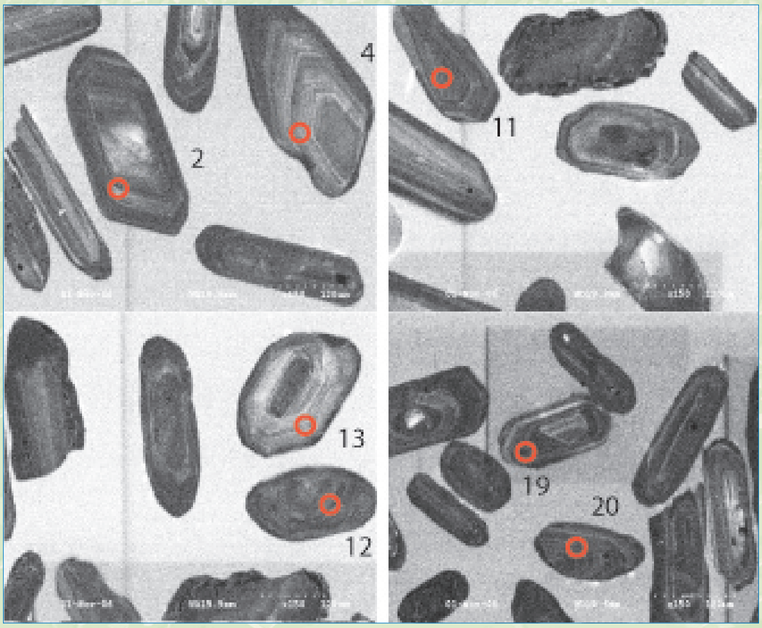
Sveriges geologiska undersökning

Results from radiometric datings and other isotope analyses 1



Fredrik Hellström & Jenny Andersson (Eds.)

SGU-rapport
2007:28

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Cover: Cathodoluminesence image of zircon from a gneissic granite in the Hudiksvall area. See paper by Bergman & Hellström (p. 10–11).

Contents

Editor's preface

Radiometric age determinations are carried out as an integral part of the bedrock mapping programme of the Geological Survey of Sweden. Results from these age determinations have previously been published in five volumes of SGU publication series C. From now on the results will be published as short notes in the report series "SGU-rapporter". This publication presents U-Pb and Sm-Nd isotopic data from different geological provinces of the Swedish Precambrian bedrock, from Norrbotten in the north to Halland in the south (see Fig. 1).

The fruitful co-operation with the Laboratory for Isotope Geology of the Swedish Museum of Natural History in Stockholm (director, Dr. Per Andersson, head of NORDSIM, Dr. Martin Whitehouse) is gratefully acknowledged.

Uppsala, 2007-10-29

Fredrik Hellström and Jenny Andersson

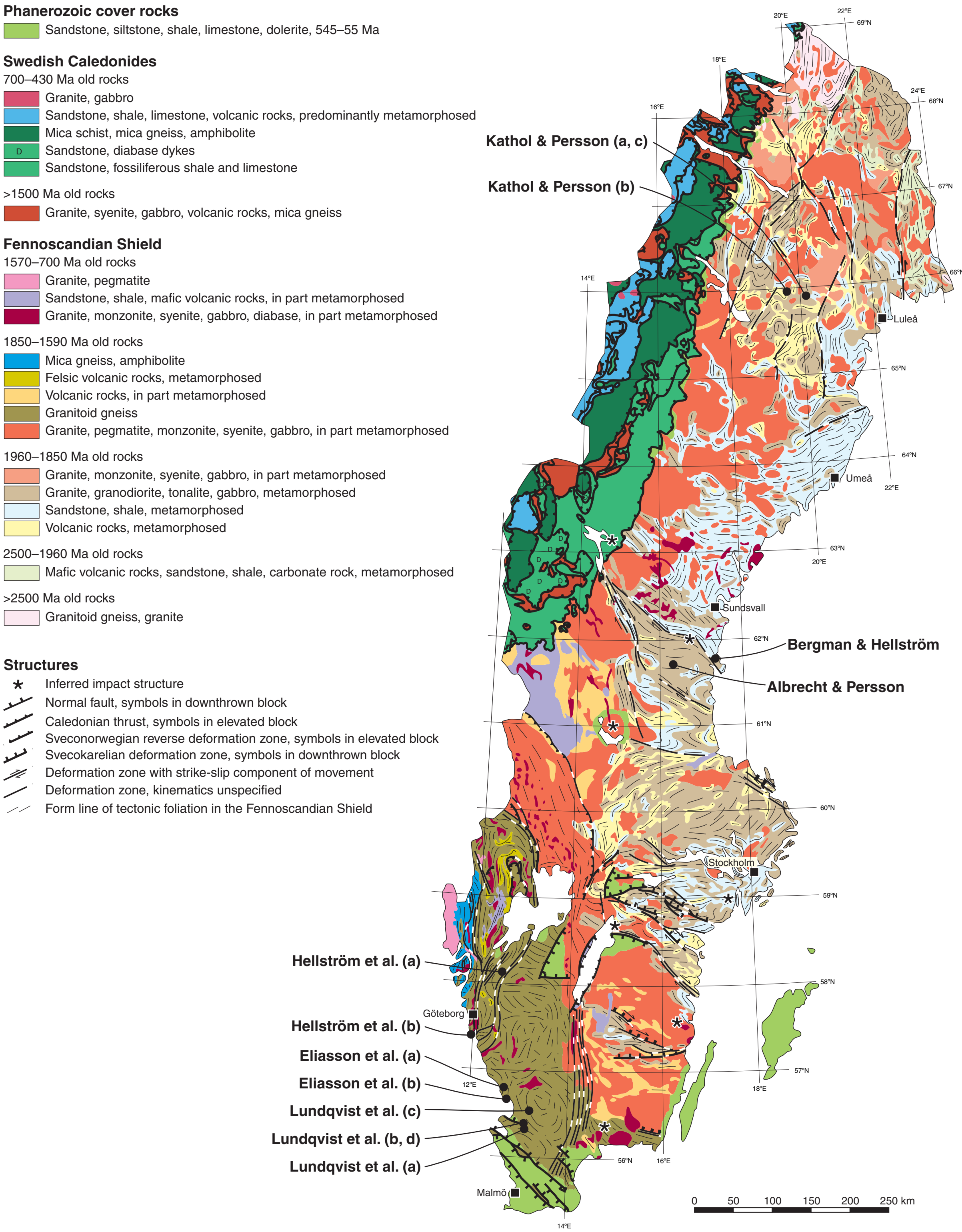

Fig. 1. Bedrock map of Sweden. The map was compiled on a commission basis from the Swedish Nuclear Fuel and Waste Management Company (SKB), and is based on the bedrock map of Sweden (Stephens et al. 1994). Location of areas within which results are presented in this publication are indicated.

Analytical methods

U-Pb TIMS zircon analysis

Analytical methods for the U-Pb datings performed at the Laboratory for Isotope Geology in Stockholm can be summarised as follows. The zircons were separated using standard magnetic and heavy liquid techniques. Most fractions were abraded according to the Krogh (1982) method. They were spiked with a ^{205}Pb-$^{233-236}U$ tracer and dissolved in HF:HNO_3 in Teflon® capsules in autoclaves according to the method of Krogh (1973). After decomposition and evaporation the samples were dissolved in 3.1N HCl and loaded onto anion exchange columns with 50 µl resin volume for extraction of Pb and U which were collected together. H_3PO_4 was added and the solution was evaporated and subsequently loaded on Re single filaments with silica gel. The isotopic ratios were measured on a Finnigan MAT 261 mass spectrometer equipped with five faraday cups. For most samples, Pb was measured in the static mode on the faraday cups. U and some small Pb samples, yielding low signals, were measured in peak jumping mode on a secondary electron multiplier. The calculation of the corrected isotope ratios and the error propagation were made using the PBDAT program of Ludwig (1991a), and the decay constants recommended by by Steiger & Jäger (1977) were used. The calculation of the intercept ages and the drawing of the concordia plot were made with the ISOPLOT-program by Ludwig (version rev 2.49, 2001). The total Pb blank was 1–5 pg (standard value 2 pg) and the U blank less than 1 pg. The assigned composition of common Pb is calculated according to the Pb evolution model of Stacey & Kramers (1975). The mass fractionation for Pb is 0.10±0.04% per a.m.u. U mass fractionation was monitored and corrected for by means of the $^{233-236}U$ ratio of the spike. All analytical errors are given as 2σ.

U-Pb SIMS zircon analysis

Zircon mineral separates were obtained from density separation of about one kg of crushed rock sample using a Wilfley water table. The magnetic minerals were removed by a hand magnet. About 100–200 hand picked crystals from each sample were cast in epoxy. The zircon mounts were polished and after gold coating examined by cathodoluminescence (CL) imaging, using standard electron microscopy at the Museum of Natural History in Stockholm, Sweden (Hitachi S-4300 electron microscope, Gatan CL 3 detector).

High-spatial resolution secondary ion mass spectrometer (SIMS) analysis was made using a Cameca IMS 1270 at the Nordsim facility at the Swedish Museum of Natural History in Stockholm. Detailed descriptions of the analytical procedures for these analyses are given in Whitehouse et al. (1999) and Whitehouse & Kamber (2005). Analytical data are given in tables attached to the individual reports. Diagrams and age calculations of isotopic data were made using software Isoplot 3.00 (Ludwig 2003). The amount of common ^{206}Pb in measured ^{206}Pb is estimated from ^{204}Pb assuming a present day terrestrial Pb following the model of Stacey & Kramers (1975). Statistical precisions of age estimates are given at the 2σ level (unless otherwise explicitly stated).

Sm-Nd TIMS whole-rock analysis

About 100 mg of sample powder was weighed out in teflon capsules and spiked with a mixed ^{149}Sm-^{150}Nd or ^{147}Sm-^{150}Nd tracer. The samples were decomposed in 2 ml suprapur concentrated HF and 20 drops of concentrated HNO_3 in autoclaves at 205 °C for 5 days. Additional treatment with nitric and hydrochloric acids and subsequent centrifugation was carried out in order to eliminate solid residues. Initial ion exchange was performed in columns filled with 3.5 ml AG50W x 8 hydrogen form resin. Samples were loaded in 1 ml 2.5N HCl and REE eluted with 6N HNO_3. During a second ion exchange procedure Sm and Nd were separated from the other REE in Ln-spec columns (Pin & Zalduegui 1997). Samples were loaded in 2 ml 0.05N HNO_3, and Nd collected in 0.25N HCl and Sm in 0.75N HCl. Finally, the purified element fractions were treated with 6N HCl, a few drops of concentrated HNO_3 and H_2O_2 on hot plates in order to remove any organic residues.

Sm and Nd were loaded on Re double filaments and analysed on a Triton thermal ionisation mass spectrometer (TIMS) from Thermo Scientific, equipped with a multi-collector. The analyses were made in the static mode. $^{143}Nd/^{144}Nd$ ratios were corrected for ^{144}Sm interference and normalised to $^{146}Nd/^{144}Nd$ = 0.7219. Errors in the measurements are given as two standard deviations of the mean from the mass spectrometer runs in the last digits.

The La Jolla Nd standard gave an average $^{143}Nd/^{144}Nd$ ratio of 0.511846±5 (2σ). The recommended value is 0.512854 and the measured data were corrected accordingly.

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U-Pb zircon geochronology of the Ljusdal metagranite, the Svecofennian Province, central Sweden

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Albrecht, L. & Persson, P.-O., 2007: U-Pb zircon geochronology of the Ljusdal metagranite, the Svecofennian Province, central Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28,* 8–9.

Rock	Ljusdal metagranite
Sample number	LAL051204
Coordinates (RT90)	6843195/1522500
Map sheet	15G NV Bollnäs
Locality	Northern Uvåsåsen
Project	Gävleborgs län, regional mapping [SGU code 1106402]

Aim of study

The aim of this study was to date igneous crystallisation of the Ljusdal granite in the Bollnäs area.

Sample description

The dated sample is a reddish-grey, coarsely K-feldspar megacrystic, foliated metagranite with finely medium-grained matrix.

Analytical results and interpretation of geochronological data

U-Pb TIMS analysis of zircon was performed at the Laboratory of Isotope geology at the Museum of Natural History, Stockholm. Analytical data are presented in Table 1. The zircon grains in the investigated metagranite are brown and mostly rounded, only few being euhedral with sharp edges and tips (Fig. 1). Most have inclusions, cracks and metamict domains and rounded cores are common. When examined under the optical microscope, crystals selected for analysis showed magmatic zonation but lacked visible cores (Fig. 1B, C, E).

Four zircon fractions were selected for analysis (Table 1 and Fig. 1). The four data points plot on the same spot in the concordia diagram, albeit close to the concordia (Fig. 2). A regression line has intercept ages of 1870±25 and 701±700 Ma, respectively. A discordia anchored at 200±400 Ma has an upper intercept age of 1858^{+9}_{-5} Ma. The analytical data indicate igneous crystallisation of the Ljusdal granite at between 1.87 Ga and 1.85 Ga.

Discussion and conclusion

Igneous crystallisation of the Ljusdal granite was dated at between 1.87 Ga and 1.85 Ga.

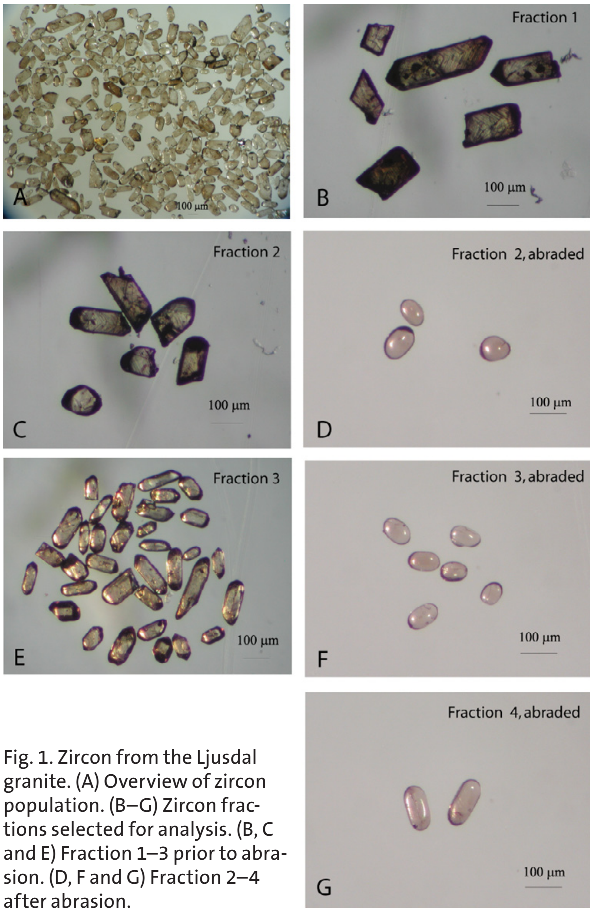

Fig. 1. Zircon from the Ljusdal granite. (A) Overview of zircon population. (B–G) Zircon fractions selected for analysis. (B, C and E) Fraction 1–3 prior to abrasion. (D, F and G) Fraction 2–4 after abrasion.

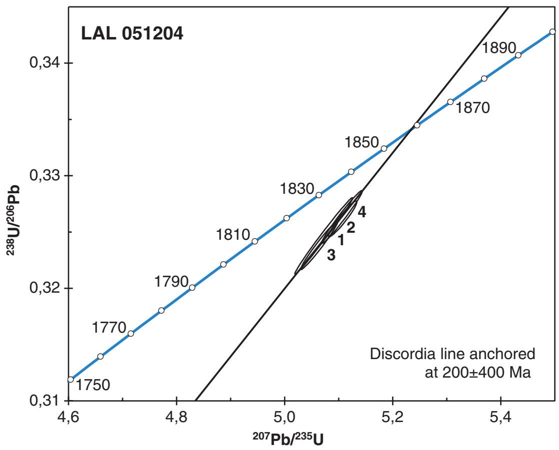

Fig. 2. Conventional U-Pb concordia diagram of zircon data from the Ljusdal metagranite. Ellipses show 2σ errors.

Table 1. U-Pb zircon data from the Ljusdal metagranite (Sample LAL051204).

Fraction	Weight (µg)	No. of crystals	U (ppm)	Th[1] (ppm)	Pb tot (ppm)	Pb com (ppm)	$^{206}Pb/^{204}Pb$[2]	^{206}Pb–^{207}Pb–^{208}Pb (At %)[3]	$^{206}Pb/^{238}U$[4]	2σ (%)	$^{207}Pb/^{235}U$[4]	2σ (%)	$^{207}Pb/^{206}Pb$[4]	2σ (%)	corr. coeff.[5]	$^{207}Pb/^{206}Pb$ Age (Ma)
1	6	1	406,1	113	136,0	0,34	11662	83.6–9.5–6.9	0,325	0,86	5,073	0,86	0,113	0,11	0,992	1853.3±2.0
2	3	3	472,6	146	160,4	0,59	7931	83.0–9.4–7.6	0,326	0,40	5,107	0,42	0,114	0,13	0,949	1857.3±2.4
3	3	5	442,5	139	149,3	0,56	7440	82.9–9.4–7.7	0,324	0,54	5,064	0,55	0,113	0,11	0,978	1854.9±2.1
4	3	2	496,9	147	169,0	1,41	4448	83.2–9.5–7.3	0,326	0,59	5,106	0,60	0,113	0,12	0,980	1855.9±2.1

1. Calculated from ^{208}Pb content. Corrected for Pb loss.
2. Corrected for mass fractionation and spike.
3. Radiogenic Pb, i.e. corrected for common Pb och blank.
4. Corrected for mass fractionation, spike, common Pb and blank.
5. Correlation coefficient between errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

The mass fractionation for Pb is 0.10 % per a.m.u.
The mass fractionation for U is calculated during measurement by monitoring the $^{233}U/^{236}U$ ratio.
Pb blank is 1–5 pg. Standard value is 2 pg.
U blank is 1 pg.

U-Pb zircon age of a gneissic granite in the Hudiksvall area, central Sweden

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Bergman, S. & Hellström, F., 2007: U-Pb zircon age of a gneissic granite in the Hudiksvall area, central Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 10–11.

Rock	Gneissic granite
Sample number	STB051046B, n2343 (Nordsim)
Coordinates (RT90)	6850560/1578825
Map sheet	16H SE Bergsjö
Locality	Könsberg, c. 11 km ENE of Hudiksvall
Project	Gävleborgs län, regional mapping [SGU code 1106402]

Aim of study

Based on field observations and geochemical data the studied gneissic granite is believed to have formed in connection with regional migmatisation. It is possibly comparable to less deformed leucogranites in the north-eastern part of Gävleborg county and the south-eastern part of Västernorrland county. Ages of 1.87–1.86 Ga are indicated for migmatisation in the Sundsvall–Härnösand area (Högdahl et al. 2006). The aim of this study was to date igneous crystallisation of the protolith and to compare this age with ages of regional migmatisation in central Sweden, for example if the granite formed during a younger migmatisation event at c. 1.82 Ga as in the south-eastern part of Gävleborg county (Högdahl et al. 2006).

Sample description

The dated sample is a pale greyish red, strongly gneissic granite with a relict porphyritic texture (Fig. 1).

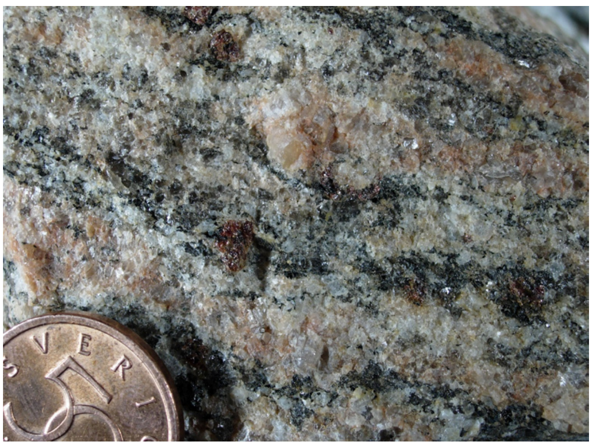

Fig. 1. The dated sample of gneissic granite from the Hudiksvall area.

Analytical results and interpretation of geochronological data

In situ U-Pb-Th SIMS analysis of zircon was performed at the NORDSIM facility at the Museum of Natural History in November 2006. The analytical results are shown in Table 1.

Zircon in the sample is generally subhedral to somewhat rounded. In CL-images most grains show distinct internal oscillatory zonation, but CL-dark unzoned rims are occasionally present (Fig. 2). A few grains have CL-light texturally older cores, possibly inherited. The U content varies between 183 and 1602 ppm and the

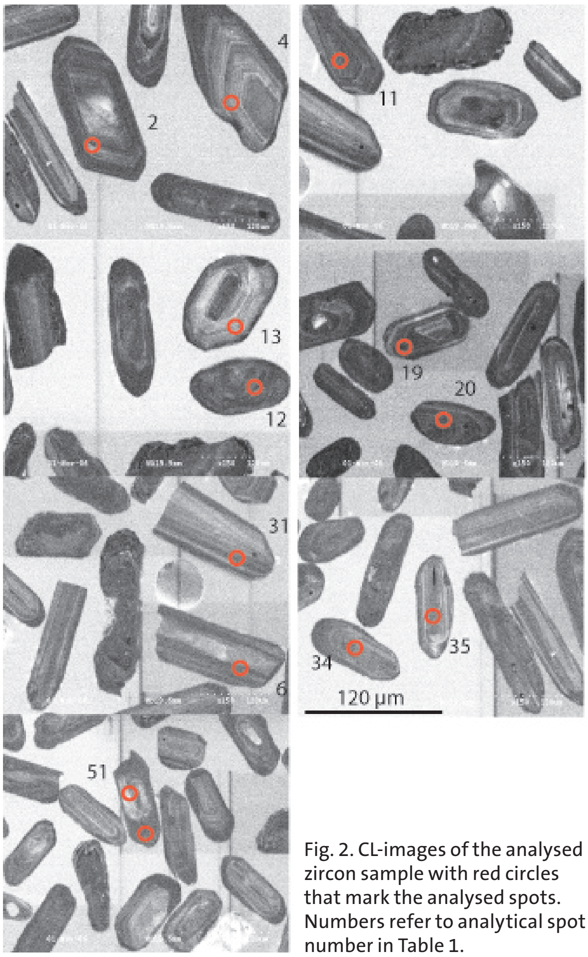

Fig. 2. CL-images of the analysed zircon sample with red circles that mark the analysed spots. Numbers refer to analytical spot number in Table 1.

Th content between 60 and 433 ppm (n=16; Table 1). Th/U ratios are 0.10–0.64.

Together, twelve concordant and two slightly reversely discordant (19c, 26c, <0.9% discordant) analyses yield a concordant age of 1868±4 Ma (2σ, MSWD=0.25, Fig. 3), identical to a $^{207}Pb/^{206}Pb$ weighted average age of 1868±4 Ma (2σ, MSWD=0.41). The analyses were aimed at undisturbed oscillatory zoned domains, except for one analysis of a CL-dark rim (51r). Another two analyses gave discordant data points (analyses 11c and 51c), among which the latter yields a significantly older $^{207}Pb/^{206}Pb$ age and indicate the presence of inherited material. The 1868±4 Ma age for principally undisturbed oscillatory zoned zircon domains are interpreted to date igneous crystallisation of the studied gneissic granite.

Discussion and conclusion

The 1868±4 Ma age (Fig. 3) for igneous crysallisation of the granitic protolith overlaps well with ages for migmatisation at between 1.87–1.86 Ga previously obtained in the Sundsvall-Härnösand area (Högdahl et al. 2006). This points to that granitic magmatism was significant during the 1.87–1.86 Ga old early phase of Svecokarelian migmatisation.

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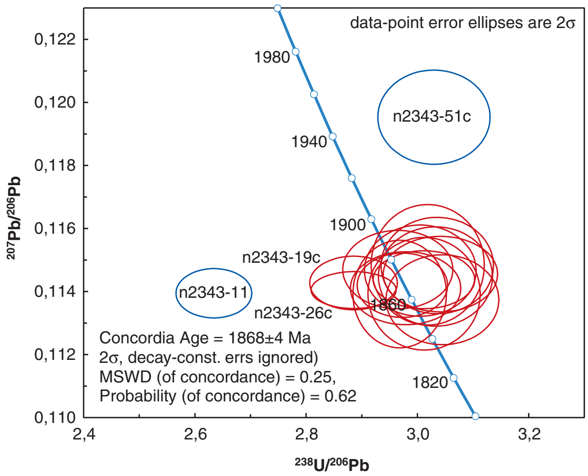

Fig. 3. Terra-Wasserburg concordia diagram. Analyses used for age-calculation are shown in red. Data point error ellipses are shown in 2σ.

Table 1. SIMS U-Pb-Th zircon data

Sample/spot #	U ppm	Pb ppm	Th/U calc	$^{206}Pb/^{204}Pb$ measured	f_{206} %	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	Disc. % 2σ lim.
n2343-02c	451	175	0.17	23293	0.08	3.005	1.37	0.11466	0.52	1875	9	1852	22	
n2343-04c	278	109	0.231	43577	0.04	3.019	1.38	0.11485	0.68	1878	12	1845	22	
n2343-04r	1115	431	0.128	94062	0.02	2.979	1.36	0.11410	0.41	1866	8	1866	22	
n2343-06c	686	258	0.091	89355	0.02	3.036	1.36	0.11482	0.54	1877	10	1836	22	
n2343-11	555	246	0.212	114163	0.02	2.634	1.06	0.11395	0.28	1863	5	2075	19	10.53
n2343-12c	718	296	0.433	53936	0.03	3.012	1.24	0.11437	0.33	1870	6	1848	20	
n2343-13cr	183	75	0.364	80910	{0.02}	2.968	1.16	0.11392	0.61	1863	11	1872	19	
n2343-19c	1102	442	0.152	161604	0.01	2.885	1.11	0.11427	0.3	1868	6	1918	19	0.39
n2343-20c	416	167	0.262	58335	0.03	2.973	1.12	0.11420	0.36	1867	7	1869	18	
n2343-26c	1602	647	0.185	88910	0.02	2.885	1.08	0.11405	0.21	1865	4	1918	18	0.87
n2343-31c	365	147	0.338	11619	0.16	3.012	1.37	0.11393	0.64	1863	12	1848	22	
n2343-34c	451	186	0.464	81555	{0.02}	3.032	1.38	0.11448	0.56	1872	10	1837	22	
n2343-35c	672	291	0.582	163797	{0.01}	2.965	1.36	0.11469	0.44	1875	8	1874	22	
n2343-38c	796	313	0.283	29753	0.06	3.041	1.38	0.11455	0.43	1873	8	1833	22	
n2343-51c	763	301	0.244	6124	0.31	3.030	1.36	0.11953	0.51	1949	9	1839	22	-3.09
n2343-51r	742	280	0.125	13451	0.14	3.045	1.36	0.11374	0.51	1860	9	1831	22	

U-Pb zircon ion-probe geochronology of a gneissic granite in the Median Segment of the eastern Sveconorwegian Province

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Rock	Gneissic granite
Sample number	FHM050024A, n2349 (Nordsim)
Coordinates (RT90)	6454510/1310710
Map sheet	8C SW, 0c Lidköping
Locality	Västmanstorp, 3 km NE of Stora Mellby
Project	Östra Göteborg (Alingsås) [SGU code: 1104501]

Aim of study

In the northern part of the Median Segment in the eastern Sveconorwegian Province there are gneissic granitoids, with granitic, granodioritic, tonalitic and quartzdioritic compositions that lack the strong migmatic banding of the surrounding migmatitic orthogneisses (Lundqvist et al. 2006). Although the original igneous fabric is penetratively recrystallised to a fine-grained texture, these rocks typically show remnants of a relict coarse to medium-grained, unequigranular to weakly porphyritic igneous texture. They are also spatially related to minor mafic intrusions with mingling-mixing relationships. Metamorphic pyroxene in these metamafic rocks suggests that this area have experienced granulite facies metamorphism.

Based on structural character and vein intensity, the c. 1.6 Ga gneisses west of the Mylonite Zone have been chronologically subdivided in older, more strongly reworked, A-type and younger, more well preserved B-type gneisses. Emplacement of the A- and B-generation of the have been interpreted to have been separated in time by a deformation and migmatisation event (Samuelsson 1985).

Since these metagranitiods in the St Mellby-Sollebrunn area lack the migmatitic vein structures typical for the A granitoids their field appearance is similar to that of 1.56 Ga B-type metagranitoids in the Göteborg area further to the west (Lundqvist 2000). The aim of this study is to date igneous crystallisation of the St Mellby metagranitoids and thereby to determine whether they are younger than surrounding more strongly reworked migmatitic granitoids or not.

Sample description

A gneiss of monzogranitic composition was collected at Västmantorp c. 3 km north of St Mellby. The sampled rock has a relict, coarse-grained and weakly porphyritic igneous texture (Fig. 1).

Analytical results and interpretation of geochronological data

U-Pb-Th SIMS analysis of zircon was performed at the NORDSIM facility at the Museum of Natural History in November 2006. The analytical results are shown in Table 1.

Zircons in the sample are subhedral to anhedral with oscillatory zoned cores surrounded by texturally younger, thin, unzoned CL-bright domains (Fig. 2). Some grains possibly also contain inherited cores. The zircon U content is generally low (<100 ppm) and Th/U ratios vary between 0.13 and 0.94 (Fig. 3). The lowest Th/U ratios are obtained in the rims, but there is a continuous range in Th/U values towards the composition of the cores (mixing of zircon domains?). One rim analysis (4r) with exceptionally high common Pb is excluded from age calculation and not included in the further discussion below.

Six analyses were aimed at oscillatory zoned core domains and these give a concordant age of 1611±8 Ma (2σ, MSWD=1.3) or a weighted average $^{207}Pb/^{206}Pb$

Fig. 1. The dated sample of gneissic granite from St Mellby.

age of 1615±20 (95% conf. interv., MSWD=9.1). One core analysis (1c) yields a lower apparent $^{207}Pb/^{206}Pb$ age. This may be due to post crystallisation isotopic disturbance such as mixing with a younger component (spot placed too close to the CL-bright rim). If this point is excluded from age calculation, the remaining five concordant core analysis yield a concordant age of 1616±9 Ma (2σ, MSWD=0.98) or a weighted average $^{207}Pb/^{206}Pb$ age of 1619±11 Ma (2σ, MSWD=1.4). Since widespread isotopic disturbance is clearly demonstrated by the younger ages of texturally younger rim domains, the concordant age of 1616±9 Ma for the five oscillatory zoned concordant core domains is suggested as the best estimate of igenous crystallisation of the St Mellby gneiss (Fig. 4).

This age also agrees with the upper intercept age of a discordia line defined by all (except analysis 4r) core and rim analyses at 1613±32 Ma (95% conf. interv., MSWD=2.4). The discordia line has a lower intercept at 524±140 Ma indicating post igneous isotopic disturbance in addition to recent Pb-loss. This isotopic disturbance is likely caused by metamorphism in late Sveconorwegian time (c. 1.0 Ga) and the discordant analyses approximately spread within a triple array of about 1615, 1000, and 0 Ma in the discordia diagram (Fig. 4B). Four of the five rim analyses are discordant and all rim analyses give younger apparent $^{207}Pb/^{206}Pb$ ages than the core domains. None of the rim analyses are concordant at the time for Sveconorwegian metamorphism. This is likely due to a combination of factors; the spots may cross cut igneous and metamorphic domains, or alternatively the secondary CL-light domains represent partially recrystallised zircon that were not entirely reset during metamorphism. Re-examination of the location of the analytical spots is, however, beyond the scope of this study and their exact position is therefore unclear.

Discussion and conclusion

Igneous crystallisation of the St Mellby gneissic granite was dated at 1616±9 Ma, and it is thus similar in age to the more strongly reworked migmatitic gneisses (the A granitoids) in the Median Segment (e.g. Scherstén et al. 2004). It can be concluded that deformation and migmatitisation of the country rock gneisses is heterogeneous and that degree of deformation can not be used as the only criteria to discriminate between different generations of gneissic intrusives. The discordant rim analyses probably represent mixing between a younger metamorphic component (Sveconorwegian) and the protolith age.

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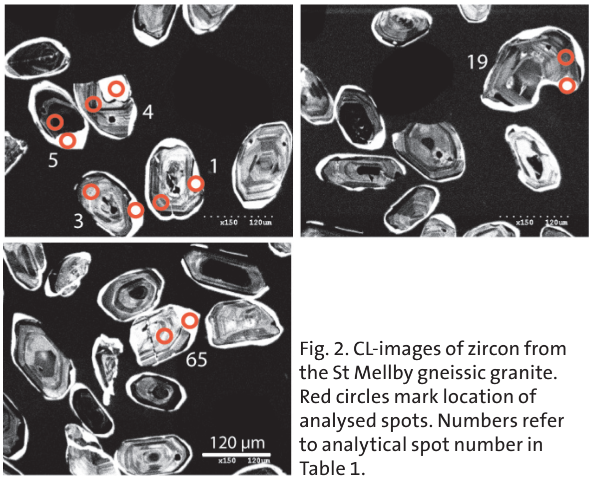

Fig. 2. CL-images of zircon from the St Mellby gneissic granite. Red circles mark location of analysed spots. Numbers refer to analytical spot number in Table 1.

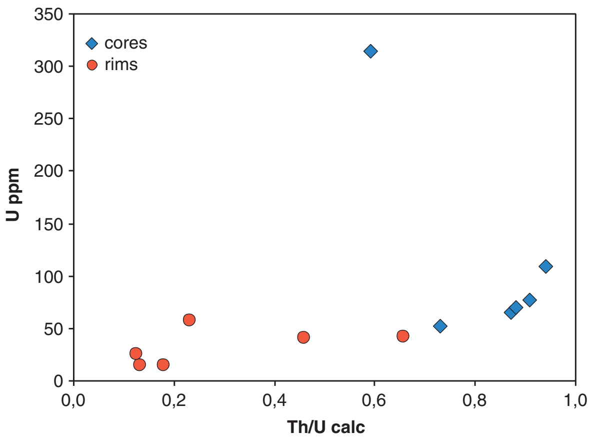

Fig. 3. U versus Th/U for analyses for analysed zircon grains.

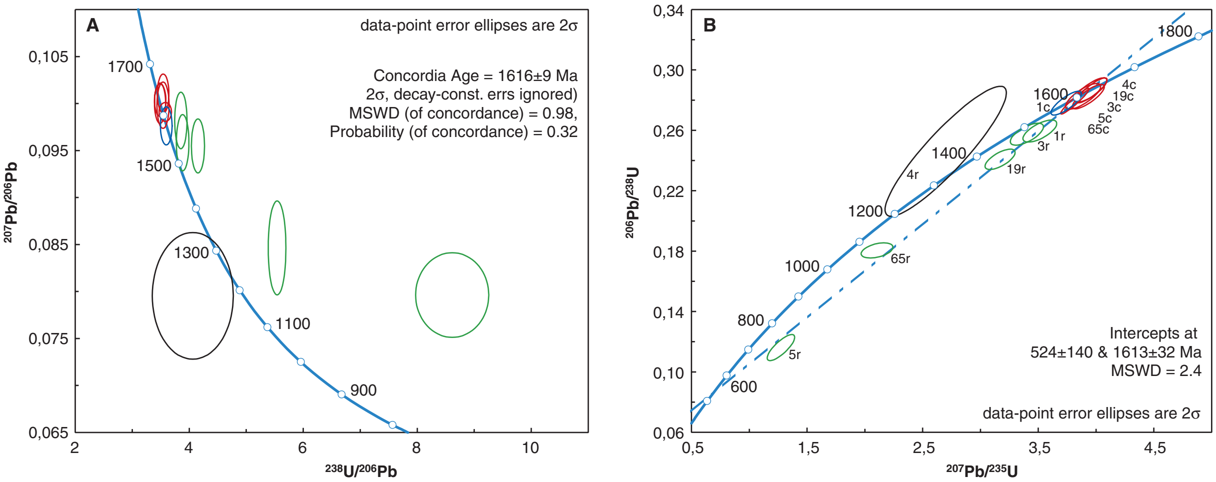

Fig. 4. Diagrams showing U-Pb SIMS data of the St Mellby gneissic granite. Core analyses used for age calculation are shown in red. Excluded core analyses (1c) shown in blue. Rim analyses shown in green. Geologically meaningless analysis with high common-Pb content shown in black. **A.** Terra Wasserburg diagram. **B.** Conventional U-Pb concordia diagram.

Table 1. SIMS U-Pb-Th zircon data from the St Mellby gneissic granite.

Sample/spot #	U ppm	Pb ppm	Th/U calc	$^{206}Pb/^{204}Pb$ measured	f_{206} %	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	Disc. % 2σ lim.
n2349-01c	70	26	0.882	27749	{0.07}	3.597	1.16	0.09762	0.85	1579	16	1581	16	
n2349-03c	52	19	0.730	37109	{0.05}	3.540	1.23	0.09982	1.01	1621	19	1604	17	
n2349-04c	109	43	0.940	20518	{0.09}	3.491	1.17	0.10034	0.70	1630	13	1624	17	
n2349-05c	314	112	0.591	102705	{0.02}	3.580	1.25	0.09911	0.41	1607	8	1588	18	
n2349-19c	77	30	0.909	43071	{0.04}	3.542	1.17	0.10106	0.84	1644	16	1603	17	
n2349-65c	65	25	0.871		{0.00}	3.488	1.14	0.10003	0.88	1625	16	1625	16	
n2349-01r	41	14	0.657	46191	{0.04}	3.853	1.15	0.09820	1.25	1590	23	1487	15	−0.7
n2349-03r	41	13	0.460	28835	{0.06}	3.884	1.16	0.09583	1.27	1544	24	1477	15	
n2349-04r	15	4	0.181	53	{35.38}	4.063	7.14	0.07954	3.46	1186	67	1419	92	
n2349-05r	25	3	0.126	3360	{0.56}	8.613	3.04	0.07962	2.31	1188	45	708	20	−28.1
n2349-19r	57	16	0.232	79680	{0.02}	4.153	1.14	0.09549	1.23	1538	23	1391	14	−4.1
n2349-65r	14	3	0.135	3874	{0.48}	5.542	1.14	0.08463	2.41	1307	46	1069	11	−6.3

U-Pb zircon ion-probe age of a gneissic granodiorite from the Onsala peninsula, south-west Sweden

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Hellström, F., Lundqvist, I. & Lundqvist, L., 2007: U-Pb zircon ion-probe age of a gneissic granodiorite from the Onsala peninsula, south-west Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 15–16.

Rock	Gneissic granodiorite
Sample number	FHM061013A, n2352 (Nordsim)
Coordinates (RT90)	6367066/1267805
Map sheet	6B SV Göteborg, 3d
Locality	Sönnerbergen, Onsala peninsula
Project	Västra Götaland (Onsala) [SGU code: 1109302]

Aim of study

On the southernmost Onsala peninsula, an unequigranular to weakly porphyritic gneissic granodiorite (Fig. 1A) show transitions to augen-bearing varieties (Fig. 1B), that resemble the 1.33 Ga Askim metagranite in adjacent areas (Austin Hegardt et al. 2007). The aim of this study was to date igneous crystallisaion of the gneissic granodiorite to determine if it belongs to the c. 1.56 Ga granitoid country rock gneisses (Lundqvist 2000) or to a younger generation of c. 1.33 Ga metagranites (Askim granite, Austin Hegardt et al. 2007).

Sample description

The sampled rock is an unequigranular to weakly porphyric gneissic granodiorite (Fig. 1). It has a relict medium-grained igneous texture, with about 0.5 cm large strung out, recrystallised aggregates of feldspar that define a shallowly WNW plunging stretching lineation (330°/30°, Fig. 1A).

Analytical results and interpretation of geochronological data

In situ U-Pb-Th SIMS analysis of zircon was performed at the NORDSIM facility at the Museum of Natural History in November 2006. The analytical results are shown in Table 1.

Zircon in the sample is long prismatic subhedral with abraded crystal faces. CL-images show oscillatory zoned cores and locally <5 µm wide, CL-bright unzoned rims (Fig. 2). The U content of the analysed zircon is 220–752 ppm and Th/U ratios vary between 0.24 and 0.45 except for analysis 14c that has about equal amounts of Th and U (Table 1).

Six concordant analyses in texturally undisturbed oscillatory zoned domains give a concordia age of 1560±7 Ma (2σ, MSWD=0.70) and a weighted average $^{207}Pb/^{206}Pb$ age of 1558±6 Ma (2σ, MSWD=2.0). One analysis (14c) slightly differs from the other analyses through its high-Th content (Th/U-ration at 1.04), low apparent $^{207}Pb/^{206}Pb$ age (1532±10 Ma) and particularly long prismatic morphology (broken crystal in Fig. 2). Excluding this weakly discordant analysis (14c), a concordia age is calculated at 1561±6 Ma (2σ, MSWD=0, Fig. 3) with an identical weighted average $^{207}Pb/^{206}Pb$ age of 1561±7 Ma (2σ, MSWD=0.53). The

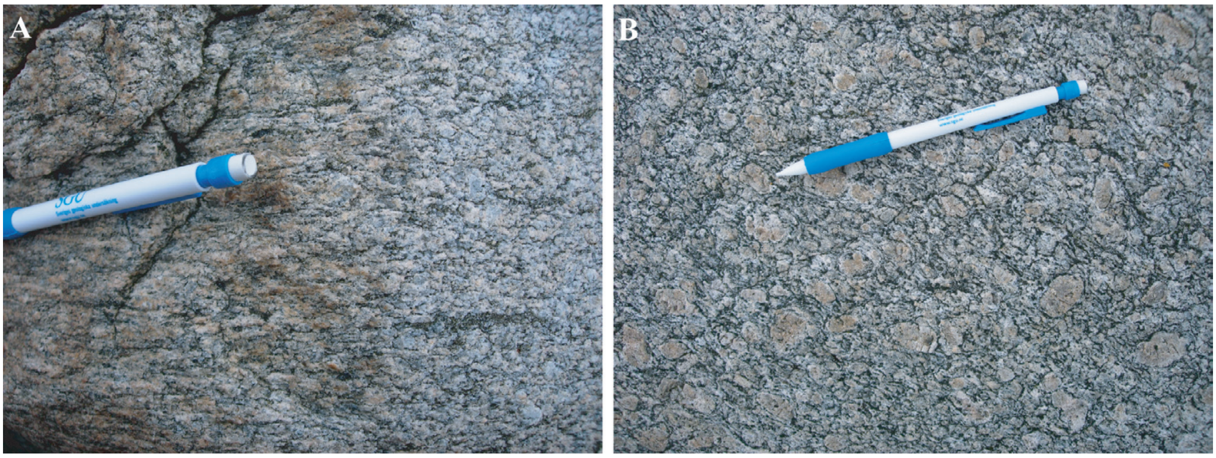

Fig. 1. **A.** The dated sample of lineated, weakly porphyric gneissic granodiorite. **B.** There are transitions to more clearly augen-bearing varieties.

data set is limited and the difference in ages between the five or six point data set is negligible. Still, the 1561±6 Ma concordant age for the five concordant analyses in oscillatory zoned zircon is here assumed as the best age estimate for igneous crystallisation of the gneissic granodiorite.

Discussion and conclusion

Igneous crystallisation of a gneissic granodiorite from the Onsala peninsula is dated at 1561±7 Ma. This age shows that it belongs to the c. 1.56 Ga old intrusions found in the western part of the Idefjorden terrane of the Sveconorwegian Province (Lundqvist 2000).

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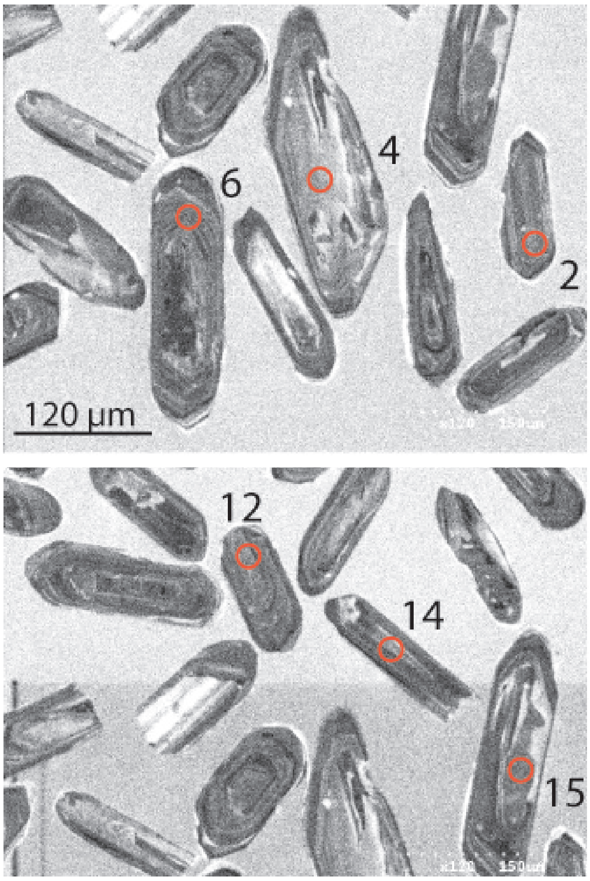

Fig. 2. CL-images of zircon from the dated gneissic granodiorite. Red circles mark location of analysed spots. Numbers refer to analytical spot number in Table 1.

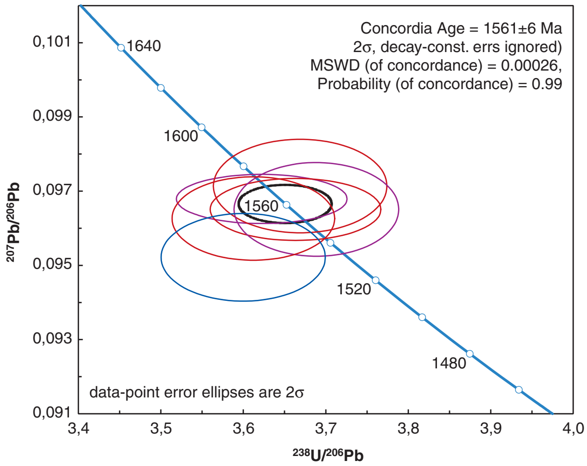

Fig. 3. Diagrams showing U-Pb SIMS data of the gneissic metagranite from the Onsala peninsula. Analysis 14 c shown in blue.

Table 1. Summary of SIMS U-Pb-Th zircon data for the gneissic granodiorite

Sample/spot #	U ppm	Pb ppm	Th/U calc	$^{206}Pb/^{204}Pb$ measured	f_{206} %	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	Disc. % conv.
n2352-6c	752	255	0.448	84569	0.02	3.622	1.17	0.09679	0.28	1563	5	1571	16	0.6
n2352-4c	220	71	0.277	28298	0.07	3.669	1.17	0.09714	0.53	1570	10	1554	16	–1.2
n2352-2c	508	169	0.423	43229	0.04	3.663	1.15	0.09651	0.35	1558	7	1556	16	–0.1
n2352-15c	503	159	0.237	21873	0.09	3.689	1.11	0.09651	0.53	1558	10	1546	15	–0.8
n2352-12c	585	194	0.341	70092	{0.03}	3.612	1.12	0.09626	0.48	1553	9	1575	16	1.6
n2352-14c	491	189	1.035	31321	0.06	3.600	1.13	0.09522	0.51	1532	10	1580	16	3.5

U-Pb zircon age of an ignimbritic rhyolite from Benbryteforsen in the area between Moskosel and Vidsel, southern Norrbotten County, Sweden

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Rock	Metarhyolite
Sample number	KBK060001X
Coordinates (RT90)	7318323/1690193
Map sheet	25J Moskosel, 3i
Locality	Benbryteforsen at river Piteälven, 25 km ENE of Moskosel
Project	Moskosel-Harads [SGU code: 1106301]

Aim of study

The volcanic sequence at Benbryteforsen consists of an intercalation of re-deposited volcanic sandstones and primary deposited volcaniclastic rhyolites, including ignimbrites (Kathol et al. 2006). Compared to well preserved, mainly felsic volcanoclastic rocks of the Arvidsjaur Group further to the south and south-west in the Arvidsjaur area (c.f. Kathol & Weihed 2005), the rocks at Benbryteforsen are locally strongly deformed and in places isoclinally folded. As the volcanic rocks at Benbryteforsen, and their continuation further to the northwest, do not have a spatial relationship to the rocks of the Arvidsjaur Group (of the Arvidsjaur area), dating of the Benbryteforsen rocks aims to clarify whether these rocks are similar in age to the Arvidsjaur Group.

Sample description

The sampled rock is an ignimbritic, sparsely feldspar-porphyritic metarhyolite (Fig. 1).

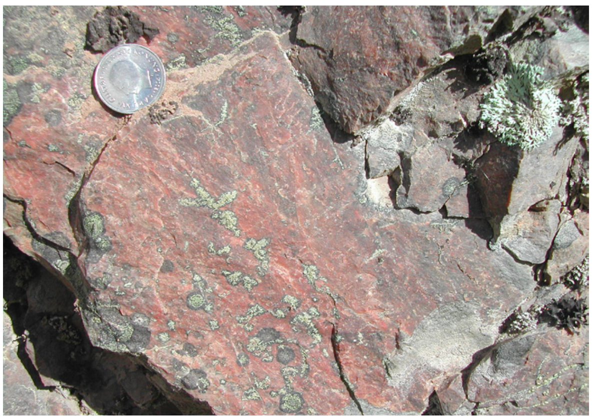

Fig. 1. Ignimbritic rhyolite, Benbryteforsen. (RT90: 7318323/1690193).

Analytical results

U-Pb TIMS zircon analysis was performed at the Laboratory of Isotope Geology at the Museum of Natural History, Stockholm. Analytical data are presented in Table 1. Zircon grains in the sample are small and short prismatic (Fig. 2). Many are euhedral with sharp edges and terminations. They are predominantly colourless but generally turbid, and only a minority is transparent. Under the optical microscope, some of them show magmatic zonation but no cores or overgrowths were observed. Due to the small grain size, crystal fractions selected for analysis were not abraded or weighed.

Five zircon fractions were selected for analysis (Table 1). The data points define a discordia line with intercept ages of 1873±30 and 64±580 Ma (MSWD=5.1). A discordia line anchored at 100±300 Ma yields an upper intercept age of 1874±13 Ma (MSWD=4.4, Fig. 3). Considering the small discordance of fraction 1, this age is chosen as the best estimate of the crystallisation age of the ignimbritic rhyolite at Benbryteforsen.

Discussion and conclusion

The 1874±13 Ma age for igneous crystallisation of the ignimbritic rhyolite at Benbryteforsen indicates that subaerial volcanic rocks has been deposited synchronously with the volcanic rocks of the Arvidsjaur Group in areas to the north of the type locality of this group.

References

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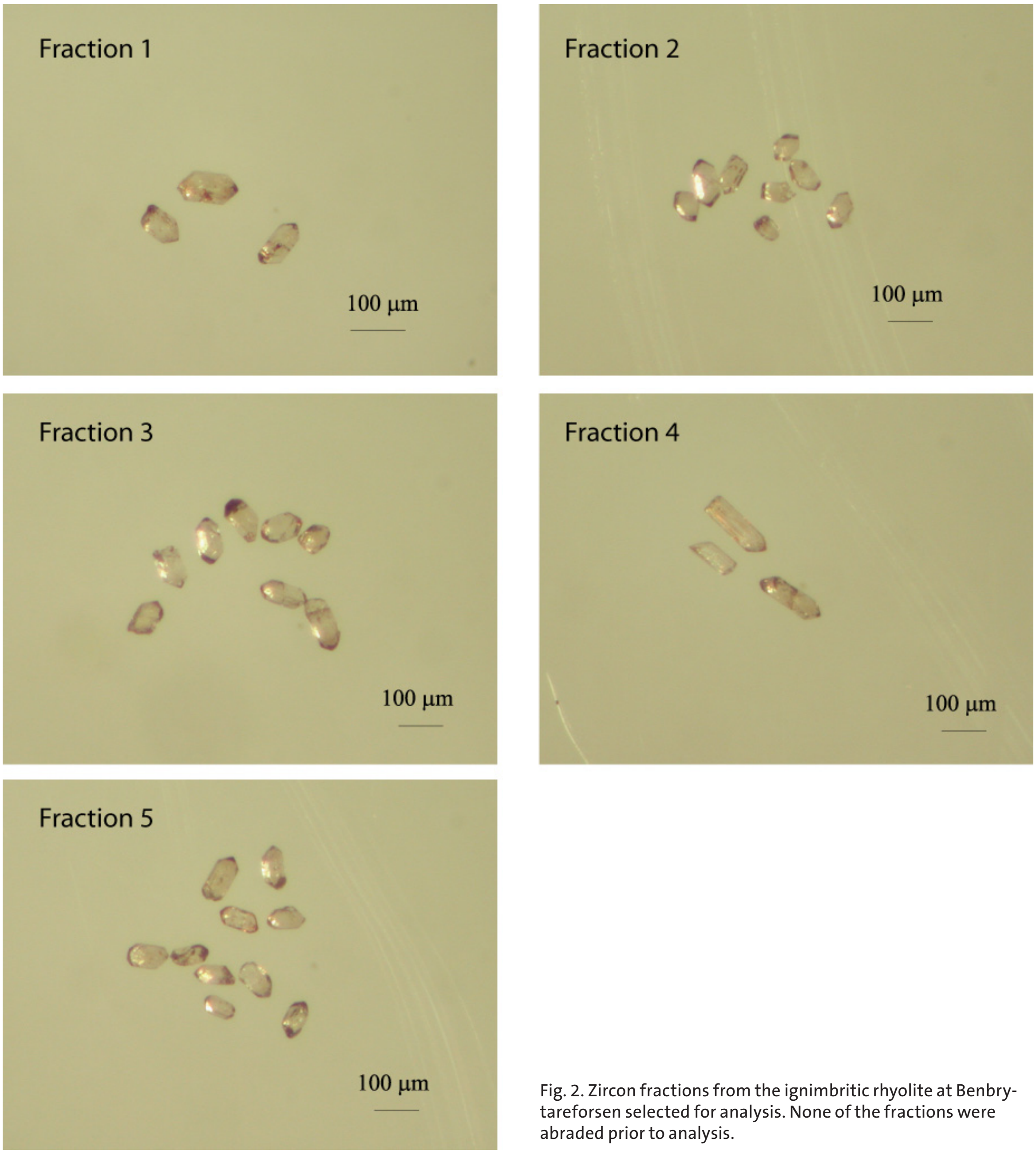

Fig. 2. Zircon fractions from the ignimbritic rhyolite at Benbrytareforsen selected for analysis. None of the fractions were abraded prior to analysis.

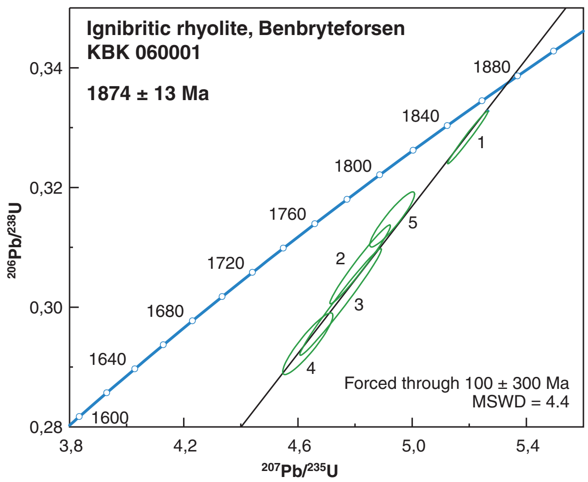

Fig. 3. Conventional U-Pb diagram of zircon data for an ignimbritic rhyolite at Benbryteforsen. Data-point error ellipses are 2σ. Numbers refer to fraction-ID in Table 1.

Table 1. U-Pb isotopic zircon data from the Benbryteforsen ignimbritic rhyolite.

Fraction	Weight (µg)	No. of crystals	U (ppm)	Th[1] (ppm)	Pb tot (ppm)	Pb com (ppm)	$^{206}Pb/^{204}Pb$[2]	$^{206}Pb–^{207}Pb–^{208}Pb$ (At %)[3]	$^{206}Pb/^{238}U$[4]	2σ (%)	$^{207}Pb/^{235}U$[4]	2σ (%)	$^{207}Pb/^{206}Pb$[4]	2σ (%)	corr. coeff.[5]	$^{207}Pb/^{206}Pb$ Age (Ma)
1	2	2	424	118	145	2	2744	83.5–9.6–6.9	0,3284	1,10	5,195	1,12	0,11474	0,18	0,987	1876±3
2	2	6	461	111	147	3	2230	84.4–9.6–6.0	0,3072	1,75	4,818	1,80	0,11376	0,39	0,976	1860±7
3	1	2	1276	310	403	12	1385	84.3–9.7–6.0	0,3009	2,42	4,750	2,46	0,11449	0,42	0,986	1872±8
4	1	2	577	223	189	10	544	81.5–9.3–9.2	0,2939	1,43	4,635	1,55	0,11437	0,64	0,912	1870±12
5	1	3	706	204	245	16	644	83.4–9.5–7.1	0,3147	1,19	4,930	1,30	0,11363	0,51	0,919	1858±9

The zircon fractions were not weighted prior to analysis (due to small grain size) and weight and isotopic concentrations are estimated values only.

1. Calculated from ^{208}Pb content. Corrected for Pb loss.
2. Corrected for mass fractionation and spike.
3. Radiogenic Pb, i.e. corrected for common Pb och blank.
4. Corrected for mass fractionation, spike, common Pb and blank.
5. Correlation coefficient for errors in $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$.

The mass fractionation for Pb is 0.10 % per a.m.u.
The mass fractionation for U is calculated during measurement by monitoring the $^{233}U/^{236}U$ ratio.
Pb blank is 1-5 pg. Standard value is 2 pg.
U blank is 1 pg.

U-Pb zircon age of a granodiorite from Övre Ljusselet in the Moskosel area, southern Norrbotten County, Sweden

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Kathol, B. & Persson, P.-O., 2007: U-Pb zircon age of a granodiorite from Övre Ljusselet in the Moskosel area, southern Norrbotten County, Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 20–22.

Rock	Granodiorite
Sample number	KBK060072X
Coordinates (RT90)	7324021/1663971
Map sheet	25J Moskosel, 4c
Locality	Övre Ljusselet at river Piteälven, 11 km NNW of Moskosel
Project	Moskosel–Harads [SGU code: 1106301]

Aim of study

Between the river Piteälven in the north and lake Malmesjaure in the south, a granodioritic to tonalitic intrusion at Övre Ljusselet shows intrusive contacts to mainly volcanoclastic rocks and redeposited volcanic sand- and siltstones (Falk 1973, C. Lundmark, SGU, pers. com.). This study aims to date the crystallsation age of the granodiorite to bracket the time interval for deposition of the volcanic succession. It also aims to evaluate the assignment of the granodiorite–tonalite intrusion to the Jörn GI suite (Kathol & Weihed 2005).

Sample description

The sampled rock is an isotropic, finely medium-grained, light grey to grey granodiorite (Fig. 1).

Fig. 1. Granodiorite at the sampling locality at Övre Ljusselet. The rock contains quartz dioritic enclaves and granitic dykes. (RT90: 7324021/1663971).

Analytical results

U-Pb TIMS analysis of zircon was performed at the Laboratory of Isotope Geology at the Museum of Natural History, Stockholm. Analytical data are presented in Table 1. Zircon in the sampled granodiorite is mostly euhedral with only low-index crystal faces although rounded and multi-faceted ones also occur (Fig. 2). The quality is generally poor and also the analysed crystals contain fractures and metamict domains. Thin overgrowths are common and rounded cores are also seen under the optical microscope. Most crystals are short prismatic but a small portion are strongly elongated (aspect ratios of 5–10). Fraction 4 consists of one elongated crystal with an aspect ratio of 7. Magmatic zonation is common and in some cases it can be difficult to distinguish secondary rims from zonation. All analysed crystals except fraction 4 were strongly abraded.

Five fractions were selected for U-Pb analysis (Table 1). A discordia through points 3–5 has concordia intercepts at 1883±34 Ma and 119±1600 Ma (MSWD=2.4; Fig. 3). The lower intercept is poorly defined and consequently, has a large error. Anchoring the discordia at a lower intercept of 100±400 Ma gives an upper intercept age of 1882±8 Ma (MSWD=1.2). Fraction 1 is less discordant than fractions 3–5 but indicates a 10 Ma younger age and probably includes secondary domains. The $^{207}Pb/^{206}Pb$ age for this analysis (fraction 1) is 1874±3 Ma, i.e. within the error limits of the 1882±8 Ma intercept age for fractions 3–5. The discordant fraction no. 2 also indicates a younger age and probably contains younger material as well, and was therefore excluded from the age calculation. The age of 1882±8 Ma is chosen as the best estimate for the crystallisation age of the granodiorite.

Discussion and conclusion

The obtained igneous crystallisation age at 1882±8 Ma for the granodiorite from Övre Ljusselet confirms the assignment of this intrusion to the Jörn GI suite of the calc-alkaline Early Svecokarelian rocks. It also sets a minimum age for the deposition of the adjacent volcanic rocks. With the aid of REE and trace element

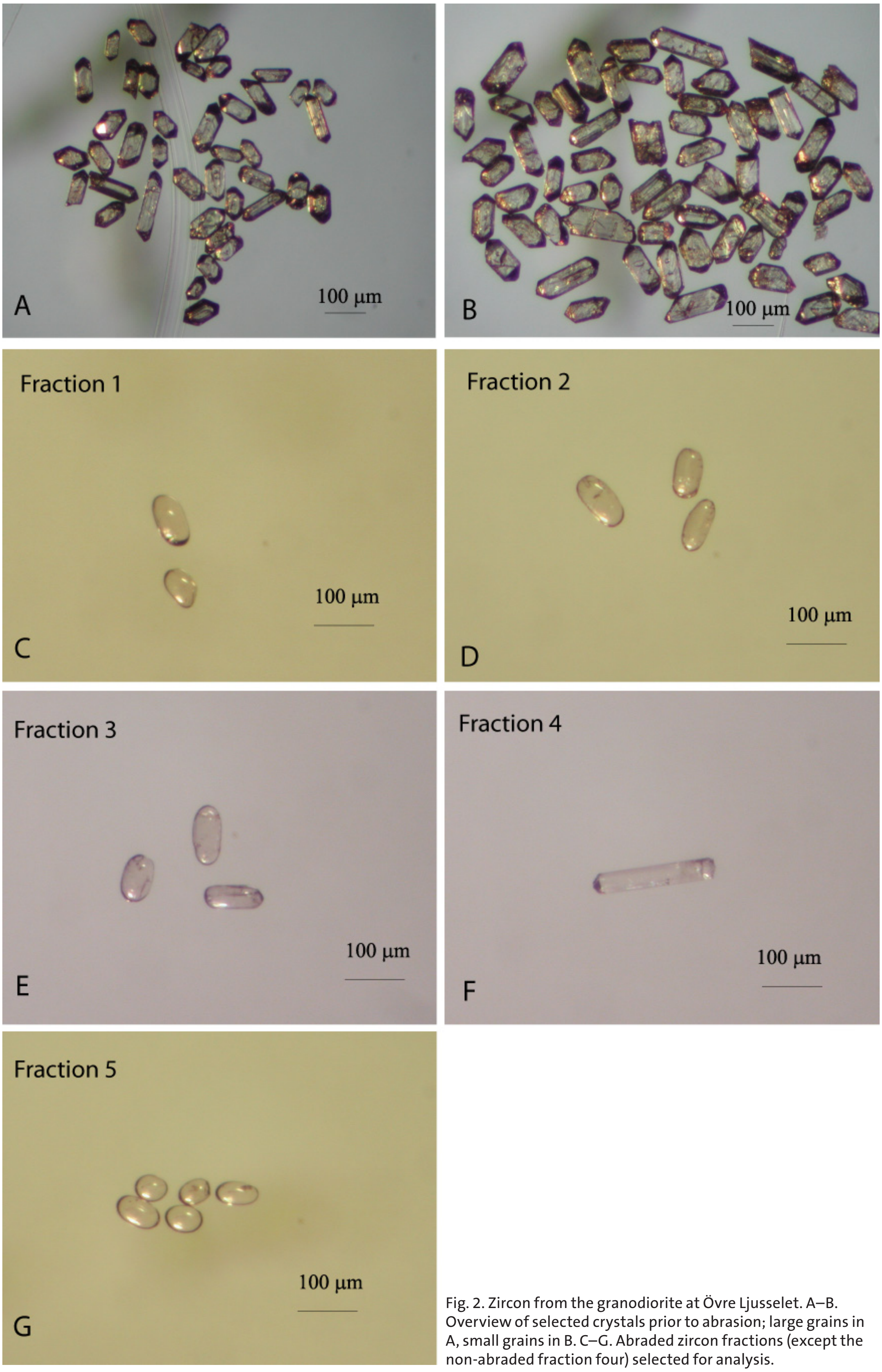

Fig. 2. Zircon from the granodiorite at Övre Ljusselet. A–B. Overview of selected crystals prior to abrasion; large grains in A, small grains in B. C–G. Abraded zircon fractions (except the non-abraded fraction four) selected for analysis.

patterns, the intrusion around Övre Ljusselet can be correlated with a granodiorite–tonalite intrusion at lake Malmesjaure. Also for this intrusion, chilled margins against a minor lens of volcaniclastic dacite have been observed. These relationships indicate that at least parts of the volcanic succession between river Piteälven and lake Malmesjaure are older than the granodiorite at Övre Ljusselet, here dated at 1882±8 Ma, which makes a direct assignment of these rocks to the 1880–1860 Ma old Arvidsjaur Group uncertain.

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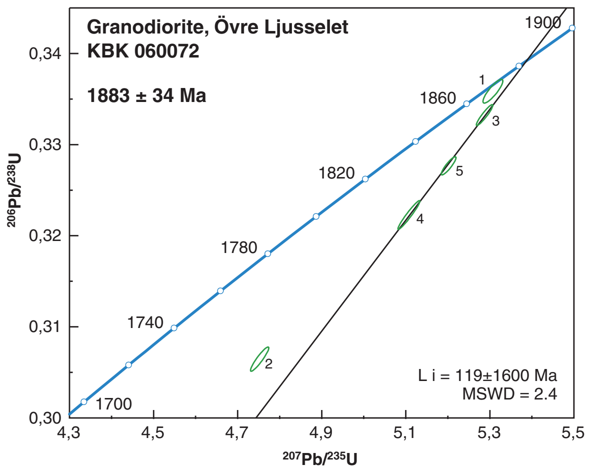

Fig. 3. Conventional U-Pb diagram of zircon data from a granodiorite at Övre Ljusselet in the Moskosel area. Data-point error ellipses are 2σ. Numbers refer to fraction-number in Table 1.

Table 1. U-Pb TIMS isotopic data for zircon from a granodiorite at Övre Ljusselet (sample KBK060072).

Fraction	Weight (µg)	No. of crystals	U (ppm)	Th[1] (ppm)	Pb tot (ppm)	Pb com (ppm)	^{206}Pb/^{204}Pb[2]	^{206}Pb–^{207}Pb–^{208}Pb (At %)[3]	^{206}Pb/^{238}U[4]	2σ (%)	^{207}Pb/^{235}U[4]	2σ (%)	^{207}Pb/^{206}Pb[4]	2σ (%)	corr. coeff.[5]	^{207}Pb/^{206}Pb Age (Ma)
1	2,0	2	194	49	68	1,5	1566	84.1–9.5–6.2	0,33586	0,32	5,30720	0,36	0,11461	0,19	0,861	1874±3
2	3,4	3	89	43	30	0,4	1752	79.5–9.0–11.5	0,30646	0,36	4,75243	0,37	0,11247	0,14	0,924	1840±2
3	3,0	3	314	93	111	3,1	1667	83.–9.6–7.2	0,33324	0,28	5,28744	0,30	0,11508	0,11	0,931	1881±2
4	2,0	1	448	175	157	4,2	1643	81.3–9.3–9.4	0,32227	0,40	5,10744	0,42	0,11494	0,11	0,962	1879±2
5	3,0	3	213	61	73	1,4	2060	83.4–9.6–7.0	0,32767	0,25	5,20192	0,27	0,11514	0,12	0,893	1882±2

The zircon fractions were not weighted prior to analysis (due to small grain size) and weight and isotopic concentrations are estimated values only

1. Calculated from ^{208}Pb content. Corrected for Pb loss.
2. Corrected for mass fractionation and spike.
3. Radiogenic Pb, i.e. corrected for common Pb och blank.
4. Corrected for mass fractionation, spike, common Pb and blank.
5. Correlation coefficient for errors in ^{206}Pb/^{238}U and ^{207}Pb/^{235}U.

The mass fractionation for Pb is 0.10 % per a.m.u.
The mass fractionation for U is calculated during measurement by monitoring the ^{233}U/^{236}U ratio.
Pb blank is 1–5 pg. Standard value is 2 pg.
U blank is 1 pg.

U-Pb zircon geochronology of a gneissic granite from Hallandsåsen, south-west Sweden

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Lundqvist, I., Hellström, F., Austin Hegardt, E. & Eliasson, T., 2007: U-Pb zircon geochronology of a gneissic granite from Hallandsåsen, south-west Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses *1. SGU-rapport 2007:*28, 23–24.

Rock	Veined, gneissic granite
Sample number	EHD050332, n2350 (Nordsim)
Coordinates (RT90)	6251746/1332696
Map sheet	4C Halmstad SE
Locality	Slätthult, 6 km S of Våxtorp
Project	Södra Halland, local mapping [SGU code: 1104301]

Aim of study

In the southernmost part of the Halland county, fault zones bound the Hallandås horst structure, which is a part of the north-west trending Tornqvist Zone (Wikman & Bergström 1987). A sample of gneissic and veined granite was selected on the horst just south of the northern bounding fault, with the objectives to investigate if the protolith- and metamorpic ages of this gneiss is similar to Eastern Segment gneisses north of the fault zone.

Sample description

The sampled rock is a veined, greyish red to reddish grey gneissic granite.

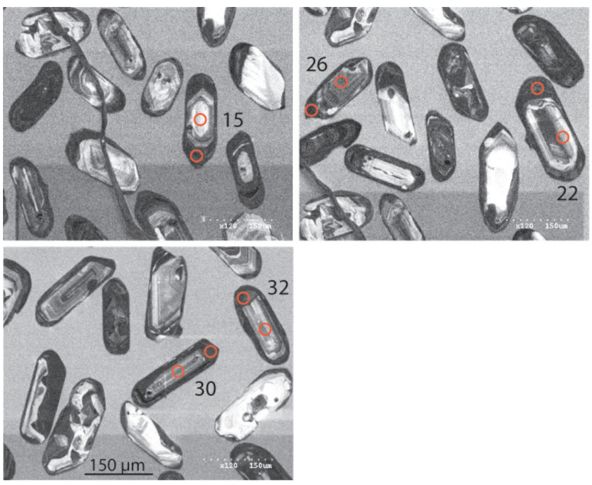

Fig. 1. CL-images of zircon from the gneissic granite. Red circles mark locations of analysed spots. Numbers refer to analytical spot number in Table 1.

Analytical results and interpretation of geochronological data

U-Pb-Th SIMS analysis of zircon was performed at the NORDSIM facility at the Museum of Natural History in November 2006. The analytical results are shown in Table 1.

Zircon in the sample is subhedral prismatic to anhedral. CL-images show oscillatory zoned cores surrounded by thin CL-dark rims and irregular embayments that in places cross-cut the oscillatory zonation (Fig. 1). The U-content of oscillatory zoned core domains are 183–540 ppm while the younger, CL-dark domains are characterised by high U contents between 910 and 2675 ppm. Th/U ratios of the cores are 0.54–1.67 whereas the secondary U-rich domains have significantly lower values at 0.03–0.15 (Fig. 2, Table 1).

Four concordant and one near concordant (22c; 1% reversely discordant) analyses in oscillatory zoned cores yield a weighted average $^{207}Pb/^{206}Pb$ age of 1687±28 Ma (95% conf. interv., MSWD=8.6, Fig. 3). The spread in analytical data does not allow calculation of a concordant age. However, one analysis (15c) records a younger age ($^{207}Pb/^{206}Pb$ age of 1620±13 Ma), that may be explained by mixing with a younger component. A concordia age based on the three remaining concordant analyses (26c, 30c and 32c), yields 1687±19 Ma (95% conf. int., MSWD=0.73; Fig. 3) and a weighted average

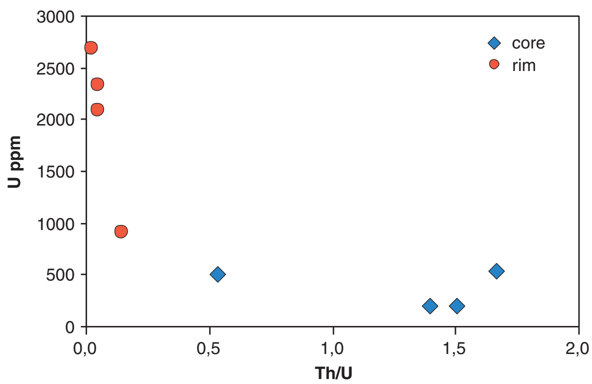

Fig. 2. U versus Th/U for analysed zircon grains.

$^{207}Pb/^{206}Pb$ age of 1686±9 Ma (2σ, MSWD=1.1). The core analyses indicate that igneous crystallisation of the granitic gneiss protolith took place at about 1.69 Ga.

Another five analyses were done at CL-dark rims (Fig. 3). Two of these points yield distinctly discordant data (26r and 32r). The data do, however, not allow definition of a discordia. This indicates a complex history of isotopic disturbance in the sample that may include both mixing with older igneous components and perhaps younger metamorphic disturbance. Three rim analyses yield concordant or almost concordant data (spot 22r is 0.8% discordant). One of these yield a significantly older apparent $^{207}Pb/^{206}Pb$ age of 1612±56 Ma. The high analytical error makes this analytical point cross-cut the discordia and it may reflect mixing with an older igneous component. The two remaining spots in secondary domains yield apparent $^{207}Pb/^{206}Pb$ ages at 1439±10 Ma (22r) and 1458±14 Ma (15r), respectively. These ages are interpreted to reflect isotopic resetting of zircon in the granitic gneiss at about 1.45 Ga, during high-grade metamorphism of the granitic protolith.

Discussion and conclusion

Igneous crystallisation of the gneissic granite is constrained at c. 1.69 Ga, similar to igneous protolith ages of Eastern Segment gneisses north of the Hallandsås fault zones (Möller et al. 2007 and references therein). Although the data set is limited, high-grade metamorphism of the gneissic granite is indicated at about 1.45 Ga, in accordance with previously published U-Pb zircon ages for pre-Sveconorwegian high-grade metamorphism in southern Sweden. The studied area thus belong to the region in the southern Eastern Segment that is affected by 1.46–1.42 Ga Hallandian high-grade metamorphism, migmatisation and veining (e.g. Söderlund et al. 2002, Möller et al. 2007).

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Söderlund, U., Möller, C., Andersson, J., Johansson, L. & Whitehouse, M., 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.

Wikman, H. & Bergström, J., 1987: Description to the map of solid rocks Halmstad SV. *Sveriges geologiska undersökning Af 133*, 79 pp.

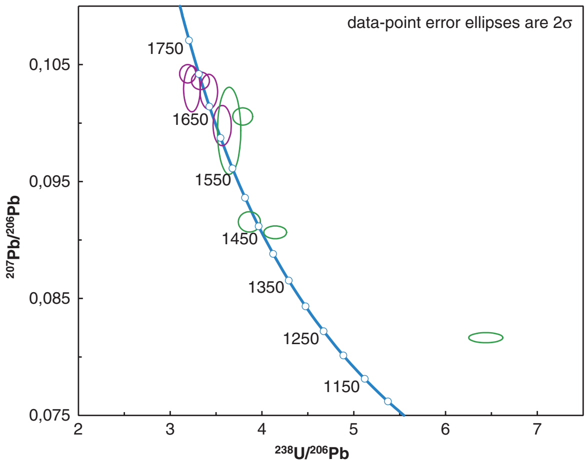

Fig. 3. Terra-Wasserburg diagram with U-Pb SIMS data for the Hallandsås gneissic granite. Analyses from oscillatory zoned cores are shown in red. Analyses in CL-dark rims are shown in green.

Table 1. SIMS U-Pb-Th zircon data for the gneissic granite.

Sample/spot #	U ppm	Pb ppm	Th/U calc	$^{206}Pb/^{204}Pb$ measured	f_{206} %	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	Disc. % 2σ lim.
n2350-15c	201	86	1.394	97766	{0.02}	3.566	1.14	0.09978	0.70	1620	13	1593	16	
n2350-32c	193	87	1.503	7434	0.25	3.421	1.14	0.10268	0.59	1673	11	1653	17	
n2350-26c	512	194	0.537	44665	0.04	3.330	1.20	0.10361	0.30	1690	5	1693	18	
n2350-22c	540	266	1.665	43399	0.04	3.191	1.14	0.10421	0.31	1700	6	1757	18	1.0
n2350-30c	183	76	0.864	1092	1.71	3.236	1.14	0.10293	0.78	1678	14	1736	17	
n2350-22r	2083	556	0.049	62182	0.03	4.144	1.23	0.09066	0.25	1439	5	1393	15	−0.8
n2350-15r	2330	667	0.051	298686	0.01	3.862	1.27	0.09155	0.39	1458	7	1484	17	
n2350-30r	1101	342	0.106	3173	0.59	3.642	1.42	0.09934	1.53	1612	28	1564	20	
n2350-32r	910	275	0.146	152972	{0.01}	3.790	1.17	0.10056	0.30	1635	6	1510	16	−6.0
n2350-26r	2675	454	0.029	23154	0.08	6.439	1.18	0.08165	0.22	1237	4	931	10	−24.5

U-Pb zircon geochronology of a gneissic granite in a WNW trending deformation zone in southern Halland, eastern Sveconorwegian Province

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Lundqvist, I., Eliasson, T., Hellström, F. & Austin Hegardt, E., 2007: U-Pb zircon geochronology of a gneissic granite in a WNW trending deformation zone in southern Halland, eastern Sveconorwegian Province. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 25–26.

Rock	Gneissic granite
Sample number	TEN050212, n2351 (Nordsim)
Coordinates (RT90)	6256556/1332145
Map sheet	4C Halmstad SE
Locality	Hedhuset, 2 km SW of Våxtorp
Project	Södra Halland, local mapping [SGU code: 1104301]

Aim of study

In the southernmost part of the Eastern Segment of the Sveconorwegian Province, WNW trending deformation zones cut NNE-NE trending gneissosity. This is evident from the aeromagnetic anomaly map, where the NNE-NE structural trend of the orthogneisses has been progressively rotated into concordance with the WNW trending shear zone. Zircon from a strongly foliated, sparsely veined gneissic granite from a WNW trending deformation zone was investigated in order to determine the age of deformation and migmatitisation in these WNW trending shear zones.

Sample desription

The dated sample is from a sparsely veined, pale reddish grey gneissic granite (Fig. 1).

Fig. 1. The dated gneissic granite.

Analytical results and interpretation of geochronological data

U-Pb-Th SIMS analysis of zircon was performed at the NORDSIM facility at the Museum of Natural History in November 2006. The analytical results are shown in Table 1.

Zircon in the sample is subhedral prismatic to rounded. CL-images show oscillatory zoned cores surrounded by CL-dark rims and irregular embayments discordantly cross-cutting into the oscillatory zoned domains (Fig. 2). A few grains have CL-bright rims (e.g. no 23 in Fig. 2). Two core and five rim domains were analysed. U-contents of the cores are 97–145 ppm and Th/U ratios are 0.61–1.00. The rims are higher in U (471–915 ppm) with distinctly lower Th/U ratios (0.005–0.070; Fig. 3, Table 1).

The two core analyses are discordant and yield apparent $^{207}Pb/^{206}Pb$ ages at 1639±44 and 1604±34 Ma,

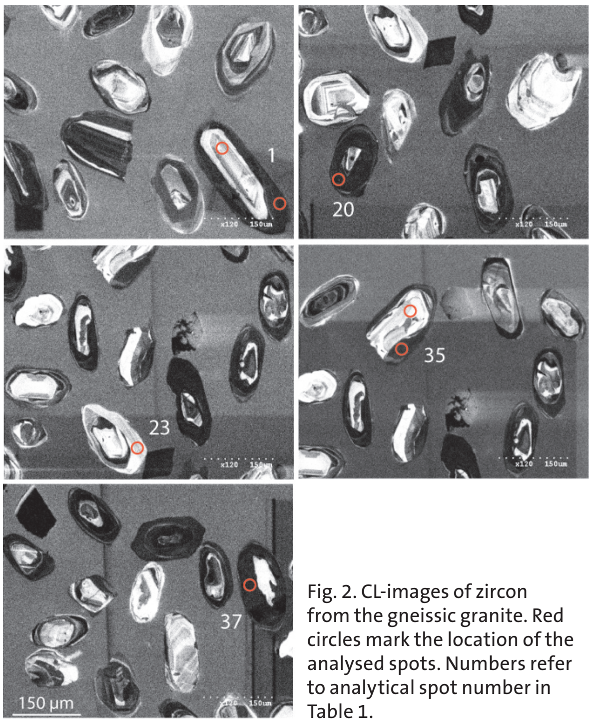

Fig. 2. CL-images of zircon from the gneissic granite. Red circles mark the location of the analysed spots. Numbers refer to analytical spot number in Table 1.

respectively (Fig. 4). The data indicate that igneous crystallisation of the granite protolith took place prior to 1.6 Ga, presumably in the range of about 1.7–1.6 Ga typical for orthogneiss protoliths in the area.

Five analyses were obtained from texturally younger CL-dark rim domains (Figs. 3 & 4). Three of these are concordant at about 1.4 Ga and yield a concordant age at 1421±7 Ma (2σ, MSWD=0.09). An additional concordant rim analysis (35r) yields an apparent $^{207}Pb/^{206}Pb$ age at 965±13 Ma. These ages most likely reflect resetting of the U-Pb isotopic zircon system during two phases of metamorphism of the granitic gneiss protolith, at 1.4 and 1.0 Ga, respectively. One rim analyis (20r) is discordant and may represent a mixture between all three zircon generations in the sample (1.7, 1.4 and 1.0 Ga).

Discussion and conclusion

Two discordant core analyses indicate a c. 1.7–1.6 Ga protolith age of the gneissic granite. It was later affected by metamorphism at about 1.42 Ga during the Hallandian orogeny (c.f. Möller et al. 2007). One analysis dated at c. 1.0 Ga shows that the gneissic granite also was affected by Sveconorwegian metamorphism, possibly related to deformation and migmatisation in the deformation zone. However, the present data are insufficient to determine the exact age of the WNW-trending ductile high-strain zone.

References

Möller, C., Andersson, J., Lundqvist, I. & Hellström, F., 2007: Linking deformation, migmatite formation and zircon U-Pb geochronology in polymetamorphic gneisses, Sveconorwegian Province, Sweden. *Journal of Metamorphic Geology 25*, 727–750.

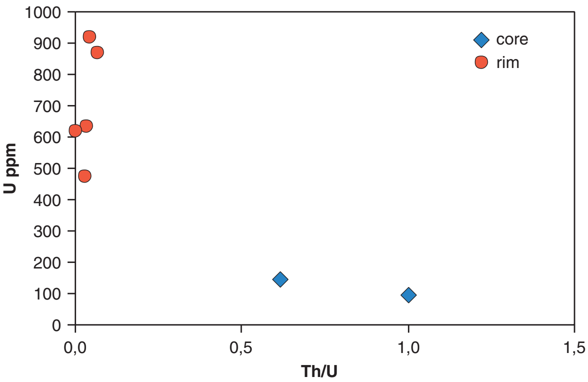

Fig. 3. U versus Th/U for analysed zircon grains.

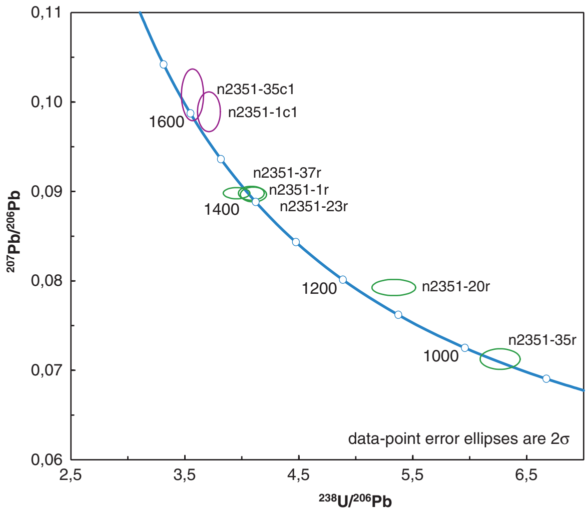

Fig. 4. Terra Wasserburg diagram showing U-Pb SIMS data for a granitic gneiss in a WNW trending shear zone in southern Halland. Analyses from oscillatory zoned cores are shown in red. Analyses in CL-dark rims are shown in green.

Table 1. SIMS U-Pb-Th zircon data for the gneissic granite.

Sample/spot #	U ppm	Pb ppm	Th/U calc	$^{206}Pb/^{204}Pb$ measured	f_{206} %	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	Disc. % 2σ lim.
n2351-1c1	145	50	0.614	36019	{0.05}	3.711	1.11	0.09891	0.92	1604	17	1538	15	
n2351-35c1	97	38	1.001		{0.00}	3.567	1.11	0.10080	1.17	1639	22	1593	16	
n2351-1r	915	255	0.049	216488	{0.01}	3.954	1.21	0.08980	0.28	1421	5	1454	16	
n2351-20r	629	129	0.038		{0.00}	5.334	1.47	0.07925	0.47	1178	9	1108	15	–2.7
n2351-23r	863	234	0.070	238550	{0.01}	4.102	1.15	0.08966	0.37	1418	7	1406	14	
n2351-35r	471	81	0.031	47875	{0.04}	6.267	1.14	0.07126	0.66	965	13	954	10	
n2351-37r	614	164	0.005	84637	{0.02}	4.084	1.14	0.08980	0.35	1421	7	1412	14	

U-Pb zircon geochronology of a metatonalite from the Laholm area in the Eastern Segment of the Sveconorwegian Province, south-west Sweden

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Lundqvist, I., Hellström, F., Austin Hegardt, E. & Eliasson, T., 2007: U-Pb zircon geochronology of a metatonalite from the Laholm area in the Eastern Segment of the Sveconorwegian Province, south-west Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 27–28.

Rock	Metatonalite
Sample number	EHD050287, n2355 (Nordsim)
Coordinates (RT90)	6267276/1341868
Map sheet	4C Halmstad SE
Locality	Vippentorpet, 12 km E of Laholm
Project	Södra Halland, local mapping [SGU code: 1104301]

Aim of study

A garnet-bearing, grey metatonalite from the Laholm area in southern Halland is less deformed than surrounding migmatitic gneisses. It exhibits no migmatitic veining, but has a strong gneissosity in its western part. This study aims at determining whether the igneous protolith of the metatonalite is younger or of the same age as that of the 1.73–1.66 Ga Eastern Segment gneisses, which dominate in the study area (e.g. Christoffel et al. 1999, Söderlund et al. 2002, Möller et al. 2007).

Sample description

The dated sample is from a dark grey, medium-grained metatonalite, garnet-bearing with strong linear fabric and metamorphosed in the amphibolite facies.

Analytical results and interpretation of geochronological data

U-Pb-Th SIMS analysis of zircon was performed at the NORDSIM facility at the Museum of Natural History in November 2006. The analytical results are shown in Table 1.

Zircon in the sample consists of subhedral grains or fragments, up to 400 µm in size. CL-images show oscillatory zoned crystals without apparent metamorphic disturbance of the zonation pattern (Fig. 1). The U contents are 106–149 ppm and Th/U ratios 0.96–0.97.

One concordant and two slightly discordant analyses (<0.9% discordant) yield a weighted average $^{207}Pb/^{206}Pb$ age of 1649±24 Ma (2σ, MSWD=0.58, Fig. 2). The data set is limited but indicates that igneous crystallisation of the metatonalite took place at about 1.7–1.6 Ga.

Discussion and conclusion

Igneous crystallisation of the metatonalite took place at 1.7–1.6 Ga and the intrusion is thus of approximately the same age as the protoliths of Eastern Segment orthogneisses. A more precise protolith age of the rock requires additional analyses.

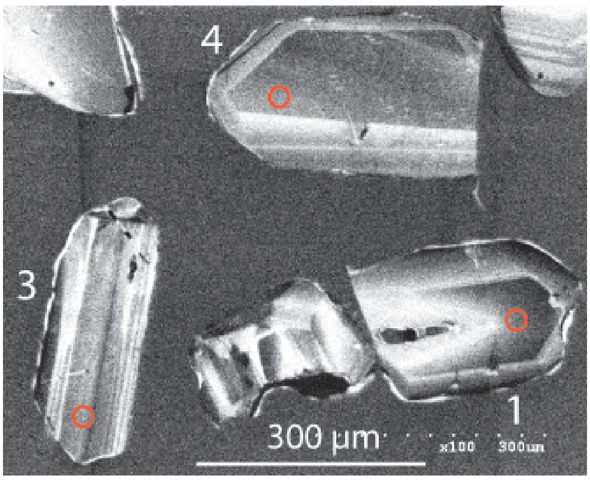

Fig. 1. CL-image of zircon from the metatonalite. Red circles mark the location of analysed spots. Numbers refer to analytical spot number in Table 1.

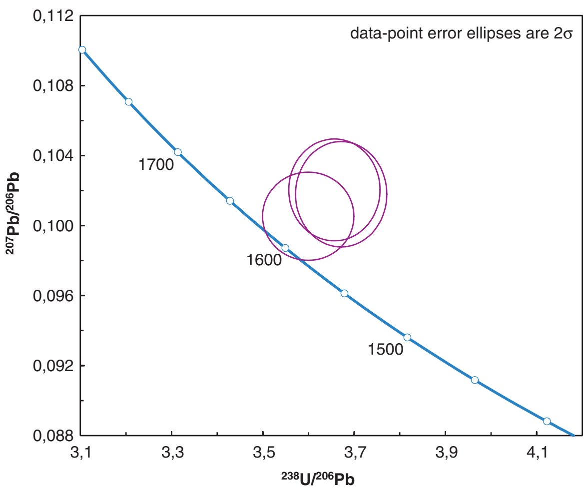

Fig. 2. Terra Wasserburg diagram showing U-Pb SIMS data for a metatonalite from the Laholm area in southern Halland.

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Table 1. SIMS U-Pb-Th zircon data from the metatonalite.

Sample/spot #	U ppm	Pb ppm	Th/U calc	$^{206}Pb/^{204}Pb$ measured	f_{206} %	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	Disc. % 2σ lim.
n2355-1c	149	58	0.972	51737	{0.04}	3.599	1.14	0.10053	1.02	1634	19	1580	16	
n2355-3c	106	41	0.966		{0.00}	3.672	1.11	0.10179	1.21	1657	22	1553	15	−0.8
n2355-4c	107	41	0.960		{0.00}	3.657	1.12	0.10204	1.17	1661	21	1558	15	−1.0

Sm–Nd analysis of a post-kinematic metadolerite in the Halmstad area in the Eastern Segment of the Sveconorwegian Province, south-west Sweden

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Eliasson, T., Lundqvist, I. & Persson, P.-O., 2007: Sm–Nd analysis of a post-kinematic metadolerite in the Halmstad area in the Eastern Segment of the Sveconorwegian Province, south-west Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28,* 29–30.

Rock	Metadolerite
Sample number	TEN050057B
Coordinates (RT90)	6283604/1314127
Map sheet	4C Halmstad NV, 6c
Locality	Grötvik, Söndrum, Quarry, 5 km WSW Halmstad
Project	Södra Halland, local mapping [SGU code: 1104301]

Aim of study

In an abandoned quarry at Grötvik some 5 km west of Halmstad an essentially undeformed dolerite dyke crosscuts the migmatitic structures of the Eastern Segment gneisses. A Sm-Nd analysis was done to estimate the approximate age of the extraction of the parental basaltic magma from a mantle reservoir and thereby get the age of the metadolerite. The age estimate will also provide information on the minimum age of the migmatisation and deformation of the host metagranite as well as the maximum age of the high-grade metamorphism affecting the dolerite.

Fig. 1. Contact between the sampled metadolerite and the reddish migmatitic granite at Grötvik, western Halmstad.

Sample description

The sample is from a dark grey, finely medium-grained, massive to weakly foliated, garnet-bearing metadolerite. The foliation is parallel with the contacts of the dyke and is interpreted to be a metamorphically accentuated flow foliation. Although the dyke is slightly curved it is essentially undeformed and crosscuts the migmatitic structures in the host rock (Fig. 1). In the southern part of the quarry the dyke is several meters thick and strikes in a north-north-west direction with a vertical to steep easterly dip (340°/80°). Towards the north the dyke narrows and it is oriented more northerly.

The metadolerite has a granoblastic texture and the metamorphic assemblage consists principally of amphibole (c. 60 vol.-%) and plagioclase (c. 30 vol.-%) with subordinate clinopyroxene (c. 2–4 vol.-%), garnet (c. 1–2 vol.-%) and opaques (c. 1–2 vol.-%). The latter are principally ilmenite and some magnetite and pyrite. Small amounts of hematite occur as lamellae in ilmenite.

Analytical results

The analytical data are shown in Table 1. The dolerite has depleted-mantle model ages of 1.8–2.0 Ga, which is older than the alleged age of the host rock. The variation of the ε_{Nd} with time is shown in Figure 2. A Sveconorwegian intrusion age of 1 Ga gives an ε_{Nd} of –2 whereas an age of 1.5 Ga gives an ε_{Nd} of +1.5.

Discussion and conclusions

Since the field relationships clearly indicate that the dolerite dyke postdates the host rock, the low ε_{Nd} values and old model ages suggest that the dolerite has been subjected to crustal contamination. It is, therefore not possible to draw conclusions about the precise intrusion age from the Sm-Nd data.

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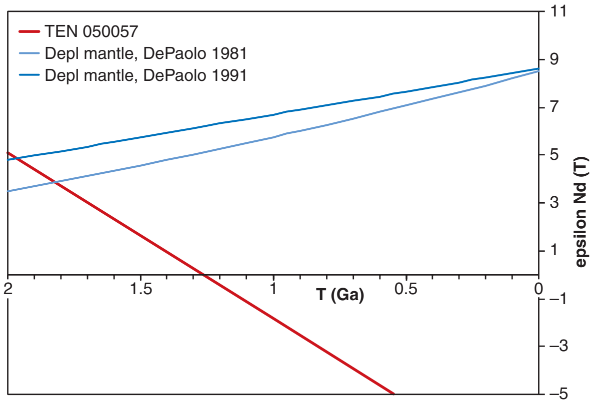

Fig. 2. ε_{Nd}–time evolution diagram for sample TEN050057B. The blue curves indicate the values for the depleted mantle, using the Sm-Nd characteristics of DePaolo (1981) and DePaolo et al. (1991).

Table 1. Sm-Nd isotopic whole-rock data.

Sample	Sm (ppm)	Nd (ppm)	$^{143}Nd/^{144}Nd$	± (2σ)	$^{147}Sm/^{144}Nd$	T_{CHUR} (Ga)	T_{DM81} (Ga)	T_{DM91} (Ga)	Age (Ga)	ε_{Nd}(T)
TEN 050057B	8.16	34.55	0.51219	0.000004	0.14281	1.29	1.83	1.97	1.400	0.92

T_{CHUR} is the model age assuming a mantle of chondritic, i.e. undepleted, mantle.
T_{DM81} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1981).
T_{DM91} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1991).

Sm-Nd analysis of a post-kinematic metadolerite in the Getinge area in the Eastern Segment of the Sveconorwegian Province, south-west Sweden

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Eliasson, T., Lundqvist, I. & Persson, P.-O., 2007: Sm–Nd analysis of a post-kinematic metadolerite in the Getinge area in the Eastern Segment of the Sveconorwegian Province, south-west Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 31–32.

Rock	Metadolerite
Sample number	TEN050214B
Coordinates (RT90)	6301910/1309470
Map sheet	5C Ullared SV, 0b
Locality	Norbjären, Bårarpåsen, Quarry, 3.5 km SW of Getinge
Project	Södra Halland, local mapping [SGU code: 1104301]

Aim of study

In the Bårarp quarry, 18 km north of Halmstad, an essentially undeformed dolerite dyke crosscuts the migmatitic structures of the Eastern Segment gneisses. Sm-Nd analysis was done to estimate the approximate age of the extraction of the parental basaltic magma from a mantle reservoir and thereby get the age of the metadolerite. The age estimate will also provide information on the minimum age of the migmatisation and deformation of the host metagranite as well as the maximum age of the high-grade metamorphism affecting the dolerite.

Sample description

The sampled dyke is about 3 m wide and is composed of a dark grey, finely medium-grained, massive, garnet-bearing metadolerite (Fig. 1). The dyke strikes to the NNE with a moderate dip to the south-east (038°/32°). It cross-cuts the migmatitic veining and gneissosity in the host granite with a low angle.

The dolerite is basically undeformed although at the margins thin selvages with mylonitic fabric occur. The metamorphic paragenesis consists principally of plagioclase (c. 40 vol.-%), amphibole (c. 20 vol.-%), garnet (c. 15 vol.-%), clinopyroxene (c. 15 vol.-%) and opaques (c. 5 vol.-%). The latter are principally ilmenite and some pyrite. Hematite occurs as thin lamellae in ilmenite.

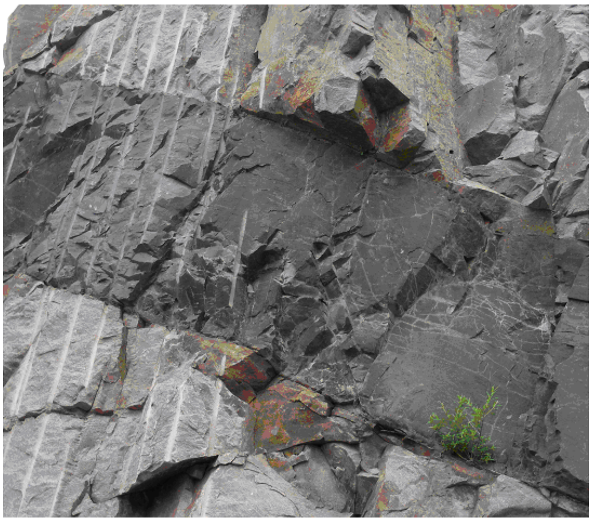

Fig. 1. The sampled flat-lying metadolerite in the Bårarp quarry. The host rock is a greyish red, fine- to medium-grained, gneissic, veined and folded granite. It is a typical "Hallandia" gneiss with red, medium-granied, winding, leucogranitic leucosome veins.

Analytical results

The analytical data are shown in Table 1. The dolerite has depleted-mantle model ages of 1.6–1.8 Ga, depending on the assumed composition of the mantle. The variation of the ε_{Nd} with time is shown in Figure 2. A Sveconorwegian intrusion age of 1 Ga gives an ε_{Nd} of 0.7, whereas an age of 1.5 Ga gives an ε_{Nd} of +3.4.

Discussion and conclusions

The depleted-mantle model ages are approximate maximum ages for the dolerite. Since those ages exceed the age of the granitic host rock, which predates the dolerite, it is obvious that the magma was subjected

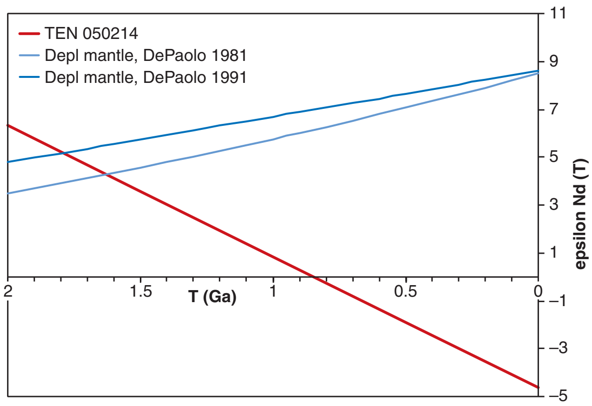

Fig. 2. ε_{Nd}–time evolution diagram for sample TEN050214B. The blue curves indicate the values for the depleted mantle, using the Sm-Nd characteristics of DePaolo (1981) and DePaolo et al. (1991).

to crustal contamination. Hence, the Sm-Nd isotopic analysis does not provide a precise determination of the intrusion age.

References

DePaolo, D.J., 1981: Neodymium isotopes in the Colorado Front Range and crust-mantle evolution in the Proterozoic. *Nature 291*, 193–196.

DePaolo, D.J., Linn, A.M. & Schubert, G., 1991: The continental crust age distribution; methods of determining mantle separation ages from Sm-Nd isotopic data and application to the Southwestern United States. *Journal of Geophysical Reseach. B, Solid Earth and Planets.* 96, 2071–2088.

Table 1. Sm-Nd isotopic whole-rock data.

Sample	Sm (ppm)	Nd (ppm)	$^{143}Nd/^{144}Nd$	± (2σ)	$^{147}Sm/^{144}Nd$	T_{CHUR} (Ga)	T_{DM81} (Ga)	T_{DM91} (Ga)	Age (Ga)	$\varepsilon_{Nd}(T)$
TEN 050214	5.14	20.07	0.512402	0.000004	0.15416	0.88	1.64	1.80	1.400	3.02

T_{CHUR} is the model age assuming a mantle of chondritic, i.e. undepleted, mantle.
T_{DM81} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1981).
T_{DM91} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1991).

Sm-Nd analysis of a felsic gneiss from Älvsborg in the area between Moskosel and Vidsel, southern Norrbotten County, Sweden

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Kathol, B. & Persson, P.-O., 2007: Sm–Nd analysis of a felsic gneiss from Älvsborg in the area between Moskosel and Vidsel, southern Norrbotten County, Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 33.

Rock	Felsic gneiss
Sample number	SPN050405L
Coordinates (RT90)	7323254/1692859
Map sheet	25J Moskosel, 4i
Locality	Älvsborg, 28 km ENE of Moskosel
Project	Moskosel-Harads [SGU code: 1106301]

Aim of study

Due to badly exposed bedrock in the Älvsborg area it could not be determined if the strong foliation of this rock is related to (1) deformation within a local, syn to post Svecokarelian deformation zone, or (2) that this gneiss occurs in several lenses which suffered underwent an older deformation phase, possibly Archaean in age.

Sample description

The sampled rock is a strongly foliated, light grey quartz-feldspar gneiss with a granodioritic normative composition (Fig. 1).

Analytical results

Sm-Nd analysis were carried out at the Laboratory of Isotope Geology, Museum of Natural History, Stockholm. The analytical results are presented in Table 1. The ^{143}Nd/^{144}Nd ratio is 0.511675±5. The model ages are 2.3 (T_{DM}) and 1.9 (T_{CHUR}) Ga. An intrusion age of 1.9 Ga produces an ε_{Nd}(T) of +0.37.

Discussion and conclusion

The Sm-Nd data indicate an Early Proterozoic origin for this gneiss. It is, however, still unclear whether the deformation is related to a local deformation zone or a more regional event. In the latter case it should be older than the undeformed granites of the 1.89–1.86 Ga old Perthite monzonite suite of the area.

Fig. 1. Felsic gneiss at Älvsborg (RT90: 7323254/1692859).

Table 1. Sm–Nd whole rock isotopic data for the gneiss from Älvsborg, southern Norrbotten.

Sample	Sm (ppm)	Nd (ppm)	^{143}Nd/^{144}Nd	± (2σ)	^{147}Sm/^{144}Nd	T_{CHUR} (Ga)	T_{DM91} (Ga)	Age (Ga)	ε_{Nd}(T)
SPN 050405	3.60	18.42	0.511675	0.000005	0.11809	1.86	2.28	1.900	0.37

T_{CHUR} is the model age assuming a mantle of chondritic, i.e. undepleted, mantle.
T_{DM81} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1981).
T_{DM91} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1991).

Sm-Nd analysis of a dolerite north of Hallandsåsen in the Eastern Segment of the Sveconorwegian Province, south-west Sweden

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Lundqvist, I., Eliasson, T. & Persson, P.-O., 2007: Sm–Nd analysis of a dolerite north of Hallandsåsen in the Eastern Segment of the Sveconorwegian Province, south-west Sweden. *In* F. Hellström & J. Andersson (eds.): Results from radiometric datings and other isotope analyses 1. *SGU-rapport 2007:28*, 37.

Rock	Dolerite
Sample number	IML050052
Coordinates (RT90)	6250585/1341670
Map sheet	4C Halmstad SO, 0i
Locality	Hällalteknallen, Sjöalt, Quarry, 10.5 km SE of Våxtorp
Project	Södra Halland berg [SGU code: 1104301]

Aim of study

North of Hallandsåsen in southern Halland there is a WNW trending post-kinematic dolerite dyke that cuts the ductile structures of the Eastern Segment gneisses in the wall rock. A Sm-Nd whole-rock analysis was done to estimate the approximate age of the extraction of the parental basaltic magma from a mantle reservoir and thereby get the age of the dolerite.

Sample description

The sample is from a dark grey, fine-grained, massive, 0.5 to 1 m wide dolerite dyke. The dyke as well as thin apophyses cut the gneissosity. The dolerite consists mainly of plagioclase, pyroxene and opaques with minor amounts of biotite and amphibole. The host rock is a grey to reddish grey, fine- to medium-grained, gneissic, veined and folded granite ("grey Hallandia"). Smaller bodies of garnet-bearing amphibolite occur subordinately in the quarry.

Analytical results

The analytical data are shown in Table 1. The dolerite has depleted-mantle model ages older than the c. 1.7 Ga intrusion age of the host rock. The variation of the ε_{Nd} with time is shown in Figure 1. An intrusion age of 1 Ga gives an ε_{Nd} of –1 whereas a Permian age (0.25 Ga) gives an ε_{Nd} of –6.

Discussion and conclusion

The Nd isotopic signature of the dolerite is clearly crustal, indicating that a large percentage of its REE was crustally derived if a "post-Hallandian" intrusion age is assumed, as field evidence suggest. It is therefore not possible to draw precise conclusions about the intrusion age from the Sm-Nd isotopic data.

References

DePaolo, D.J., 1981: Neodymium isotopes in the Colorado Front Range and crust-mantle evolution in the Proterozoic. *Nature 291*, 193–196.

DePaolo, D.J., Linn, A.M. & Schubert, G., 1991: The continental crust age distribution; methods of determining mantle separation ages from Sm-Nd isotopic data and application to the Southwestern United States. *Journal of Geophysical Reseach. B., Solid Earth and Planets.* 96, 2071–2088.

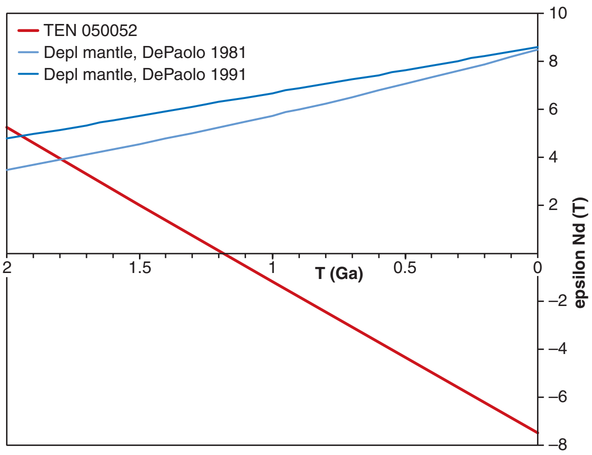

Fig. 1. ε_{Nd}–time evolution diagram for sample IML050052. The blue curves indicate the values for the depleted mantle, using the Sm-Nd characteristics of DePaolo (1981) and DePaolo et al. (1991).

Table 1. Sm-Nd isotopic whole-rock data from a dolerite dyke north of Hallandsåsen.

Sample	Sm (ppm)	Nd (ppm)	$^{143}Nd/^{144}Nd$	± (2σ)	$^{147}Sm/^{144}Nd$	T_{CHUR} (Ga)	T_{DM81} (Ga)	T_{DM91} (Ga)	Age (Ga)	ε_{Nd}(T)
IML 050052	6.10	25.07	0.512254	0.000004	0.14720	1.21	1.80	1.95	0.250	–5.92

T_{CHUR} is the model age assuming a mantle of chondritic, i.e. undepleted, mantle.
T_{DM81} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1981).
T_{DM91} is the model age assuming a depleted mantle with the Sm-Nd isotope composition of DePaolo (1991).