjell (Nilsen 1981) granites; the others included in this study are indicated as undifferentiated granitic intrusions on regional geologic maps in 1:250 000 scale (Sigmond 1975, Dons & Jorde 1978).

The material studied

Six coarse- to medium-grained quartz monzonite to granite intrusions and one rhyolite porphyry intrusion from the Telemark block were selected for U-Pb dating (Table 1):

Vehuskjerringa (sample 072496-1). The Vehuskjerringa granite (Fig. 2) is an almost circular, unfoliated granitic intrusion in Sveconorwegian metabasaltic rocks and quartz schist (Dons & Jorde 1978, Vander Auwera et al. 2003). Vehuskjerringa belongs to Group 1 of Andersen et al. (2001). An unpublished TIMS U-Pb dating suggests an emplacement age of 932 + 7/-2 Ma (S. Dahlgren, reported in Bingen et al. 2005). The sample analysed in the present study is a coarse-grained, massive biotite granite. The rock has a well-preserved magmatic microstructure with interstitial aggregates of dark brown biotite, titanite, magnetite and zircon.

Venås (sample 071996-1). The Venås granite (Fig. 2) intruded the core region of a large southeast-plunging anticline in pre-Sveconorwegian supracrustal rocks (Carter 1962), and is in contact with quartzite of the Vindeggen Group (Fig. 2). The Venås intrusion belongs to Group 2 and ranges in composition from quartz monzonite to granite, with a pink, coarse-grained granite as the most abundant rock type; toward the western margin of the intrusion, granite grades into a biotite and magnetite-rich, tonalitic border facies (Carter 1962). The granite is unfoliated but cut by numerous brittle faults (Fig. 2). Sample 071996-1 is a medium-grained quartz monzonite from the east side of the pluton. Mafic minerals occur in polycrystalline interstitial intergrowths and include magnetite, biotite, titanite, bluish-green amphibole, apatite, epidote and accessory zircon.

Fjellstadfjell (sample 072696-1). The Group 2 granite at Fjellstadfjell in eastern Telemark (Fig 2) has been emplaced into quartzite belonging to the Vindeggen Group. It is close to, but separated from, the Group 2 Gunnarstul intrusion, which has been dated at 1134 ± 21 Ma by SIMS U-Pb on zircon by Andersen et al. (2002a). The sample studied is a medium-grained, porphyritic granite with saussuritized plagioclase phenocrysts in a micrographic quartz-microcline groundmass. Mafic silicate minerals are biotite, occurring as polycrystalline aggregates and resorbed and recrystallized phenocrysts, and epidote. Zircon occurs together with magnetite, titanite replacing magnetite, biotite and epidote.

Torsdalsfjell (sample 080396-1). Torsdalsfjell is a small Group 2 intrusion located at the eastern side of the Mandal-Ustaoset line, intruded into Sveconorwegian quartzite and metavolcanic rocks (Fig. 2). The sample studied is a medium-grained, dark grey biotite granite with minor muscovite and magnetite. Biotite in the sample is heavily altered to chlorite, and plagioclase contains secondary sericite and epidote/(clino)zoisite. Zircon occurs in interstitial aggregates together with magnetite, mica and accessory apatite.

Otternes (sample 072696-2). The Otternes granite (Group 2) is situated close to the margin of the Oslo Rift (Fig. 2), where it intruded granitic gneiss of unknown age and origin. Six zircons analysed for U-Pb by SIMS by Andersen et al. (2002a) yielded a poorly constrained discordia line (MSWD=4.4) with an upper intercept at 1233 ± 90 Ma. The zircons analysed in the present study were separated from the same sample, which is a weakly foliated, pink leucogranite with minor biotite and magnetite. The sample has a well-equilibrated granular microstructure, and both alkali feldspar and plagioclase are fresh. Magnetite crystals have thin rims of titanite, which also occurs as separate crystals.

Table 1. Samples analysed in the present study

Intrusion	Sample no.	Group	UTM E (zone 33)	UTM N (zone 33)	Rock type	Sr ppm	Rb ppm	$^{87}Sr/^{86}Sr_i$ 930 Ma	εNd 930 Ma
Vehuskjerringa	072496-1	1	4546	66120	Biotite granite, coarse grained	465	165	0.7049	-1.2
Tørdal	082996-1	2	4874	65565	Biotite granite, medium grained	94	249	0.7125	-0.1
Otternes	072696-2	2	5149	65794	Leucogranite, weakly foliated	42	185	0.7391	1.8
Torsdalsfjell	080396-1	2	4283	65637	Biotite granite, medium grained	104	397	0.7172	0.5
Fjellstadfjell	072696-1	2	4824	66112	Porphyritic biotite granite	86	184	0.7241	1.2
Venås	071996-1	2	4982	66222	Quartz monzonite	80	179	0.7233	0.9
Åmannsbu	082896	2	4871	66152	Rhyolite porphyry	70	176	0.7338	0

Sr and Rb concentrations, Sr and Nd isotope compositions are from Andersen et al. (2001).

Euhedral zircons occur both interstitially and as inclusions in quartz.

Tørdal (sample 082996-1). The Tørdal granite (Fig. 2) is the southernmost occurrence of Group 2 granite in Telemark, forming part of a belt of undeformed, Sveconorwegian granites which also includes the Group 1 Treungen granite (Andersen et al. 2001). The Tørdal granite intruded granitic gneiss and metavolcanic rocks of unknown age, and is associated with granitic pegmatites enriched in Sc, Sn, Li and Be (Mitchell 1967, Dons & Jorde 1978, Bergstøl & Juve 1988). The sample studied is a medium- to coarse-grained, unfoliated biotite granite with fresh microcline and partly altered plagioclase (sericite+epidote). Dark brown to green biotite is interstitial between quartz and feldspar, and is partly altered to chlorite. Minor minerals are epidote and magnetite. Zircon is found as inclusions in quartz and feldspar, and in interstitial aggregates with biotite and magnetite.

Åmannsbu (sample 082896). The Åmannsbu intrusion (Fig. 2) is a ca. 50 m-wide dike in quartzite of the Vindeggen Group. This intrusion has a typical Group 2 strontium isotope and Rb-Sr concentration signature (Table 1), and may provide a link between rhyolitic volcanism and granitic magmatism in eastern Telemark, which makes the age of this intrusion important for the tectonomagmatic history of the region. The sample studied is a rhyolite porphyry with a fine-grained, partly recrystallized, aphanitic quartz-microcline groundmass with minor muscovite, biotite and magnetite, phenocrysts of microcline and magnetite, and polycrystalline aggregates of biotite, muscovite, epidote, titanite and zircon. In addition to the phenocryst phases, the sample contains abundant, rounded and embayed single macrocrysts and crystal aggregates of quartz, which are most likely derived from the country rock quartzite.

Zircons

Analytical methods

Zircons were separated by Wilfley table washing, heavy liquid and Frantz magnetic separation, followed by hand picking. Grains were mounted on doubly adhesive tape, cast in epoxy and polished.

U-Pb dating was performed using a Nu Plasma HR multi-collector ICPMS and a New Wave/Merchantek LUV-213 laser microprobe at the Department of Geosciences, University of Oslo. Ablations were performed in helium, and the helium-aerosol mixture is mixed with argon prior to entering the plasma. The Nu Plasma HR mass spectrometer at the Department of Geosciences is equipped with a specially designed U-Pb collector block, that allows simultaneous detection of masses 204, 206 and 207 in ion counters and masses 235 and 238 in Faraday-detectors. Mass number 235 could not be measured with sufficient precision, so ^{235}U was calculated from the higher abundance 238, using a natural ^{238}U/^{235}U ratio of 137.88. A single U-Pb measurement included 30 seconds of on-mass background measurement, followed by 60 seconds of ablation with a 55 µm stationary beam. In this study, a sample-standard bracketing procedure similar to that of Andersen et al. (2004a) and Jackson et al. (2004) has been used. Standard zircons 91500 (Wiedenbeck et al. 1995) and GJ-1 (609 Ma, Belousova et al. 2006) were used for calibration. 122 analyses of 91500 as an unknown calibrated against GJ-1 gave an age of 1072 ± 5 Ma.

Mass number 204 was used as a monitor for common ^{204}Pb. In an ICPMS analysis, ^{204}Hg, presumably originating from the argon supply, contaminates mass 204. The contribution of ^{204}Hg from the plasma was eliminated by on-mass background measurement prior to each analysis. Where necessary, the observed signals at mass 206 and 207 were corrected for common ^{206}Pb and ^{207}Pb after integration of the signal, using observed ^{204}Pb and average common-lead composition given by the Stacey-Kramers global lead evolution curve at the relevant age (Stacey & Kramers 1975).

Data reduction was made in an interactive spread-sheet program written in VBA for Microsoft Excel®, following procedures for U-Pb fractionation correction and instrumental drift. Observed errors in background and signal for standard and unknown, and the uncertainty of the published standard composition were propagated through, using normal error propagation formulas (e.g. Taylor 1997). IsoplotEx 3.0 (Ludwig 2003) was used to calculate concordia (Ludwig 1998) and intercept ages, using observed correlation coefficients for errors in the ^{206}Pb/^{238}U and ^{207}Pb/^{235}U ratios. Our long-term precision (>2 yrs) is ≤ 1 % for ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb and ≤ 1.4 % for ^{207}Pb/^{235}U (2 standard deviations).

Morphology and zoning of zircon

Zircon is an abundant accessory mineral in the central Telemark granites. Grains are moderately elongated, euhedral prisms with terminal pyramids, and well-developed, oscillatory zoning in CL and BSE images (Fig. 3a,b), which are features typical of magmatic zircons (Corfu et al. 2003). Xenocrystic cores visible in CL or BSE images are remarkably scarce in most of the samples, but unequivocal examples are in the Vehuskjerringa (Fig. 3a), Tørdal (Fig. 3c) and Torsdalsfjell (Fig. 3d) intrusions. It should be noted that even xenocrystic cores have oscillatory magmatic zoning (Fig. 3c), and that inherited zircons may therefore be difficult to recognize as such from BSE or CL images unless they have recognizable overgrowths.

Results

Sample 072496-1 from *Vehuskjerringa* (Table 2) yielded a well-defined population of concordant zircons giving a concordia age of 932 ± 4 Ma (Fig. 4a). A single xenocrystic zircon core (Fig. 4b) gives a ^{207}Pb/^{206}Pb age of 1758 ± 16 Ma, and a single analysis falls on a lead-loss line from the 932 Ma concordant population to a recent lower intercept. The age of the concordant population is identical to the unpublished ID-TIMS U-Pb zircon age of 932 + 7/-2 Ma (S. Dahlgren, in Bingen et al. 2005), and is interpreted here as the age of emplacement of the Vehuskjerringa granite.

Twenty-three zircons from sample 071996-1 from *Venås*

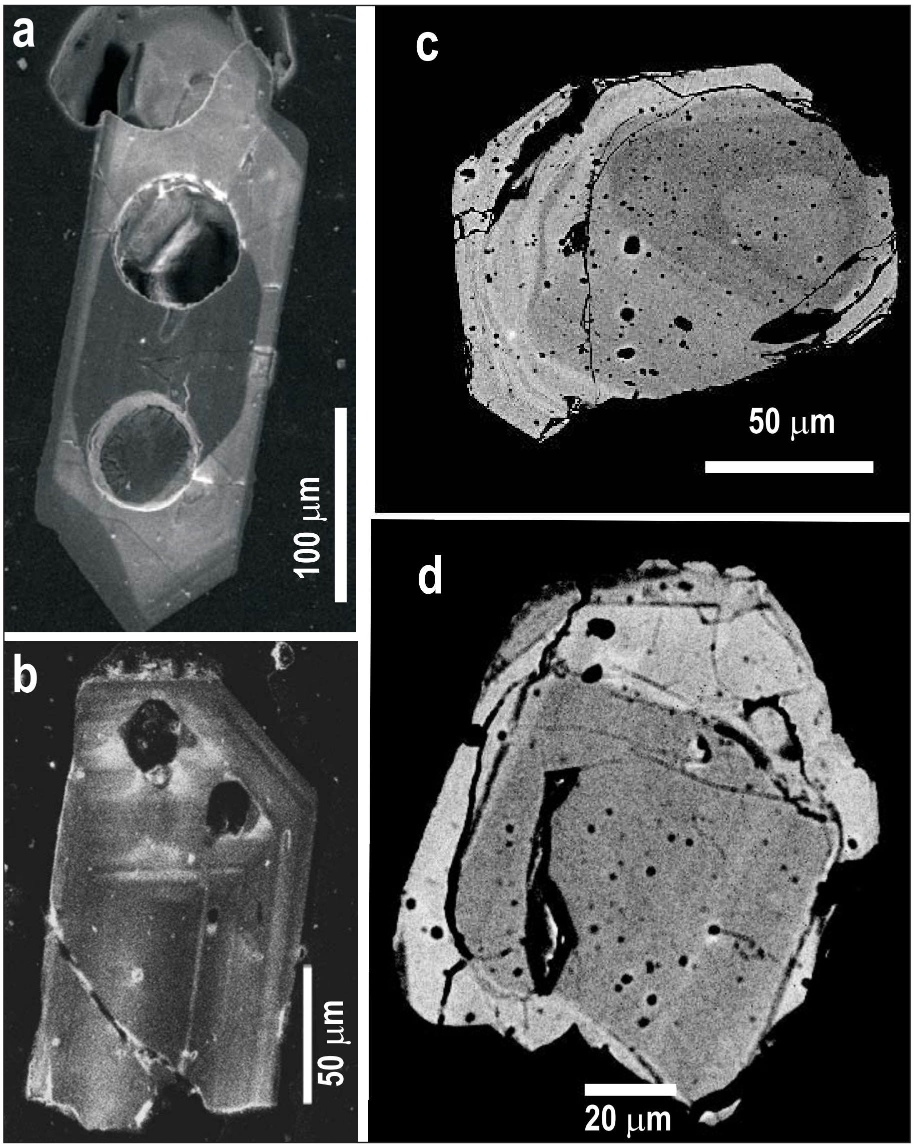

Fig. 3. SEM images of zircons, by cathodoluminescence (CL) and backscattered electrons (BSE). a: CL image of zircon Vehus25 from the Vehuskjerringa granite. The dark, CL homogeneous core is dated at 1758±16 Ma (Table 2). Note the regular shape and flat bottom of the laser ablation spots. b: CL image of magmatic zircon FJF17 from Fjellstadfjell. This zircon belongs to the 1151 ± 9 Ma population of magmatic zircons used to date this granite (Fig. 6). c: BSE image of xenocrystic core in zircon TD-09b from Tørdal. The core has low-amplitude, oscillatory zoning, and an irregularly curved interface to the BSE bright rim. Age of core: 1699 ± 18 Ma. d: BSE image of xenocrystic core in zircon TDF-08 from Torsdalsfjell. The core has a faint, parallel oscillatory zoning, whereas the host zircon is featureless. $^{207}Pb/^{206}Pb$ age of core = 1331 ± 16 Ma, its true age lies between 1331 and ca. 2400 Ma (Fig. 8).

(Table 2) plot on a well-defined lead-loss line through zero with an upper intercept age of 1157 ± 7 Ma, which is interpreted as the emplacement age of this intrusion (Fig. 5).

Eight nearly concordant zircons from *Fjellstadfjell* define an upper intercept at 1151 ± 9 Ma of a line forced through zero (Fig. 6). This is equal within uncertainty to the 1134 ± 21 Ma SIMS U-Pb age reported from the nearby Gunnarstul granite by Andersen et al. (2002a). One zircon lying off this trend is compatible with ca. 1500 Ma or older inheritance.

A line through a group of nine nearly concorcant zircons and one strongly discordant grain from the *Åmannsbu* rhyolite porphyry gives an upper intercept age of 1168 ± 27 Ma (Fig. 7). Two zircons (corrected for common lead) plot off this line, again suggesting 1.5 Ga or older inheritance.

Zircons from the *Torsdalsfjell* granite are discordant, and can be divided into two groups: inherited zircons having an $^{207}Pb/^{206}Pb$ age of 1329 + 22/-23 Ma, and a larger group of zircons plotting along a lead-loss line from 990 ± 14 Ma, which is the best estimate of the intrusive age of this granite, to a young lower intercept (Fig. 8). Some magmatic zircon grains plotting left of this line appear to have been influenced by Paleozoic and later lead loss. Because the inherited zircons may have suffered lead loss in the magma as well as in later time, their original crystallization age could be anything between 1326 Ma and early Paleoproterozoic, because a line through the inherited zircons anchored at 990 Ma gives an upper intercept of 2456 + 270/-220 Ma.

The interpretation of the zircon U-Pb data from Tørdal is complicated by abundant inherited zircons, elevated common lead contents, and the effects of Paleozoic lead loss (Fig. 9). Either of two Sveconorwegian concordant zircons at 1065 ± 17 Ma and 918 ± 7 Ma, respectively, can represent the crystallization age of the intrusion. The younger of the two is supported by seven zircons plotting along a relatively poorly defined lead-loss age from 889 ± 69 Ma to a Paleozoic lower intercept, and is therefore regarded as the best estimate of the crystallization age. The lower intercept of this line has a large error (460 ± 160 Ma), but is compatible with lead loss in Caledonian, and perhaps even early Oslo Rift, time. The 1061 Ma concordant zircon may have been inher-

Table 2. LAM-ICPMS U-Pb analyses of zircons from Sveconorwegian anorogenic intrusions in Telemark.

Sample Analysis	ppm U	^{206}Pb	$^{206}Pb_c$(%)	206/204	Ratios $^{207}Pb/^{206}Pb^*$	1SE	$^{207}Pb/^{235}U^*$	1SE	$^{206}Pb/^{238}U^*$	1SE	Rho	Discordance Central %	Minimum rim (%)	Ages $^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ
Vehuskjerringa granite																			
Vehus_10	83	11.4	6.70E-01	4276	0.0681	0.0011	1.4435	0.0339	0.1536	0.0026	0.893	6.2	0.4	872	33	907	14	921	15
Vehus_3b	53	7.2	0.00E+00	3503	0.0729	0.0007	1.5699	0.0174	0.1561	0.0019	0.517	-8	-2	1011	18	958	7	935	10
Vehus_5	40	5.5	0.00E+00	4057	0.0699	0.0007	1.5230	0.0142	0.1580	0.0021	0.88	2.6		924	20	940	6	946	12
Vehus_6	36	4.8	0.00E+00	2351	0.0711	0.0007	1.5083	0.0136	0.1538	0.0020	0.841	-4.1		959	19	934	5	922	11
Vehus-11	51	6.9	0.00E+00	24888	0.0706	0.0007	1.5125	0.0164	0.1553	0.0022	0.93	-1.7		946	19	935	7	930	12
Vehus-13	48	5.6	3.20E+00	362	0.0711	0.0014	1.2789	0.0337	0.1303	0.0017	0.915	-18.9	-13.5	961	37	836	15	790	10
Vehus-14	47	6.4	0.00E+00	8245	0.0704	0.0008	1.5267	0.0155	0.1572	0.0022	0.721	0.3		940	21	941	6	941	12
Vehus-15	70	9.4	3.40E-01	1896	0.0707	0.0008	1.4994	0.0232	0.1537	0.0021	0.938	-3	-0.2	949	21	930	9	922	12
Vehus-18	40	5.4	0.00E+00	3174	0.0705	0.0008	1.4851	0.0158	0.1527	0.0021	0.799	-2.9		942	21	924	6	916	12
Vehus-20	40	5.4	0.00E+00	12338	0.0701	0.0006	1.4889	0.0151	0.1540	0.0018	0.705	-0.8		931	17	926	6	923	10
Vehus-22	30	4	0.00E+00	3399	0.0700	0.0007	1.4912	0.0139	0.1545	0.0019	0.848			927	19	927	6	926	11
Vehus-23	161	21.8	0.00E+00	363839	0.0692	0.0008	1.4764	0.0125	0.1546	0.0020	0.901	2.6		906	22	921	5	927	11
Vehus-24	40	5.4	2.40E-01	2890	0.0694	0.0009	1.4702	0.0225	0.1536	0.0024	0.848	1.4		910	25	918	9	921	13
Vehus-26	152	20.8	4.10E-01	2067	0.0705	0.0009	1.5171	0.0174	0.1560	0.0023	0.654	-0.9		943	24	937	7	934	13
Vehus-28	25	3.3	0.00E+00	2288	0.0707	0.0007	1.4984	0.0141	0.1537	0.0018	0.74	-3		948	18	930	6	921	10
Vehus-30	29	3.9	1.90E-01	1553	0.0710	0.0009	1.5104	0.0173	0.1542	0.0020	0.578	-3.6		957	23	935	7	924	11
Vehus-31	55	7.4	0.00E+00	14975	0.0702	0.0008	1.5030	0.0157	0.1551	0.0023	0.922	-0.6		935	21	932	6	929	13
Vehus-33	27	3.6	0.00E+00	1841	0.0706	0.0009	1.5288	0.0190	0.1570	0.0027	0.788	-0.5		945	24	942	8	940	15
Vehus-34	26	3.5	0.00E+00	1719	0.0705	0.0009	1.5217	0.0207	0.1565	0.0028	0.815	-0.6		943	24	939	8	937	16
Vehus-35	53	7.3	2.80E-02	6541	0.0698	0.0008	1.5207	0.0182	0.1579	0.0024	0.909	2.8		922	23	939	7	945	13
Vehus-37	37	5	1.40E-01	2026	0.0719	0.0008	1.5232	0.0147	0.1535	0.0022	0.804	-6.9	-2.1	984	22	940	6	920	12
Vehus-38	27	3.7	0.00E+00	4458	0.0706	0.0007	1.5177	0.0131	0.1557	0.0019	0.748	-1.5		947	19	938	5	933	10
Vehus-39	38	5.3	0.00E+00	5900	0.0708	0.0008	1.5359	0.0180	0.1572	0.0023	0.696	-1.1		951	23	945	7	941	13
Vehus-25	370	96.3	1.10E-01	9475	0.1075	0.0010	4.4164	0.0496	0.2977	0.0035	0.939	-5	-3.5	1758	16	1715	9	1680	18
Venås granite																			
VEN-1	84	13.7	1.10E+00	1176	0.0770	0.0014	1.9689	0.0449	0.1852	0.0024	0.801	-2.5		1122	35	1105	15	1096	13
VEN-3	156	26	0.00E+00	7091	0.0782	0.0008	2.0586	0.0270	0.1907	0.0025	0.903	-2.6		1153	20	1135	9	1125	13
VEN-4	119	20.5	3.30E-01	2421	0.0776	0.0008	2.1085	0.0309	0.1969	0.0027	0.912	2.1		1137	20	1152	10	1158	15
VEN-7	52	8.9	1.90E-01	1904	0.0798	0.0011	2.1625	0.0350	0.1964	0.0031	0.498	-3.2		1192	27	1169	11	1156	17
VEN-8	94	15.2	0.00E+00	8117	0.0782	0.0008	1.9999	0.0270	0.1854	0.0024	0.823	-5.1	-1.2	1151	20	1115	9	1096	13
VEN-8	94	15.2	0.00E+00	8117	0.0782	0.0008	1.9999	0.0270	0.1854	0.0024	0.823	-5.1	-1.2	1151	20	1115	9	1096	13
VEN-9	83	13.3	1.30E+00	855	0.0782	0.0009	1.9541	0.0288	0.1810	0.0024	0.502	-7.5	-1.1	1153	23	1100	10	1073	13
VEN-11	5	0.7	0.00E+00	3518	0.0775	0.0021	1.7309	0.0636	0.1618	0.0054	0.71	-15.9	-3.7	1135	51	1020	24	967	30
VEN-12	90	15.2	0.00E+00	5128	0.0793	0.0009	2.1199	0.0332	0.1937	0.0027	0.742	-3.6		1181	22	1155	11	1141	15
VEN-14	114	18.7	4.90E-01	1689	0.0783	0.0008	2.0202	0.0293	0.1870	0.0025	0.885	-4.5	-1.3	1154	21	1122	10	1105	13
VEN-16	125	20.5	0.00E+00	3641	0.0789	0.0008	2.0529	0.0281	0.1886	0.0025	0.927	-5.2	-2.7	1170	20	1133	9	1114	14
VEN-17	88	14.5	0.00E+00	5635	0.0783	0.0008	2.0530	0.0284	0.1900	0.0025	0.943	-3.1	-0.9	1155	20	1133	9	1121	14
VEN-18	163	26.3	8.60E-02	33497	0.0780	0.0009	1.9866	0.0283	0.1847	0.0024	0.542	-5		1146	21	1111	10	1092	13
VEN-19	82	13.7	0.00E+00	12318	0.0783	0.0008	2.0591	0.0291	0.1905	0.0026	0.941	-2.9	-0.6	1155	20	1135	10	1124	14
VEN-20	113	18.3	6.70E-01	1442	0.0776	0.0009	1.9790	0.0287	0.1848	0.0025	0.409	-4.1		1137	22	1108	10	1093	13
VEN-21	113	19.2	2.50E+00	570	0.0789	0.0019	2.0658	0.0661	0.1896	0.0027	0.859	-4.7		1171	46	1138	22	1119	14
VEN-22	120	20.3	0.00E+00	5810	0.0780	0.0008	2.0916	0.0301	0.1943	0.0027	0.958	-0.2		1147	19	1146	10	1145	14
VEN-23	123	20.3	1.50E+00	874	0.0782	0.0010	2.0084	0.0293	0.1861	0.0027	0.48	-4.8		1152	24	1118	10	1100	14
VEN-24	101	16.7	2.60E-01	2043	0.0780	0.0008	2.0440	0.0290	0.1898	0.0025	0.868	-2.5		1148	21	1130	10	1121	13
VEN-25	143	23.7	4.40E-01	1915	0.0795	0.0009	2.0866	0.0326	0.1902	0.0026	0.923	-5.6	-3	1185	21	1144	11	1123	14
VEN-25b	101	16.7	1.80E+00	689	0.0785	0.0012	2.0029	0.0416	0.1848	0.0025	0.908	-6.2	-3.2	1160	28	1116	14	1093	14

Sample Analysis	ppm U	^{206}Pb	$^{206}Pb_c$(%)	Ratios 206/204	$^{207}Pb/^{206}Pb^*$	1SE	$^{207}Pb/^{235}U^*$	1SE	$^{206}Pb/^{238}U^*$	1SE	Rho	Discordance Central %	Minimum rim (%)	Ages $^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ
VEN-26	115	20.1	1.40E-01	4336	0.0782	0.0015	2.1343	0.0664	0.1978	0.0037	0.812	1.1		1153	36	1160	22	1163	20
VEN-28	91	15	1.10E-01	3663	0.0786	0.0010	2.0372	0.0351	0.1878	0.0026	0.728	-4.9		1162	24	1128	12	1110	14
Fjellstadfjell granite																			
FJF-010	172	35	0.00E+00	2745	0.0784	0.0003	2.1700	0.0123	0.2007	0.0012	0.808	2		1158	7	1171	4	1179	7
FJF-011	64	12.9	0.00E+00	2290	0.0779	0.0005	2.1375	0.0267	0.1990	0.0022	0.875	2.3		1145	12	1161	9	1170	12
FJF-03a	36	6.9	0.00E+00	484	0.0780	0.0006	2.0577	0.0319	0.1913	0.0029	0.886	-1.8		1147	14	1135	11	1129	16
FJF-03b	68	14.1	0.00E+00	1753	0.0777	0.0004	2.1888	0.0197	0.2042	0.0018	0.848	5.6	2.7	1140	10	1177	6	1198	9
FJF-04	78	16.1	0.00E+00	2654	0.0777	0.0004	2.1580	0.0219	0.2016	0.0019	0.885	4.4	1.7	1138	10	1168	7	1184	10
FJF-05	79	16.3	0.00E+00	2292	0.0783	0.0005	2.1880	0.0239	0.2028	0.0021	0.813	3.4		1154	12	1177	8	1190	11
FJF-06	91	18.4	0.00E+00	1817	0.0782	0.0004	2.1537	0.0226	0.1998	0.0019	0.889	2.1		1152	9	1166	7	1174	10
FJF-09a	112	22.5	0.00E+00	2390	0.0815	0.0003	2.2224	0.0161	0.1977	0.0013	0.847	-6.3	-4.5	1234	7	1188	5	1163	7
FJF-09c	92	17.8	0.00E+00	1878	0.0789	0.0004	2.0709	0.0137	0.1903	0.0010	0.721	-4.4	-2.3	1170	9	1139	5	1123	6
FJF-12	141	27.5	0.00E+00	2954	0.0788	0.0004	2.0798	0.0144	0.1914	0.0011	0.749	-3.6	-1.4	1167	8	1142	5	1129	6
FJF-15	165	32.8	0.00E+00	6549	0.0775	0.0003	2.0874	0.0147	0.1953	0.0014	0.874	1.4		1135	7	1145	5	1150	7
FJF-17	192	37.5	0.00E+00	5364	0.0786	0.0003	2.0817	0.0128	0.1922	0.0011	0.769	-2.6	-0.6	1161	7	1143	4	1133	6
Åmannsbu rhyolite porphyry																			
AB-06b	1147	120.4	1.70E+00	790	0.0642	0.0007	0.9018	0.0171	0.1019	0.0010	0.922	-17.1	-11.9	748	23	653	9	626	6
AB-19	30	6	0.00E+00	754	0.0776	0.0015	2.2313	0.1268	0.2085	0.0110	0.956	8.1		1137	36	1191	40	1221	58
AB-12a	769	147.6	5.20E-01	2125	0.0777	0.0008	2.0092	0.0236	0.1875	0.0019	0.599	-3.1		1140	18	1119	8	1108	11
AB-05a	1097	218.4	3.20E-01	3895	0.0778	0.0007	2.0899	0.0212	0.1948	0.0014	0.838	0.5		1142	16	1145	7	1147	8
AB-04	74	15.2	0.00E+00	4654	0.0780	0.0008	2.1858	0.0404	0.2033	0.0034	0.908	4.5	0.1	1146	21	1177	13	1193	18
AB-08a	468	94	6.70E-02	7187	0.0783	0.0007	2.1260	0.0216	0.1971	0.0014	0.805	0.5		1154	16	1157	7	1159	7
AB-05b	522	105.3	0.00E+00	16562	0.0784	0.0006	2.1356	0.0245	0.1977	0.0017	0.74	0.6		1156	17	1160	8	1163	9
AB-07b	81	16.4	0.00E+00	1986	0.0788	0.0008	2.1579	0.0349	0.1988	0.0027	0.89	0.2		1166	20	1168	11	1169	15
AB-14a	652	133.8	0.00E+00	6798	0.0795	0.0007	2.2098	0.0221	0.2015	0.0014	0.873	-0.2		1186	16	1184	7	1183	7
AB-09a end	64	12.6	7.80E-02	1626	0.0796	0.0010	2.1324	0.0510	0.1943	0.0040	0.905	-3.9		1187	25	1159	17	1145	22
AB-01	578	118.9	2.30E-01	5302	0.0796	0.0008	2.2071	0.0234	0.2011	0.0013	0.712	-0.6		1188	20	1183	7	1181	7
AB-16	754	152	0.00E+00	13202	0.0800	0.0007	2.1803	0.0224	0.1978	0.0013	0.73	-3	-0.2	1196	17	1175	7	1163	7
AB-08b	66	14.2	2.40E+00	541	0.0813	0.0015	2.3461	0.0642	0.2094	0.0042	0.775	-0.3		1228	35	1226	19	1225	22
AB-14b	97	19.6	2.50E-01	1364	0.0839	0.0012	2.2975	0.0413	0.1986	0.0030	0.747	-10.4	-5.4	1290	25	1212	13	1168	16
AB-11b	691	138.1	0.00E+00	3093	0.0843	0.0009	2.2802	0.0265	0.1961	0.0014	0.713	-12.3	-9.6	1300	19	1206	8	1154	8
AB-17	48	9.9	1.10E+00	594	0.0877	0.0014	2.4867	0.0801	0.2056	0.0052	0.903	-13.6	-8.7	1376	30	1268	23	1205	28
Torsdalsfjell granite																			
TDF-02	925	110.2	0.00E+00	7823	0.0720	0.0005	1.1652	0.0203	0.1174	0.0017	0.937	-28.9	-26.6	986	13	784	10	716	10
TDF-03_core	1502	93.7	1.70E-01	6135	0.0691	0.0009	0.5861	0.0165	0.0615	0.0015	0.922	-59	-56.3	901	25	468	11	385	9
TDF-03_rim	2280	82.9	4.40E-01	1675	0.0672	0.0010	0.3337	0.0113	0.0360	0.0012	0.932	-74.2	-71.9	843	31	292	9	228	7
TDF-04	569	74.5	0.00E+00	7600	0.0719	0.0005	1.2651	0.0239	0.1277	0.0020	0.927	-22.4	-19.3	982	15	830	11	775	12
TDF-05	762	84.1	5.00E-02	5237	0.0696	0.0004	1.0364	0.0158	0.1081	0.0013	0.905	-29.2	-26.6	915	12	722	8	662	8
TDF-07_corr	847	92.9	1.90E-01	10350	0.0665	0.0004	0.9843	0.0171	0.1073	0.0015	0.953	-21.2	-18.7	823	13	696	9	657	9
TDF-10	1131	81.9	2.80E+00	492	0.0599	0.0006	0.5672	0.0141	0.0687	0.0010	0.936	-29.7	-22.7	601	22	456	9	428	6
TDF-11	575	56.1	0.00E+00	4837	0.0704	0.0004	0.9273	0.0138	0.0955	0.0011	0.752	-39.2	-35.9	940	12	666	7	588	6
TDF-13b	648	79.3	0.00E+00	19589	0.0709	0.0004	1.1687	0.0202	0.1195	0.0017	0.955	-25.1	-23.1	955	11	786	9	728	10
TDF-14_end	854	95	2.60E-03	7772	0.0713	0.0008	1.0768	0.0212	0.1095	0.0015	0.866	-32.4	-29	967	22	742	10	670	9
TDF-14_front	880	127.5	1.20E-03	8337	0.0726	0.0009	1.4368	0.0432	0.1435	0.0034	0.918	-14.8	-9.5	1003	23	904	18	865	19
TDF-15	2373	141.6	3.60E-01	3163	0.0639	0.0005	0.5147	0.0097	0.0584	0.0009	0.946	-51.8	-49.8	738	14	422	6	366	5
TDF-9	694	89.4	0.00E+00	4565	0.0721	0.0004	1.2575	0.0212	0.1265	0.0019	0.949	-23.6	-21.4	988	12	827	10	768	11

TDF-08	54	10.2	0.00E+00	1341	0.0857	0.0008	2.2045	0.0366	0.1867	0.0022	0.68	-18.6	-14.7	1331	16	1182	12	1103	12
TDF-12	238	44.2	0.00E+00	8733	0.0854	0.0005	2.1418	0.0347	0.1819	0.0024	0.917	-20.3	-18.1	1325	11	1162	11	1077	13
Tørdal granite																			
TD-01a	2426	314.7	5.90E-01	775	0.0784	0.0005	1.3688	0.0113	0.1267	0.0006	0.581	-35.6	-33.8	1157	13	876	5	769	3
TD-01b	3758	348.1	2.90E+00	555	0.0593	0.0012	0.7349	0.0160	0.0898	0.0019	0.808	-4.5		579	43	559	9	555	11
TD-02b	2026	286.8	2.80E+00	427	0.0689	0.0008	1.2798	0.0163	0.1348	0.0007	0.126	-9.4	-1.8	894	24	837	7	815	4
TD-03	1436	225	7.40E-01	2105	0.0698	0.0010	1.4730	0.0259	0.1530	0.0008	0.807	-0.6		923	29	919	11	918	4
TD-04	5444	539.4	7.20E-02	2242	0.0675	0.0005	0.9042	0.0080	0.0971	0.0005	0.736	-31.5	-29.2	854	15	654	4	597	3
TD-05	1930	296.5	0.00E+00	1937	0.0764	0.0006	1.5898	0.0160	0.1509	0.0008	0.933	-19.4	-18.1	1106	15	966	6	906	5
TD-08b	3743	517.4	7.80E-02	24493	0.0674	0.0005	1.2569	0.0112	0.1353	0.0007	0.935	-4	-2.3	850	15	827	5	818	4
TD-08c	3438	425.2	9.00E-02	499	0.0941	0.0008	1.5745	0.0177	0.1214	0.0010	0.895	-54	-53.1	1510	15	960	7	739	6
TD-09a	6698	641.2	2.10E+00	631	0.0637	0.0010	0.8470	0.0271	0.0964	0.0021	0.904	-19.9	-12.4	732	31	623	15	593	12
TD-11	1477	215.9	6.40E-01	2082	0.0669	0.0005	1.3170	0.0126	0.1428	0.0010	0.738	3.2		835	15	853	6	860	6
TD-14b_core	115	21.2	1.70E+00	695	0.0750	0.0009	1.8469	0.0321	0.1788	0.0021	0.805	-0.7		1067	23	1062	11	1060	11
TD-15a	1400	197.4	1.40E-01	10913	0.0669	0.0005	1.2749	0.0132	0.1382	0.0008	0.912	-0.2		836	16	835	6	834	5
TD-15b	1299	165.2	4.60E-01	2801	0.0661	0.0005	1.1328	0.0128	0.1243	0.0010	0.95	-7.2	-5.3	810	15	769	6	755	6
TD-27	473	71.4	2.30E+00	444	0.0734	0.0008	1.4577	0.0230	0.1442	0.0014	0.536	-16.2	-10.7	1024	22	913	9	868	8
TD-09b	195	60.2	0.00E+00	39842	0.1041	0.0009	4.3393	0.0533	0.3025	0.0028	0.92	0.4	.	1698	15	1701	10	1703	14
Otternes granite																			
OTT-01	567	96	1.00E+00	1163	0.0729	0.0006	1.6530	0.0159	0.1644	0.0013	0.8	-3.3	-0.4	1012	15	991	6	981	7
OTT-03a	786	144.2	1.60E+00	922	0.0741	0.0008	1.8088	0.0228	0.1771	0.0008	0.629	0.7	.	1044	21	1049	8	1051	4
OTT-03b	534	87.4	1.10E+00	1182	0.0737	0.0005	1.6098	0.0154	0.1585	0.0010	0.778	-8.7	-6.2	1032	14	974	6	949	6
OTT-04a	856	150.6	1.60E+00	967	0.0729	0.0010	1.7045	0.0165	0.1695	0.0019	0.311	-0.3	.	1012	27	1010	6	1009	11
OTT-04b	484	102.2	0.00E+00	4132	0.0799	0.0006	2.2836	0.0227	0.2072	0.0011	0.753	1.7	.	1196	14	1207	7	1214	6
OTT-04c	186	35.8	0.00E+00	2554	0.0772	0.0005	2.0065	0.0214	0.1886	0.0012	0.827	-1.2	.	1126	14	1118	7	1114	7
OTT-05	844	152.3	3.00E-01	3889	0.0760	0.0005	1.8476	0.0196	0.1763	0.0011	0.934	-4.8	-3.3	1095	14	1063	7	1047	6
OTT-06	568	116.4	3.40E-01	3085	0.0796	0.0010	2.2006	0.0328	0.2006	0.0011	0.76	-0.7		1186	23	1181	10	1179	6
OTT-07b	829	142.7	4.20E-01	2945	0.0749	0.0006	1.7353	0.0173	0.1681	0.0009	0.824	-6.5	-4.2	1066	14	1022	6	1001	5
OTT-08	1078	215.2	1.50E-01	7619	0.0779	0.0005	2.0980	0.0186	0.1955	0.0009	0.832	0.7		1143	13	1148	6	1151	5
OTT-09	762	147.8	1.70E-01	6105	0.0781	0.0006	2.0566	0.0216	0.1909	0.0010	0.927	-2.3	-0.4	1151	14	1134	7	1126	5

Italics: Analyses used to constrain the emplacement age (concordia or upper intercept age) of the granites.

Discordance: Normal discordance is indicated by negative numbers.

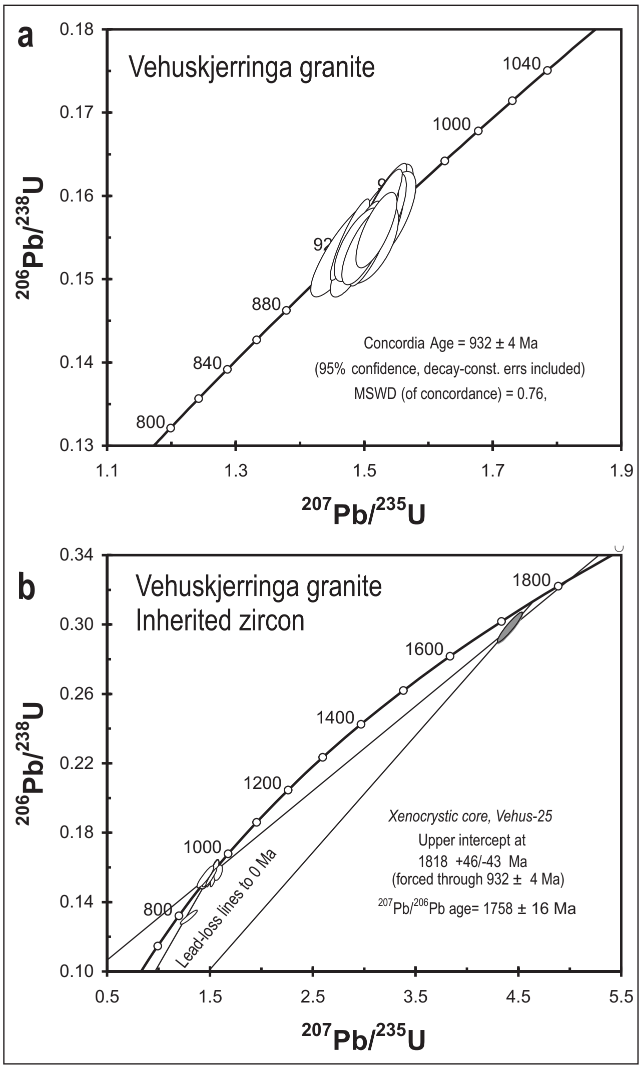

Fig. 4. Concordia diagrams for the Vehuskjerringa granite. Error ellipses for individual analyses have been plotted at 2 σ. a: The main population of concordant zircons. b: Paleoproterozoic inherited zircon, and zircon having suffered lead-loss in recent time.

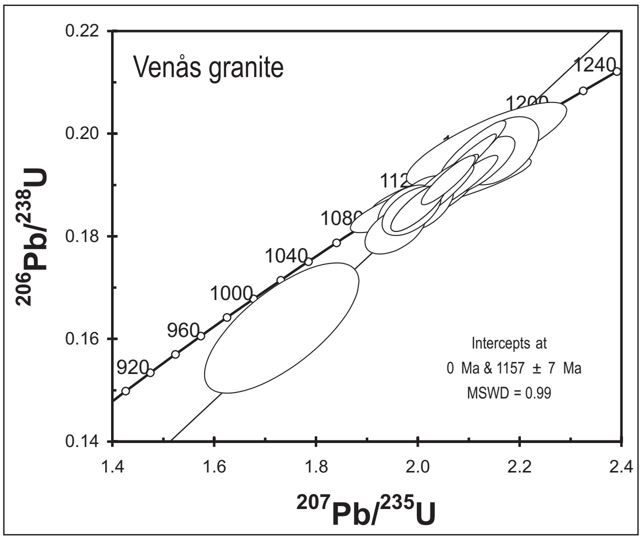

Fig. 5. Concordia diagram for the Venås granite. Error ellipses for individual analyses have been plotted at 2 σ.

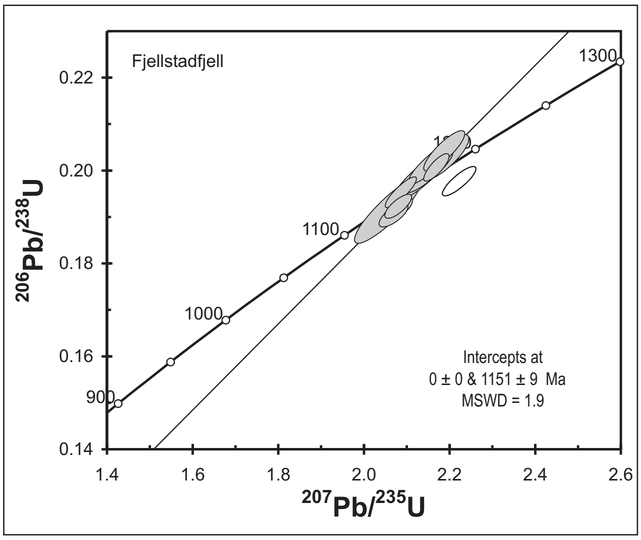

Fig. 6. Concordia diagram for the Fjellstadfjell granite. Error ellipses for individual analyses have been plotted at 2 σ. The shaded ellipses are igneous zircons giving the crystallization age of the intrusion, the white ellipse is an inherited zircon which has lost part of its radiogenic lead in the magma.

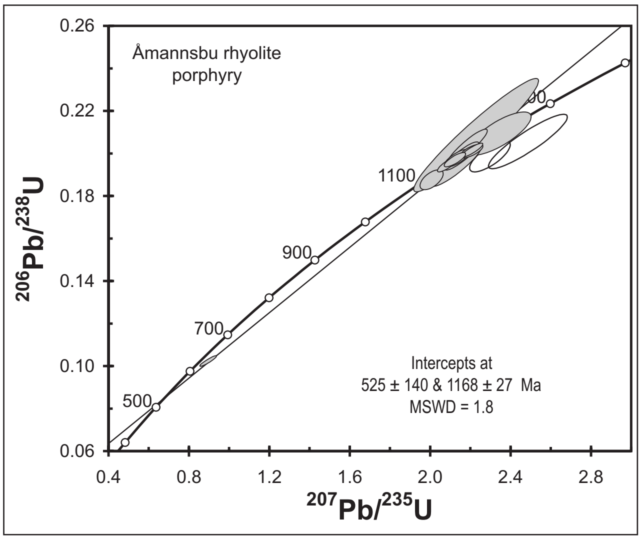

Fig. 7. Concordia diagram for the Åmannsbu rhyolite porphyry. Colour coding and plotting conventions as in Fig. 11.

ited from rocks of age similar to the Fjellstadfjell, Gunnarstul and Åmannsbu intrusions. A Paleoproterozoic, inherited zircon is concordant at 1699 ± 18 Ma (Fig. 9, inset). The remaining zircons analysed scatter widely in the diagram, and are indicated by their $^{207}Pb/^{206}Pb$ ages in Fig. 9; these zircons are obviously xenocrysts in the granite, which have lost lead in two events (when picked up by the magma, and in Paleozoic to recent time). The $^{207}Pb/^{206}Pb$ ages indicated in Fig. 9 are minimum limits for their source(s).

Zircons in the Otternes granite have a range of Sveconorwegian $^{207}Pb/^{206}Pb$ ages, from ca. 1200 Ma to below 1000 Ma, which cannot be fitted to any single lead-loss line (Fig. 10). A group of five late Sveconorwegian zircons plot

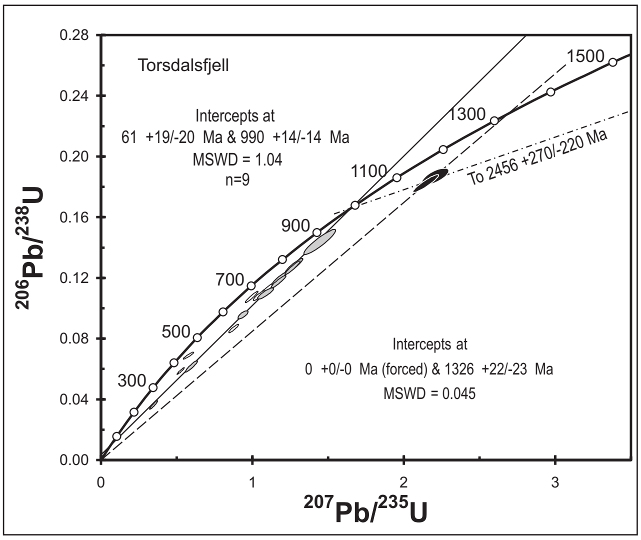

Fig. 8. Concordia diagram for the Torsdalsfjell granite. Grey ellipses are magmatic zircons plotting along a discordia line from 990 ± 14 Ma, which is the crystallization age of the intrusion. Error ellipses (±2 σ) for zircons, which were omitted from the regression, are shown with white fill. The two black ellipses are inherited zircons in the granite. These may have any age between the intercept of a recent lead-loss line at 1326 Ma, and the early Paleoproterozoic upper intercept of a discordia anchored at the crystallization age of the host granite.

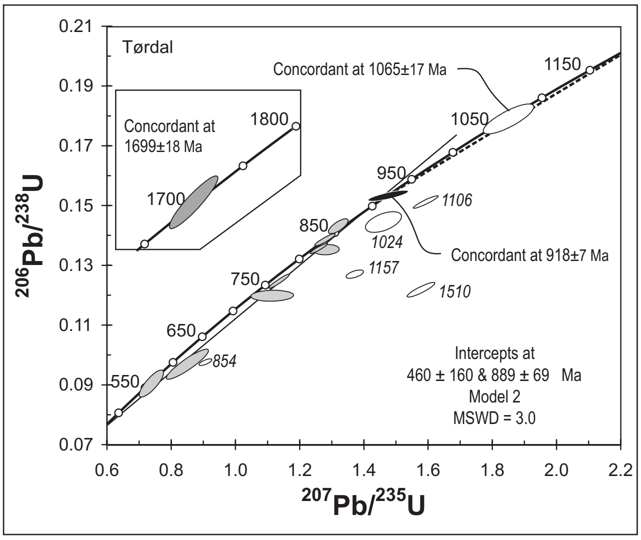

Fig. 9. Concordia diagram for the Tørdal granite. Error ellipses for individual analyses have been plotted at 2 σ. Zircons with shaded ellipses have been used to constrain a model 2 lead-loss line with upper intercept at 889 ± 69 Ma and a Paleozoic lower intercept. Strongly discordant, inherited zircons, which have probably lost lead both in the magma and in Paleozoic time, are identified by their respective $^{207}Pb/^{206}Pb$ ages. The heavy, dotted line is a lead-loss line from 1210 Ma (the age of granitic protoliths in S Telemark; Andersen et al., 2007) to the age of crystallization of the Tørdal granite.

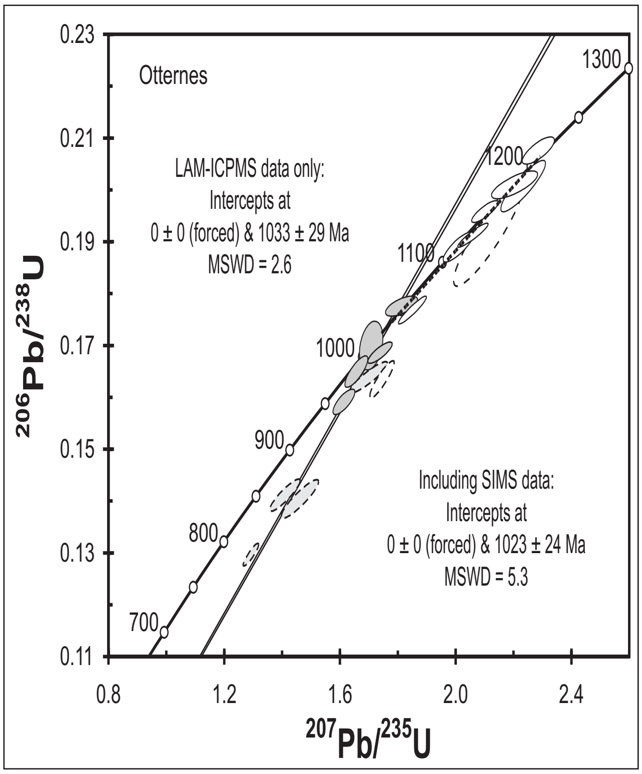

Fig. 10. Concordia diagram for the Otternes granite. The grey error ellipses represent magmatic zircons which have lost some lead in recent time, the white ellipses are inherited zircons which have lost lead in the magma. A lead-loss line has been drawn from an upper intercept at 1210 Ma to the crystallization age of the granite. SIMS analyses from Andersen et al. (2002a) are identified by broken contours.

along a recent lead loss line from 1033 ± 29 Ma. When four of the six zircons from the same sample analysed by SIMS by Andersen et al. (2002a) are included, the fit becomes worse, but the age remains constant within uncertainty at 1023 ± 24 Ma. The remaining six zircons (eight, if two SIMS analyses are included) scatter along or below the concordia between the upper intercept of this line and a point on the concordia at ca. 1200 Ma. These zircons must have been inherited from a source-rock similar in age to the early Sveconorwegian granitoids in the Vrådal-Kviteseid area (Andersen et al. 2007), and have lost variable amounts of lead when entrained in the magma. The old but imprecise (1233 ± 90 Ma) date reported for this sample by Andersen et al. (2002a) is not supported by the new data, and an interpretation of the two sets of data together suggests that zircons of two different ages were erroneously regressed together in the earlier study.

Discussion

Timing of granitic magmatism in Telemark

The zircon ages obtained in this study confirm the early start and long duration of Sveconorwegian A-type granitic magmatism in Telemark (Fig. 11). The oldest Group 2 intrusions are contemporaneous with anorogenic granites of the Gjerstad suite in the southernmost part of the Telemark block and in the Bamble-Lillesand block (Vennesla: 1166 + 61/-21 Ma, Hovdefjell: 1168 ± 2 Ma; Bingen & van Breemen 1998 and references therein) and with Sveconorwegian volcanic rocks in the Telemark block (1169 ± 3 Ma and 1159 ± 8 Ma for Nore Group and Sørjkevatn Formation by SIMS U-Pb,

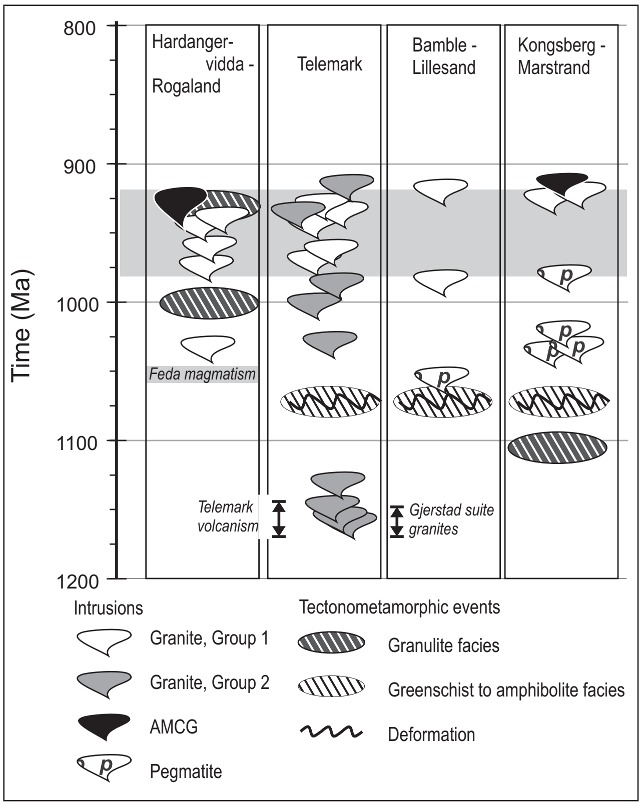

Fig. 11. Time-space diagram of Sveconorwegian A-type magmatism relative to other magmatic, metamorphic and deformational events in southwestern Fennoscandia. Horizontal, shaded bands represent the ca. 1050 Ma, subduction related Feda magmatism in the Hardangervidda-Rogaland block (Bingen & van Breemen 1998) and the main period of anorogenic magmatism across the region (this work). *Age constraints:* Anorogenic intrusions: Compilation by Andersen (2005) and the results of this study. Metamorphic and deformational events: Compilation by Andersen (2005) and references therein. Telemark volcanism: Laajoki et al. (2002) and Bingen et al. (2005) and references therein. Gjerstad suite intrusions: Bingen & van Breemen (1998). WGR: Western Gneiss Region, AMCG (Anorthosite, mangerite, charnockite, granite complexes): Schärer et al. (1996), Andersen & Griffin (2004), Scherstén et al. (2000). Pegmatites: Baadsgaard et al. (1984), Romer & Smeds (1996).

Bingen et al. 2003; 1145 to 1155 Ma by TIMS U-Pb for Brunkeberg Formation and Oftefjell, Høydalsmo and Heddal groups, Laajoki et al. 2002). With an age of 1168 ± 27 Ma, the Åmannsbu rhyolite porphyry may indeed be a subvolcanic equivalent of Sveconorwegian extrusive rhyolites. The youngest of the Group 2 intrusions so far dated are Tørdal at 918 ± 7 Ma (Fig. 9), and Bessefjell at 940 ± 19 Ma (Andersen et al. 2002a). Torsdalsfjell and Otternes have ages between these extremes, overlapping with Group 1 granites in the Hardangervidda-Rogaland block (Rosskreppfjord: 1036 ± 23 Ma, Byklom: 979 + 9/-12 Ma; Andersen et al. 2002a).

The 932 ± 4 Ma age for the Vehuskjerringa granite is within the range of emplacement ages obtained for other Group 1 granites in Telemark. It is significantly younger than the 967 ± 4 Ma age of the Vrådal granite (Andersen et al. 2007), but within error of the Tovdal (940 ± 10 Ma, Andersen et al. 2002a) and Herefoss (926 ± 8 Ma; Andersen 1997) granites. Outside of Telemark, Group 1 anorogenic intrusions emplaced in this period include the Båhus (922 ± 5 Ma Eliasson & Schöberg, 1991) and Flå (928 ± 3 Ma; Nordgulen 1999) granites. Also, the layered intrusions of the Rogaland Intrusive Complex (Schärer et al. 1996; Andersen & Griffin 2004) formed at this time. The Vehuskjerringa granite was thus emplaced near the culmination of a region-wide event of anorogenic magmatism (Fig. 11).

Sources of inherited zircons

With the exceptions of the Bandak and Tørdal granites, inherited zircons are scarce in the Sveconorwegian A-type granites dated in this study and by Andersen et al. (2002a). In Tørdal and Bandak, ca.1500 Ma or younger zircons predominate. The protosources of 1500 Ma zircons are most likely magmatic rocks coeval with or slightly younger than the Rjukan Group rhyolites. The few inherited zircons observed in the other granites in this study span an age range from Paleoproterozoic to early Sveconorwegian. Sveconorwegian zircons must have formed in older Sveconorwegian granites or in volcanic rocks. The protosource of the Paleoproterozic zircons found in Vehuskjerringa and Tørdal overlap in age with granitic rocks of the Transscandinavian Igneous Belt (Åhäll & Larson 2000), but are distinctly older than the Mesoproterozoic calc-alkaline rocks of the adjacent Kongsberg-Marstrand and Bamble-Lillesand blocks (Andersen et al. 2004a). Andersen et al. (2002b) reported non-radiogenic Hf isotope compositions ($^{176}Hf/^{177}Hf \leq 0.2819$ at 930 Ma) for presumably inherited zircons in several late Sveconorwegian granites; however, the zircons were not dated by U-Pb. The Hf isotope composition of those zircons agrees with a Paleoproterozoic crustal source, such as TIB-granitoids with initial $^{176}Hf/^{177}Hf = 0.2815$ to 0.2818 at 1670-1850 Ma (Andersen et al. 2006).

The direct source of Paleoproterozoic material involved in the petrogenesis of Sveconorwegian granites in Telemark may be Paleoproterozoic granitoids in the local, unexposed basement, or metasedimentary rocks containing a significant, but possibly far-transported component of detritus derived from such granitoids. The fact that the Sveconorwegian granites discussed here, including Vehuskjerringa (Vanden Auwera et al. 2003), have a clear A-type, rather than S-type mineralogical and geochemical character may speak against a significant contribution from sedimentary rocks to the source of granitic magma. Paleoproterozoic detrital zircons are common in Precambrian metasedimentary rocks in southern Norway, and they are nearly always accompanied by significant age populations of Mesoproterozic (ca. 1.5 Ga and/or ≤ 1.2 Ga) detrital zircons (Knudsen et al. 1997, Haas et al. 1999, Bingen et al. 2001, 2003, 2005, Andersen et al. 2004b). The age distribution of the inherited zircons in Tørdal may match the detrital zircon age pattern of Sveconorwegian metasedimentary rocks, but such potential source rocks are absent from the surroundings of that intrusion (Mitchell 1967, Dons & Jorde 1978). The Vehuskjerringa granite intruded Sveconorwegian metasupracrustal rocks, but inherited zircons are rare in that intrusion – the presence of a single, Paleoproterozic zircon among those analysed in the present study cannot be regarded as evidence of contamination by local, Sveconorwegian metasedimentary rocks.

The variations in Sr, Nd and Pb isotopes in Group 1 granites from southern Norway indicate the existence of source rocks in the unexposed crust whose crustal history goes back at least to 1600-1900 Ma (Andersen et al. 2001). The presence of Paleoproterozoic inherited zircon in late Sveconorwegian granites from Telemark adds to the evidence that the granitic magmas have formed from, or interacted with, rocks older than the oldest rocks so far recognized at the present-day surface.

Tectonic and petrogenetic significance

The ca. 250 million year long period of A-type granitic magmatism in Telemark time spans the duration of contractional tectonometamorphic events in southwestern Fennoscandia, such as the high-grade metamorphism affecting the Bamble-Lillesand and Tromøy blocks at ca. 1130 Ma (Kullerud & Dahlgren 1993, Knudsen & Andersen 1999), the subsequent thrusting of the Bamble-Lillesand and Tromøy blocks above the Telemark block at ca. 1070 Ma (Mulch 2003), and the emplacement of the orogenic Feda-suite granites in the Hardangervidda Rogaland block at ca. 1050 Ma (Bingen & van Breemen 1998). Thus, the Group 2 granites cannot have formed in response to a single and region-wide process, such as melting in an underthrusted continental slab, or postorogenic, extension-related heating (Andersson et al. 1996). The recurrent nature of A-type granitic magmatism in the region must reflect several events of anatectic melting in the deep crust, probably related to successive episodes of crustal extension and/or emplacement of mantle-derived magmas into the deep crust. The earliest of these events overlaps the anorogenic Gjerstad-suite magmatism in southern Telemark and in the Bamble-Lillesand block, and with bimodal, extension-related volcanism in Telemark, and may be another expression of the extensional tectonic regime in southwestern Fennoscandia at this time.

That granites as old as ca.1160 Ma lack a penetrative plastic deformational fabric is somewhat surprising, given that both ca.1210 Ma granitoids (Andersen et al. 2007) and ca. 1170-1145 Ma volcanic rocks (Brewer et al. 2002) in the Telemark block have undergone greenschist- to amphibolite- facies metamorphism and deformation. The reason for the lack of a deformation fabric may be the existence of lateral deformation gradients within the Telemark block, with the Venås, Fjellstadfjell and Gunnarstul granites occupying positions that coincided with a domain of low strain during the later Sveconorwegian deformation event, or that the granites were situated at a level in the crust above the brittle-ductile transition, so that they reacted to stress by fracturing and faulting rather than by ductile deformation.

In a study of Group 1 granites from the Hardangervidda-Rogaland block, Vanden Auwera et al. (2003) concluded that late Sveconorwegian A-type granitic magmas were the product of fractional crystallization of mafic parent magmas formed by melting of potassic and hydrous source rocks in the lower crust or lithospheric mantle. The source itself was thought to be no older than 1130 Ma, and was probably generated in the same event that caused the potassic, subduction-related Feda magmatism at 1050 Ma. The emplacement ages of granites from southwestern Fennoscandia summarized in Fig. 11 show that this model cannot be applied to the Group 2 granites in Telemark, or at least not to those intrusions that are significantly older than the maximum age of the anomalous source (e.g. Åmannsbu, Venås, Fjellstadfjell, Gunnarstul).

Group 2 granitic magmas could only form where suitable crustal precursors with a low-Sr character were present at depth. At the present surface, such rocks are represented by the ca. 1500 Ma Rjukan Group metarhyolites and slightly younger intrusions (Andersen et al. 2002c).

Conclusions

The LAM-ICPMS U-Pb age data from magmatic zircons in Sveconorwegian A-type granitic intrusions from the Telemark block in southern Norway indicate that Group 2 granites (characterized by < 150 ppm Sr and $^{87}Rb/^{86}Sr$ >5) were emplaced over a 250 million year period from ca. 1168 Ma to ca. 918 Ma. In contrast, Group 1 intrusions (> 150 ppm Sr and $^{87}Rb/^{86}Sr$ <5) in Telemark were emplaced in a shorter time interval, from ca. 970 Ma to ca. 925 Ma, coinciding with the climax of late Sveconorwegian A-type magmatism in southwestern Fennoscandia in general. The earliest group of granitic intrusions in eastern Telemark (1160-1150 Ma) are contemporaneous with anorogenic intrusions in southern Telemark and in the Bamble-Lillesand block (the Gjerstad suite augen gneisses) and with extension-related volcanism in Telemark (Oftefjell and Høydalsmo Groups). The early start and long duration of this magmatism in Telemark cannot be reconciled with tectonic models calling for a single tectonometamorphic process as its cause across southwestern Fennoscandia. Rather, these granites must have formed in response to recurrent crustal extension and/or emplacement of mafic, mantle-derived magmas into the lower crust.

The presence of scarce Paleoproterozoic xenocrystic zircons support indications from Sr, Pb and Nd isotopes (Andersen 1997, Andersen et al. 2001) that Paleoproterozic crustal rocks have been involved in the petrogenesis of A-type granites in the region.

Acknowledgments

Thanks are due to Gunborg Bye-Fjeld and Tulio Benites for skilled technical assistance. Arild Andresen (Oslo) and Laura S. Lauri (Helsinki) have given helpful comments on various drafts of the manuscript. We thank Bernard Bingen, Ellen Sigmond, and the recently deceased Timothy Brewer for their constructive reviews. This study has received economic support from the Department of Geosciences, University of Oslo, through the Småforsk funding program for 2006. The Isotope Geology Laboratory at the Department of Geosciences was established with support from Norwegian Research Council. This is Contribution no. 2 from the University of Oslo Isotope Geology Laboratory.

References

Åhäll, K.-I. & Larson, S. Å., 2000: Growth-related 1.85-1.55 Ga magmatism in the Baltic Shield; a review addressing the tectonic characteristics of Svecofennian, TIB 1-related, and Gothian events. *GFF 122*, 193-206.

Andersen, T. 1997: Radiogenic isotope systematics of the Herefoss granite, South Norway: an indicator of Sveconorwegian (Grenvillian) crustal evolution in the Baltic Shield. *Chemical Geology* 135, 139-158.

Andersen, T. 2005: Terrane analysis, regional nomenclature and crustal evolution in southwestern Fennoscandia. *GFF 127*, 157-166.

Andersen, T. & Griffin, W. L. 2004: Lu-Hf and U-Pb isotope systematics of zircons from the Storgangen intrusion, Rogaland Intrusive Complex, SW Norway: Implications for the composition and evolution of Precambrian lower crust in the Baltic Shield. *Lithos 73*, 271-288.

Andersen, T., Andresen, A. & Sylvester, A. G. 2001: Nature and distribution of deep crustal reservoirs in the southwestern part of the Baltic Shield: Evidence from Nd, Sr and Pb isotope data on late Sveconorwegian granites. *Journal of the Geological Society, London 158*, 253-267.

Andersen, T., Andresen, A. & Sylvester, A. G. 2002a: Timing of late- to postorogenic Sveconorwegian granitic magmatism in the Telemark and Rogaland-Vest Agder sectors, S. Norway. *Norges geologiske undersøkelse Bulletin 440*, 5-18.

Andersen, T., Griffin, W. L. & Pearson, N. J. 2002b: Crustal evolution in the SW part of the Baltic Shield: The Hf isotope evidence. *Journal of Petrology 43*, 1725-1747.

Andersen, T., Sylvester, A. G. & Andresen, A. 2002c: Age and petrogenesis of the Tinn granite, Telemark, South Norway, and its geochemical relationship to metarhyolite of the Rjukan group. *Norges geologiske undersøkelse Bulletin 440*, 19-26.

Andersen, T., Griffin, W. L., Jackson, S. E., Knudsen, T.-L. & Pearson, N. J. 2004a: Mid-Proterozoic magmatic arc evolution at the southwest margin of the Baltic Shield. *Lithos 73*, 289-318.

Andersen, T., Laajoki, K. & Saeed, A. 2004b: Age, provenance and tectonostratigraphic status of the Blefjell quartzite, Telemark sector, southern Norway. *Precambrian Research 135*, 217-244.

Andersen, T., Andersson, U. B. & Graham, S. 2006a: Hf isotope variations in Transscandinavian Igenous Belt zircons. Abstract, 27th Nordic Winter Meeting, Oulu 2006. *Bulletin of the Geological Society of Finland, Special Issue 1*, 2006, 8.

Andersen, T., Griffin, W. L. & Sylvester, A. G. 2007: Sveconorwegian underplating in southwestern Fennoscandia: LAM-ICPMS Hf isotope evidence from granites and gneisses in Telemark, southern Norway. *Lithos 93*, 273-287.

Andersson, M. Lie, J.E. & Husebye, E. 1996: Tectonic setting of post-orogenic granites within SW Fennoscandia based on deep seismic and gravity data. *Terra Nova 8*, 558-566.

Baadsgaard, H., Chaplin, C. & Griffin, W. L. 1984: Geochronology of the Gloserheia pegmatite, Froland, southern Norway. *Norsk Geologisk Tidsskrift 64*, 111-119.

Belousova, E. A., Griffin, W. L. & Reilly, S. Y. 2006: Zircon crystal morphology, trace element signatures and Hf isotope composition as a tool for petrogenetic modelling: Examples from eastern Australian granitoids. *Journal of Petrology 47,* 329-353.

Bergstøl, S. & Juve, G. 1988. Scandian ixiolite, pyrochlore and bazzite in Granite Pegmatite in Tørdal, Telemark, Norway. A contribution to the Mineralogy and Geochemistry of Scandium and Tin. *Mineralogy and Petrology 38*, 229-243.

Bingen, B. & van Breemen, O. 1998: Tectonic regimes and terrane boundaries in the high-grade Sveconorwegian belt of SW Norway, inferred from U-Pb zircon geochronology and geochemical signature of augen gneiss suites. *Journal of the Geological Society, London 155*, 143-154.

Bingen, B., Birkeland, A., Nordgulen, Ø. & Sigmond, E.M.O. 2001: Correlation of supracrustal sequences and origin of terranes in the Sveconorwegian orogen of SW Scandinavia: SIMS data on zircon in clastic metasediments. *Precambrian Research 108*, 293-318.

Bingen, B., Nordgulen, Ø., Sigmond, E. M. O., Tucker, R., Mansfeld, J. & Högdahl, K. 2003: Relations between 1.19-1.13 Ga continental magmatism, sedimentation and metamorphism, Sveconorwegian province, S Norway. *Precambrian Research 124*, 215-241.

Bingen, B., Skår, Ø., Marker, M., Sigmond, E. M. O., Nordgulen, Ø., Ragnhildstveit, J., Mansfeld, J., Tucker, R. D. & Liégeois, J.-P. 2005: Timing of continental building in the Sveconorwegian orogen, SW Scandinavia. *Norsk Geologisk Tidsskrift 85*, 87-116.

Brewer, T. S., Daly, J. S. & Åhäll, K.-I. 1998: Contrasting magmatic arcs in the Palaeoproterozoic of the south-western Baltic Shield. *Precambrian Research 92*, 297-315.

Brewer, T. S., Åhäll, K.-I., Darbyshire, D. P. F. & Menuge, J. F. 2002: Geochemistry of late Mesoproterozoic volcanism in southwestern Scandinavia: Implications for Sveconorwegian / Grenvillian plate tectonic models. Journal of the *Geological Society, London 159*, 129-144.

Carter, N. L. 1962. Petrology of the Venås granite and the surrounding rocks, east Telemark, Norway. *Norsk Geologisk Tidsskrift 42*, 45-75.

Corfu, F. 1980: U-Pb and Rb-Sr systematics in a polyorogenic segment of the Precambrian shield, central southern Norway. *Lithos 13*, 305-323.

Corfu, F., Hanchar, J. M., Hoskin, P. W. O. & Kinny, P. 2003: Atlas of zircon textures. *In* Hanchar, J.M. & Hoskin, P.W.O (eds.) Zircon. *Reviews in Mineralogy & Geochemistry 53*,. 469-500.

Dons, J. A. 1960: Telemark supracrustals and associated rocks. In Holtedahl, O. (ed.): Geology of Norway. *Norges geologiske undersøkelse 208,* 49-58.

Dons, J. A. & Jorde, K. 1978: Geologisk kart over Norge, Berggrunnskart SKIEN, M 1:250 000. *Norges geologisk undersøkelse*, Trondheim.

Eliasson, T. & Schöberg, H. 1991: U-Pb dating of the post-kinematic Sveconorwegian (Grenvillian) Bohus granite, SW Sweden: Evidence of restitic zircon. *Precambrian Research 51,* 337-350.

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

Haas, G. J. L. M. de, Andersen, T. & Vestin, J. 1999: Application of detrital zircon geochronology to assembly of a Proterozoic terrain - an example from the Baltic Shield. *Journal of Geology 107*, 569-586.

Heaman L. M. & Smalley, P. C. 1994: A U-Pb study of the Morkheia complex and associated gneisses, southern Norway - implications for disturbed Rb-Sr systems and for the temporal evolution of Mesoproterozoic magmatism in Laurentia. *Geochimica et Cosmochimica Acta 58,* 1899-1911.

Högdahl, K., Andersson, U. B. & Eklund, O. 2004: The Transscandinavian Igneous Belt (TIB) in Sweden: a review of its character and evolution. *Geological Survey of Finland Special Paper 37*, 125 pp.

Jackson, S. E., Pearson, N. J., Griffin, W. L. & Belousova, E. A. 2004: The application of laser ablation-inductively coupled plasma-mass spectrometry to in-situ U-Pb zircon geochronology. *Chemical Geology 211*, 47-69.

Killeen, P. G. & Heier, K. S. 1975: Radioelement distribution and heat production in Precambrian granitic rocks, southern Norway. *Det Norske Videnskaps-Akademi, Matematisk-Naturvitenskapelig Klasse, Skrifter, Ny serie 35*, 32 pp.

Knudsen, T.-L. & Andersen, T. 1999: Petrology and geochemistry of the Tromøy gneiss complex, south Norway, an alleged example of Proterozoic depleted lower continental crust. *Journal of Petrology 40,* 909-933.

Knudsen, T.-L., Andersen, T., Maijer, C. & Verschure, R. H. 1997: Trace element characteristics and selective elemental depletion during medium- to high-grade metamorphism of Proterozoic rocks from the Bamble sector, Southern Norway. *Chemical Geology 143*,145-169.

Koistinen, T, Stephens, M. B. Bogatchev, V. Nordgulen, Ø., Wennerström, M. & Korhonen, J. 2001: *Geological map of the Fennoscandian Shield, scale 1:2 000 000*. Geological Surveys of Finland, Norway and Sweden and the North-West Department of Natural Resources of Russia.

Kullerud, L. & Dahlgren, S. H. 1993: Sm-Nd geochronology of Sveconorwegian granulite-facies mineral assemblages in the Bamble

Shear Belt, South Norway. *Precambrian Research 64*, 389-402.

Laajoki, K., Corfu, F. & Andersen, T. 2002: Lithostratigraphy and U-Pb geochronology of the Telemark supracrustals in the Bandak-Sauland area, Telemark, South Norway. *Norsk Geologisk Tidsskrift 82,* 119-138.

Ludwig, K. R. 1998: On the treatment of concordant uranium-lead ages. *Geochimica et Cosmochimica Acta 62*, 665-676.

Ludwig, K. R. 2003: *User's manual for Isoplot 3.00. A Geochronological Toolkit for Microsoft Excel*. Berkeley Geochronology Center, Special Publication No. 4a, Berkeley, California.

Menuge, J. F. & Brewer, T. S. 1996. Mesoproterozoic anorogenic magmatism in southern Norway. *In* Brewer, T.S. (ed.). Precambrian Crustal evolution in the North Atlantic Region. *Geological Society of London Special Publication 112*, 275-295.

Mitchell R. H., 1967: The Precambrian rocks of the Telemark area in south central Norway. V The Nissedal supracrustal series. *Norsk Geologisk Tidsskrift 47*, 295-332.

Mulch, A., 2003: *Integrated high-spatial resolution $^{40}Ar/^{39}Ar$ geochronology, stable isotope geochemistry, and structural analysis of extensional detachment systems: Case studies from the Porsgrunn-Kristiansand Shear Zone (S-Norway) and the Shuswap Metamorphic Core Complex (Candada)*. Thése de Doctorat, Faculté des Sciences, Université de Lausanne, Lausanne, Switzerland, 333pp.

Nilsen, K. S. 1981: *Geologiske undersøkelser av Bessefjell- og Bandak-granittene i Vest-Telemark, deres nærliggende bergarter og mineraliseringer.* Unpublished Cand. Real. Thesis (in Norwegian), University of Oslo, 344 pp.

Nordgulen, Ø. 1999: Geologisk kart over Norge, Berggrunnskart HAMAR, M 1:250 000. *Norges geologiske undersøkelse,* Trondheim.

Nordgulen, Ø., Tucker, R. D., Sundvoll, B., Solli, A., Nissen, A. L., Zwaan, K. B., Birkeland, A. & Sigmond, E. M. O. 1997: Palaeo- to Mesoproterozoic intrusive rocks in the area between Numedal and Mjøsa, SE Norway. *In* Nordgulen, Ø., Padget, P., Robinson, P. & McEnroe, S. (eds.), *Copena Conference,* 97.131, 69-70. Norges geologiske undersøkelse, Trondheim.

Romer, R. L. & Smeds, S.-A. 1996: U-Pb columbite ages of pegmatites from Sveconorwegian terranes in southwestern Sweden. *Precambrian Research 76*, 15-30.

Schärer, U., Wilmart, E. & Duchesne, J.-C. 1996: The short duration and anorogenic character of anorthosite magmatism: U-Pb dating of the Rogaland complex, Norway. *Earth and Planetary Science Letters 139*, 335-350.

Scherstén, A., Årebäck, H., Cornell, D., Hoskin, P., Åberg, A. & Armstrong, R. 2000: Dating mafic-ultramafic intrusions by ionmicroprobing contact-melt zircon: examples from SW Sweden. *Contributions to Mineralogy and Petrology 139*, 115-125.

Sigmond, E. M. O. 1975: Geologisk kart over Norge, Berggrunnskart SAUDA, M 1:250 000. *Norges geologisk undersøkelse*, Trondheim.

Sigmond, E. M. O. 1986: The Mandal-Ustaoset line, a newly discovered major fault zone in South Norway. *In* Tobi, A.C., Touret, J.L.R. (eds.). *The deep Proterozoic crust of the North Atlantic provinces*. D. Reidel, Dordrecht, 323-331.

Sigmond, E. M. O. 1998: Geologisk kart over Norge, Berggrunnskart ODDA, M 1:250 000. *Norges geologisk undersøkelse*, Trondheim.

Sigmond, E. M. O., Gustavson, M. & Roberts, D.1984: Berggrunnskart over Norge, 1:1 million. *Norges geologiske undersøkelse*, Trondheim.

Sigmond, E. M. O., Birkeland, A. & Bingen, B. 2000: A possible basement to the Mesoproterozoic quartzites on Hardangervidda, South-central Norway: zircon U-Pb geochronology of a migmatitic gneiss. *Norges geologiske undersøkelse Bulletin 437*, 25-32.

Smalley, P. C. & Field, D. 1985: Geochemical constraints on the evolution of the Proterozoic continental crust in southern Norway (Telemark Sector). *In* Tobi, A.C., Touret, J.L.R. (eds.). *The deep Proterozoic crust of the North Atlantic provinces*. D. Reidel, Dordrecht, 551-566.

Söderlund, U. Möller, C., Andersson, J., Johansson, L. & Whitehouse, M. J. 2002: Zircon geochronology in polymetamorphic gneisses in the Sveconorwegian orogen, SW Sweden: ion microprobe evidence for 1.46-1.42 and 0.98-0.96 Ga reworking. *Precambrian Research 113,* 193-225.

Stacey, J. S. & Kramers, J. D. 1975: Approximation of terrestrial lead isotope evolution by a two-stage model. *Earth and Planetary Science Letters 26*, 207-221.

Sylvester, A. G. 1964: The Precambrian rocks of the Telemark area in south central Norway, III. Geology of the Vrådal granite. *Norsk Geologisk Tidsskrift 44*, 445-482.

Sylvester, A. G. 1998: Magma mixing, structure, and re-evaluation of the emplacement mechanism of Vrådal pluton, central Telemark, southern Norway. *Norsk Geologisk Tidsskrift 78*, 259-276.

Taylor, J. R. 1997: *An introduction to error analysis*. Second edition. University Science Books, Sausalito, California. 327 pp.

Vander Auwera, J., Bogaerts, M., Liégeois, J.-P., Demaiffe, D., Wilmart, E., Bolle, O. & Duchesne, J.C. 2003. Derivation of the 1.0-0.9 Ga ferro-potassic A-type granitoids of southern Norway by extreme differentiation from basic magmas. *Precambrian Research 124*, 107-148.

Wiedenbeck, M., Alle, P., Corfu, F., Griffin, W. L., Meier, M., Oberli, F., Von Quadt, A., Roddick, J. C. & Spiegel, W. 1995: Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses. *Geostandards Newsletter 19 (1)*, 1-23.