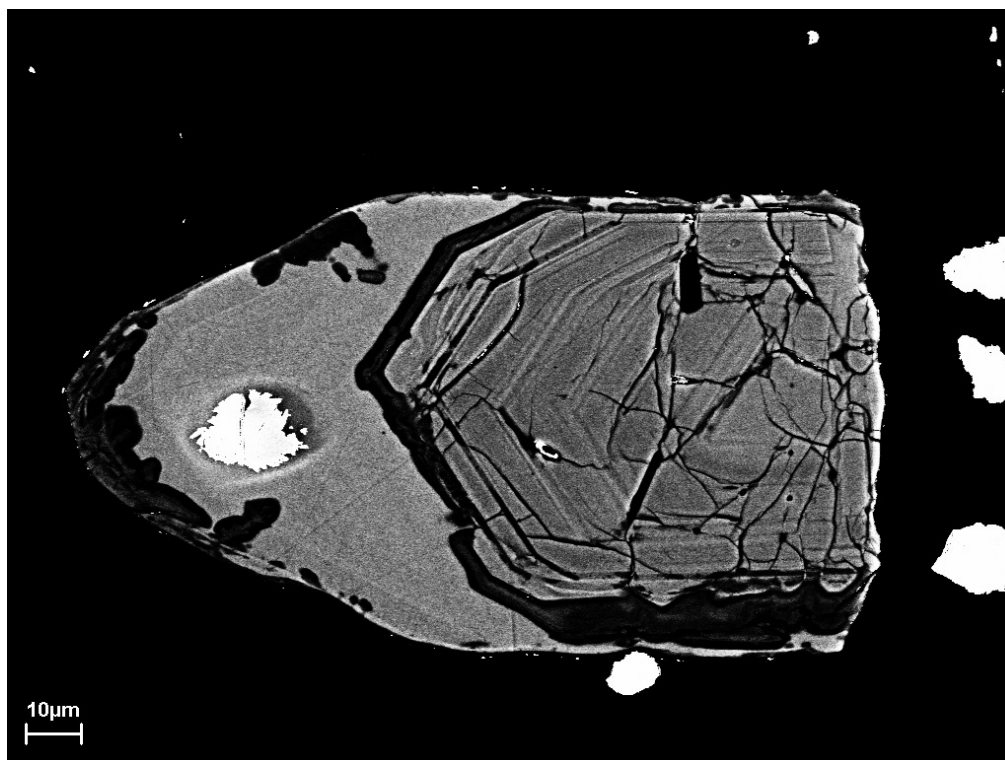


# U-Pb zircon SIMS geochronology of a leucogranite at Björkö in the Sundsvall area, central Sweden

Fredrik Hellström, Jenny Andersson, Katarina Persson Nilsson, Torbjörn Bergman & Andrius Rimša

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Cover: Back scattered electron image of U-Pb SIMS analysed zircon crystal from a leucogranite at Björkönen in the Sundsvall area (see also Fig. 5).

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<b>Rock</b>	Leucogranite	
<b>Tectonic domain</b>	Svecofennian	Bothnian Basin
<b>Sample number</b>	TOB050126A	n2342 and n2872
<b>Coordinates (RT90)</b>	6904569 / 1589172	
<b>Map sheet</b>	17H Sundsvall SO, 0h	
<b>Locality</b>	Björkönen	Minor, abandoned quarry
<b>Project</b>	Sundsvall berg och bergkvalitet	SGU project code: 1108401

## **INNEHÅLL**

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## BACKGROUND

The central part of the Fennoscandian Shield is dominated by Palaeoproterozoic rocks formed and modified during the Svecokarelian Orogeny (Rankama & Welin 1972), with igneous rock forming ages between 1.96 and 1.75 Ga (Lundqvist et al. 1998; Andersson et al. 2006 and references therein; Fig. 1). This accretionary orogen had a general growth direction to the south or south-west from an Archaean nucleus in the north-east (e.g. Gaál & Gorbatshev 1987, Nironen 1997). Lahtinen et al. (2005) suggested that this composite orogeny could be divided into four orogenies (Lapland-Savo, Fennian, Svecobaltic and Nordic) with partly overlapping, tectonic histories between 1.92 and 1.79 Ga.

The Bothnian Basin, in central Sweden (Fig. 1), is composed of Svecofennian turbiditic metagreywackes. These were intruded by early orogenic calc-alkaline metagranitoids and were later deformed and metamorphosed under low-pressure, high-temperature conditions



Fig. 1. Bedrock map of the Fennoscandian Shield, modified from Koistinen et al. (2001) and Bergman et al. (2008).

during the Svecokarelian Orogeny (Lundqvist et al. 1990). This event caused extensive, crustal scale, partial melting of the crust, and formation of both metatextitic and diatextitic migmatites, as well as leucocratic granites.

The timing for migmatisation and formation of leucogranites in the Bothnian Basin has previously been constrained at about 1.82 Ga (U–Pb TIMS multigrain monazite analysis of a leucogranite in the Sundsvall area by Claesson & Lundqvist 1995). In contrast, Högdahl et al. (2008) reported reworking in zircon associated with migmatisation and crystallisation of leucogranites at about 1.87–1.86 Ga to the north and east of the Ljusdal Batholith (Fig. 1).

The Geological Survey of Sweden (SGU) carried out bedrock mapping in the Bothnian Basin at around the towns of Sundsvall and Härnösand during the years 2005–2008. A simplified bed rock map of the southern part of the recently mapped area is presented in Figure 2. The bedrock in the mapped area is dominated by migmatites and leucogranites. The leucogranites occur as minor, 1–3 cm wide, layer parallel assemblages of neosome in stromatic migmatites, as thicker, centimeter to decimeter wide veins with cross-cutting relations to the stromatic layering of the same rocks (often formed axial planar to folds) or as larger bodies or sheets also often with cross-cutting relations to the migmatites. These field relations suggest that the leucogranites are coeval or slightly younger than the wallrock migmatites. They are thus interpreted to have formed by the assemblage of partial melts produced during the regional migmatisation and folding event.

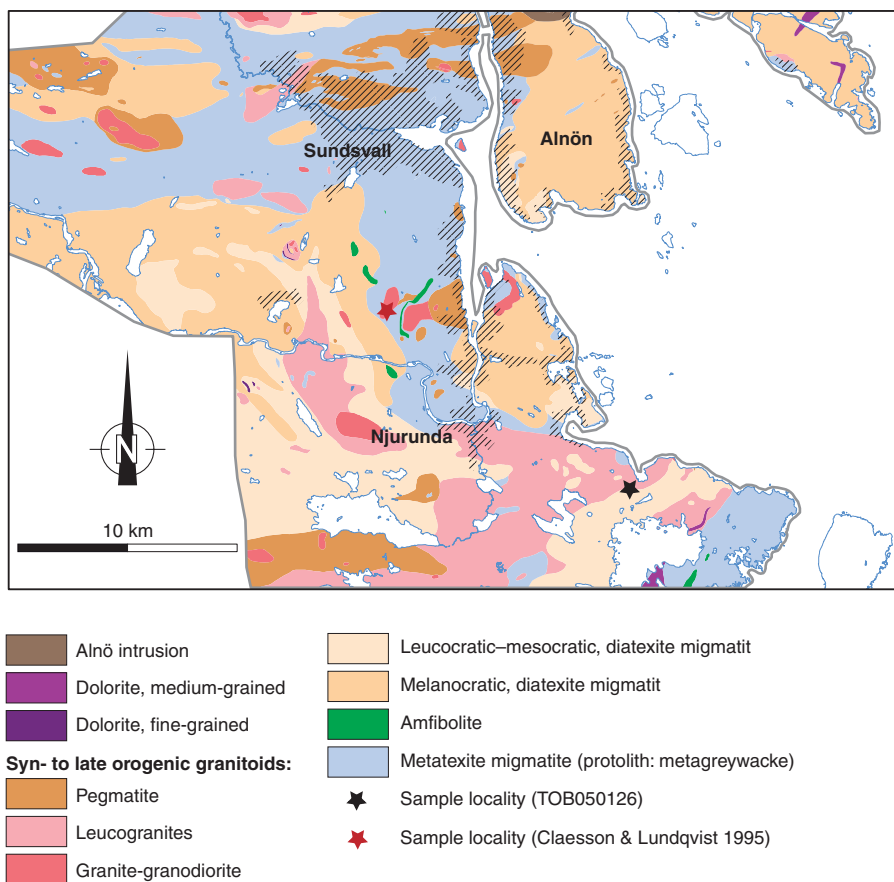


Fig. 2. Simplified bedrock map of the Sundsvall area (from SGU's database).

The leucogranites in this area have previously been assumed to belong to a pre-orogenic early Paleoproterozoic group of intrusive rocks due to the previously obtained U–Pb zircon age of about 2.03 Ga for these rocks (multi-grain fractions zircon analysis, Welin et al. 1993). This age most likely represents a mixed age with a contribution of inherited zircons from the Bothnian Basin metaturbidites (cf. Claesson & Lundqvist 1995).

The aim of this study was to use U–Th–Pb zircon analysis to directly date crystallisation of a leucogranite (Fig. 3) in the Sundsvall area. This age data will help to constrain the time relations between migmatitisation and leucogranite formation in the Bothnian Basin and test the conflicting results obtained from in situ zircon and multi-grain monazite analysis presented by Claesson & Lundqvist (1995) and Högdahl et al. (2008). Age constraints on leucogranite formation will also add to the understanding of the time scale of Svecokarelian high-temperature metamorphism in the Fennoscandian Shield.

### **SAMPLE DESCRIPTION**

A representative sample of a foliated meta-leucogranite was selected in an abandoned quarry at Björköen where it forms part of the largest coherent body of leucogranite exposed in the recently mapped area. The sample is a fine- to medium-grained, weakly foliated, leucocratic, unequigranular granite (Fig. 3). The meta-leucogranite has a mineral assemblage consisting of quartz, K-feldspar, plagioclase, biotite, muscovite, garnet and cordierite. The cordierite is pinitised and some biotite is chloritised due to retrogression. In places the leucogranites contain up to 2–3 cm large patches rich in biotite pseudomorphing cordierite. The foliation is defined by biotite-rich streaks, some of which possibly are remnant schlieric structures from the diatexite migmatites.

### **ANALYTICAL METHODS**

Zircon mineral separates were obtained from density separation of about 0.4 kg of crushed rock sample using a Wilfley water table. The magnetic minerals were removed by a hand magnet. Handpicked crystals were mounted in transparent epoxy resin together with chips of reference zircon 91500. 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 done using a Cameca IMS 1270 at the NordSIM facility at the Swedish Museum of Natural History in Stockholm. Detailed descriptions of the analytical procedures are given in Whitehouse et al. (1997, 1999) and Whitehouse & Kamber (2005). Pb/U ratios, elemental concentrations and Th/U ratios were calibrated relative to the Geostandards zircon 91500 reference, which has an age of c. 1065 Ma (Wiedenbeck et al. 1995, 2004). Common Pb corrected isotope values were calculated using modern common Pb composition (Stacey & Kramers 1975) and measured  $^{204}\text{Pb}$ . Decay constants follow the recommendations of Steiger & Jäger (1977). Diagrams and age calculations of isotopic data were made using software Isoplot 3.00 (Ludwig 2003). Statistical precisions of age estimates are given as  $2\sigma$  (unless otherwise explicitly stated). Back-scattered electron images (BSE) of analyzed zircon were obtained using a ZEISS SUPRA 35-VP field emission scanning electron microscope at the Evolutionary Biology Centre, Uppsala University.

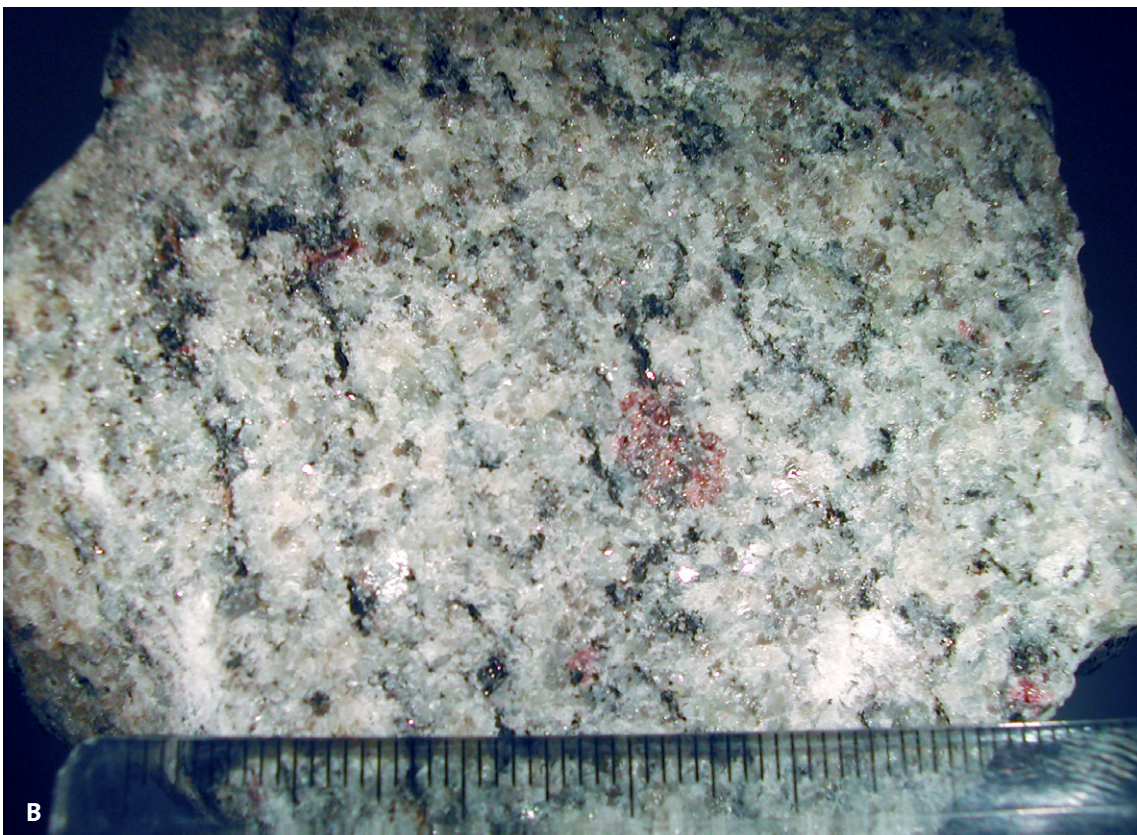


Fig. 3. **A.** Field photograph of leucogranite at the sampling locality at Björkö. **B.** Photo of hand specimen of the dated sample of leucogranite (mm scale bar).

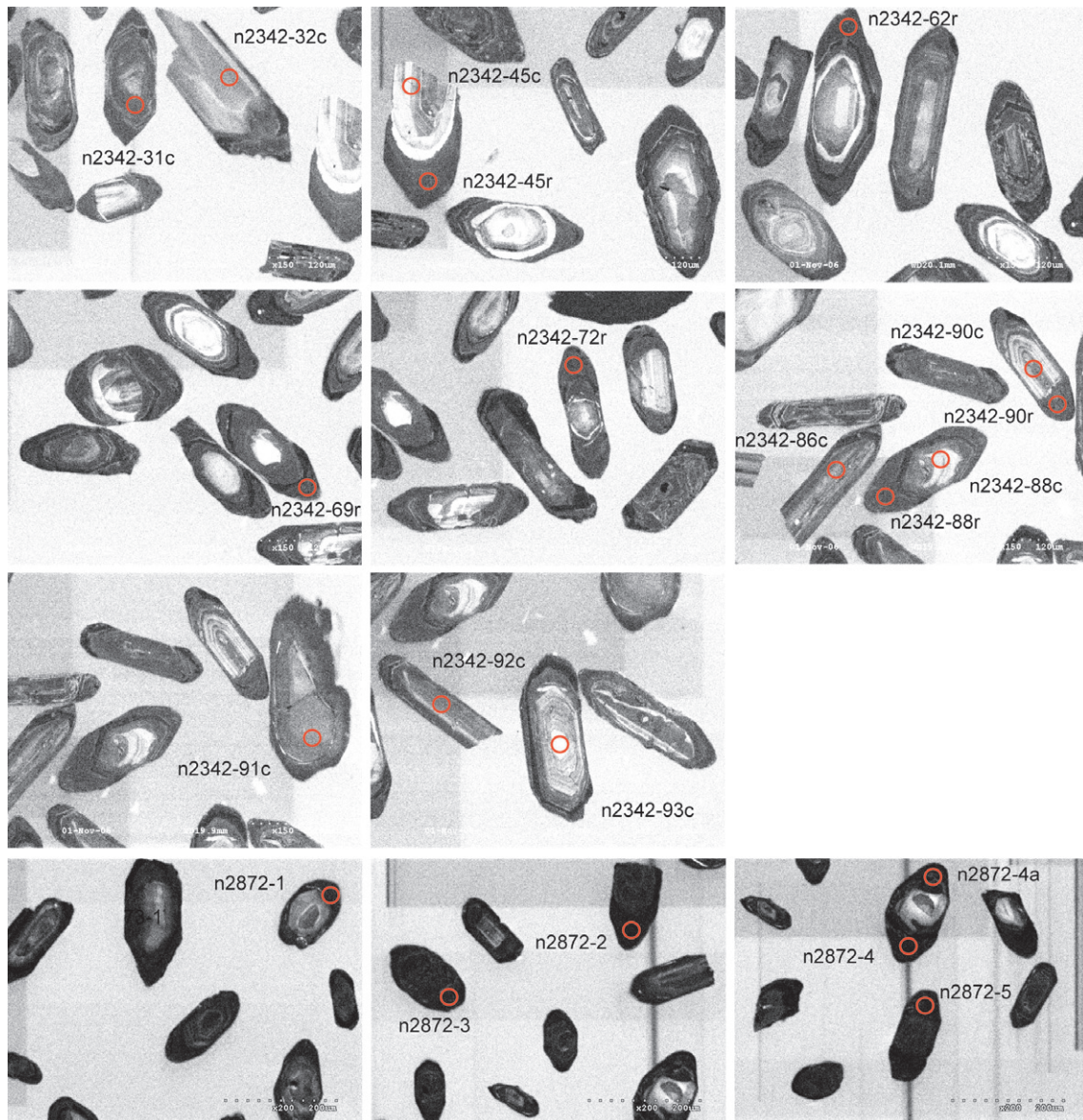


Fig. 4. CL-images of zircon from the meta-leucogranite. Red circles mark approximate location of analysed spots. Numbers refer to analytical spot number in Table 1.

## ANALYTICAL RESULTS

The zircons typically occur as subhedral prisms with distinctly rounded outer terminations. The interiors are unclear and turbid and cracks are common. Core-rim relations are observed also under the optical microscope; rim domains are somewhat clearer and less cracked than the turbid core domains.

## Textural data

BSE- and CL-images of internal textures show oscillatory zoned, structurally old, anhedral core domains surrounded by texturally younger BSE-bright (CL-dark) rim domains (Figs. 4 and 5). The structurally old, typically oscillatory zoned core domains are interpreted to

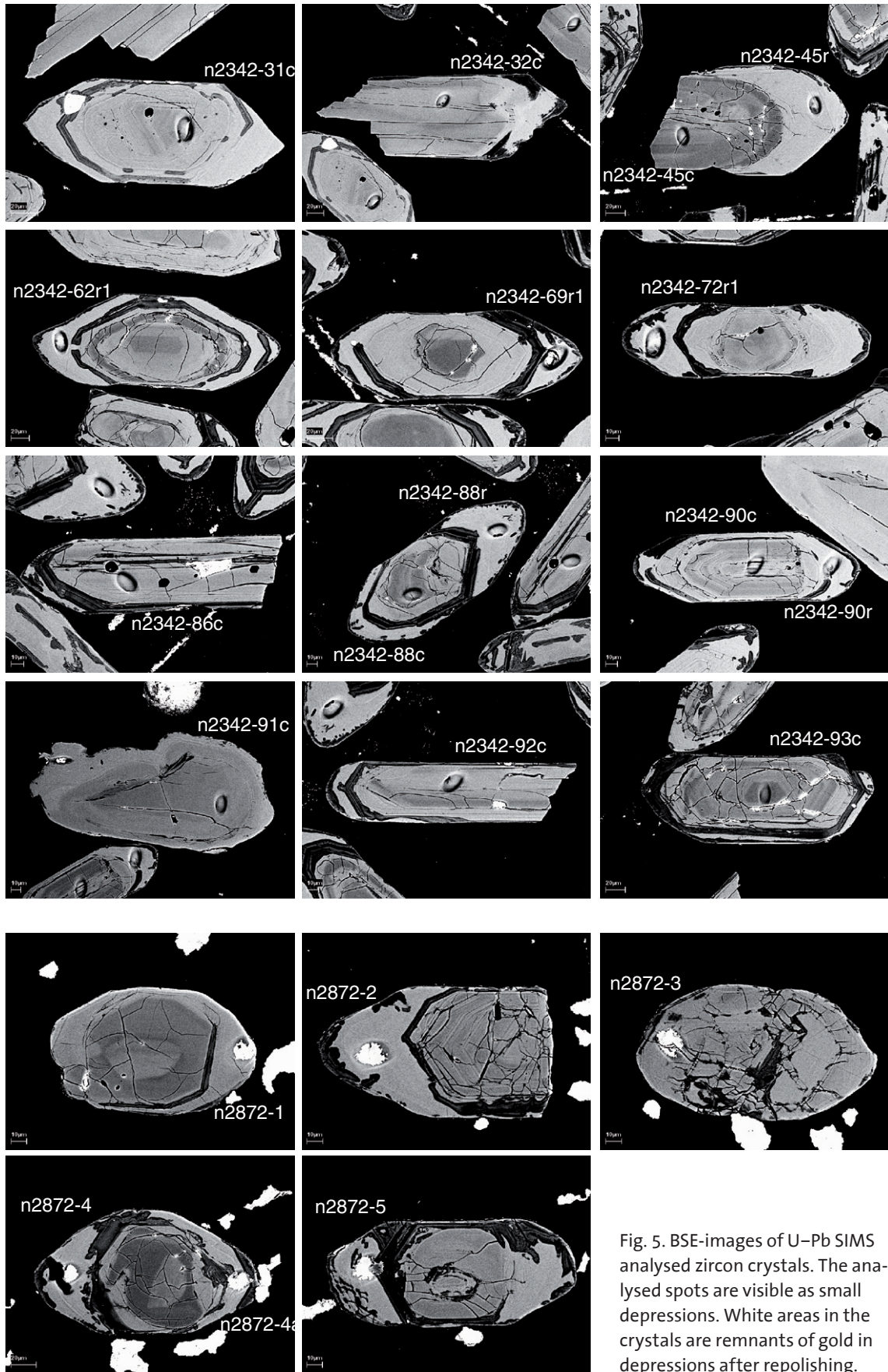


Fig. 5. BSE-images of U–Pb SIMS analysed zircon crystals. The analysed spots are visible as small depressions. White areas in the crystals are remnants of gold in depressions after repolishing.

represent igneous zircon while the CL-dark (BSE-light) rims are interpreted to represent secondary zircon. The rim domains commonly show weak oscillatory zoning in places occurring as relict igneous zonation typically developed concordant to the zonation in the protolith zircon core. The border zone between the texturally old igneous core domains and BSE-bright outer domains typically host BSE-dark (CL-bright), a few micrometer wide semi-continuous band presumably of U-rich metamict character. This band is in places seen to be irregularly cross-cut by the BSE-bright rim domain. The outermost parts of the crystals are texturally characterised by BSE-dark, a couple of  $\mu\text{m}$  wide, irregular domains or patches that in places are seen to cross-cut the relict igneous zonation of the BSE-bright secondary rim domains (Fig. 5, n2872-2, 4, n2342-69, 62). The external morphology and internal textures of the zircon grains suggests that the population is composed of xenocrystic igneous zircon replaced (recrystallised?) by a voluminous phase of secondary zircon growth. A later phase of metamorphic abrasion and alteration of the outermost parts of the crystals is suggested by the rounded outer terminations and texturally youngest BSE-dark alteration fronts.

## U-Pb-Th isotopic data

U-Th-Pb analytical data collected from texturally different parts of the zircon population is presented in Table 1 and Figures 6 and 7. In total 21, points were analysed.

### *Texturally old domains*

Eight spots were aimed at texturally old core domains with well preserved primary igneous oscillatory zoning of the protolith zircon. U-contents range between 1077 and 86 ppm and Th/U ratios are between 0.9 and 0.4 (Table 1, Fig. 6). Spot analysis n2342-91c yields distinctly lower Th content and also the textural context of this spot is ambiguous since the spot location straddles the boundary to a BSE-bright, altered, texturally younger domain

Table 1. SIMS U-Pb-Th zircon data (TOB050126A).

Sample/ spot #	U (ppm)	Pb (ppm)	Th/U calc.	$^{206}\text{Pb}/^{204}\text{Pb}$ measured	$f_{206}\%$	$^{238}\text{U}/^{206}\text{Pb}$	$\pm\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$ %	$\pm\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$ %	age (Ma)	$^{206}\text{Pb}/^{208}\text{U}$ age (Ma)	$^{206}\text{Pb}/^{208}\text{U}$ age (Ma)	$\pm\sigma$	Disc. % 2 $\sigma$ lim.
n2342-31c	361	187	0.45	54263	0.03	2.467	1.37	0.14673	0.66	2308	11	2194	25.6	-2.1	
n2342-32c	474	196	0.43	14393	0.13	2.996	1.36	0.11451	0.48	1872	9	1857	22.0		
n2342-45c	247	173	0.91	172302	{0.01}	2.051	1.36	0.18007	0.46	2653	8	2560	28.8	-1.1	
n2342-45r	827	315	0.04	69991	0.03	2.949	1.36	0.11398	0.36	1864	7	1882	22.3		
n2342-62r	2666	1019	0.01	226944	0.01	2.918	1.13	0.11394	0.15	1863	3	1900	18.6		
n2342-69r	3756	3509	5.43	173105	0.01	2.717	1.25	0.11401	0.11	1864	2	2020	21.7	6.9	
n2342-72r	2832	1069	0.01	201826	0.01	2.954	1.17	0.11368	0.16	1859	3	1880	19.2		
n2342-86c	603	235	0.28	7762	0.24	3.080	1.36	0.11474	0.44	1876	8	1812	21.5	-0.6	
n2342-88c	229	108	0.40	19685	0.10	2.638	1.36	0.12954	0.67	2092	12	2072	24.2		
n2342-88r	2567	970	0.00	129128	0.01	2.947	1.36	0.11292	0.21	1847	4	1883	22.3		
n2342-90c	935	481	0.96	23295	0.08	2.713	1.37	0.12328	0.39	2004	7	2023	23.8		
n2342-90r	2736	1015	0.00	153666	0.01	3.003	1.37	0.11260	0.26	1842	5	1853	22.1		
n2342-91c	401	166	0.08	91319	{0.02}	2.762	1.36	0.12161	0.57	1980	10	1992	23.4		
n2342-92c	1077	471	0.59	22365	0.08	2.933	1.36	0.11452	0.35	1872	6	1891	22.3		
n2342-93c	86	41	0.78	5502	0.34	2.823	1.36	0.12230	1.31	1990	23	1955	23.0		
n2872-1	686	261	0.01	10454	0.18	2.930	0.89	0.11317	0.70	1851	13	1893	14.6		
n2872-2	2443	933	0.01	108699	0.02	2.914	0.88	0.11112	0.47	1818	8	1902	14.5	2.5	
n2872-3	1088	356	0.08	539	3.47	3.489	0.83	0.11486	0.73	1878	13	1625	11.9	-11.6	
n2872-4	2510	986	0.01	146856	0.01	2.842	0.73	0.11303	0.57	1849	10	1944	12.3	2.8	
n2872-4a	2667	977	0.01	78178	0.02	3.043	0.76	0.11361	0.42	1858	8	1832	12.1		
n2872-5	4322	1118	0.01	67686	0.03	4.296	0.74	0.10591	0.39	1730	7	1349	9.0	-22.2	



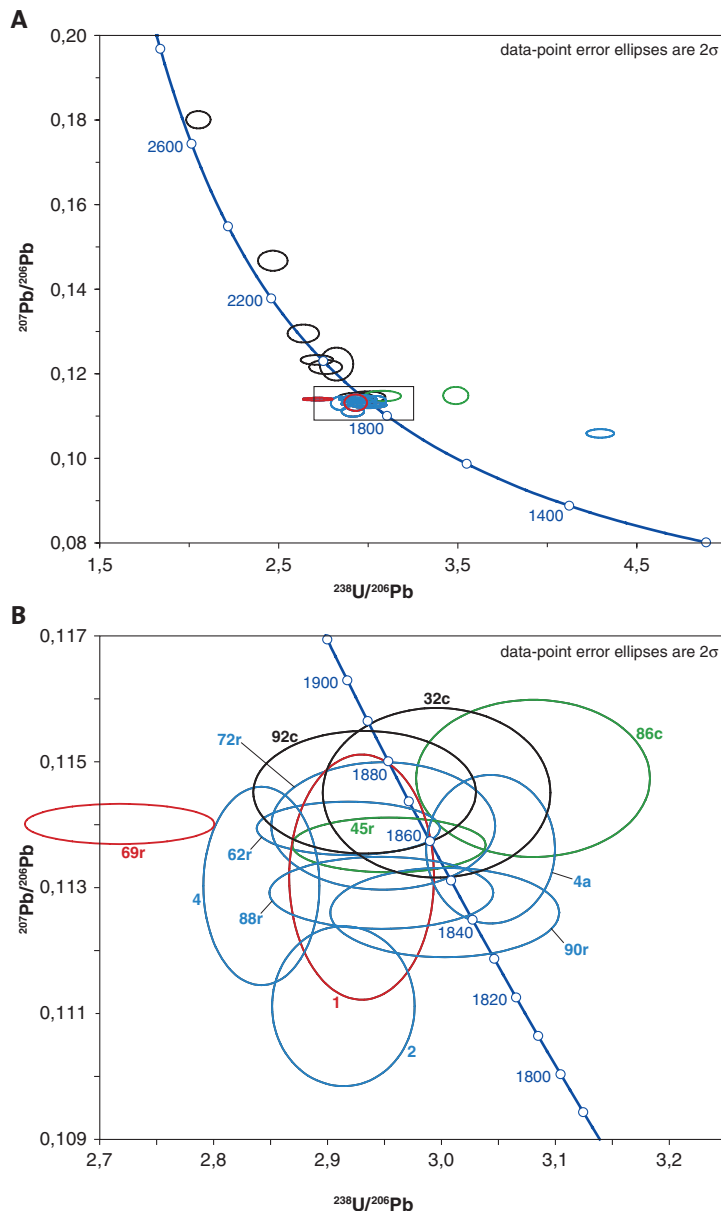


Fig. 7. Terra Wasserburg diagrams showing U–Pb zircon data from a leucogranite from the Sundsvall area. **A.** All analyses. **B.** Enlargement of framed area in A. The colour of the ellipses denotes texturally different zircon domains. Key: black = texturally old domains with well preserved oscillatory zonation; green = ghost zoned core domain; blue = BSE-bright rim domain in part with faint zonation bands; red = unzoned rims.

young rim domains that, for the most part, are unzoned, but that all, in some measure, host faint zonation bands developed concordant to the igneous zonation of the protolith zircon cores (analysis n2342-45r, 62r, 72r, 88r, 90r, n2872-1, and 4a). These domains give concordant  $^{207}\text{Pb}/^{206}\text{Pb}$ -ages ranging between  $1863\pm 6$  Ma and  $1842\pm 44$  Ma (Table 1 and Fig. 7B).

More data is required to evaluate the geological significance of the observed analytical spread. Taken together, the available textural and U–Th–Pb isotopic data suggest that the texturally young zircon in the leucogranite formed at between 1.86 Ga and 1.84 Ga. The chemically abraded character of the outer morphology of the zircon grains suggests that the zircons experienced another phase of metamorphism post-dating the formation of the analysed secondary zircon domains.

## DISCUSSION AND CONCLUSION

Protolith zircon cores in the leucogranite yield igneous zircon crystallisation ages at between 2.09 and 1.87 Ga. The spread in ages of the texturally old zircon suggests that these cores are xenocrystic zircon derived from different igneous rocks forming the source to the metasedimentary rock precursor of leucogranite. It is suggested that the greywacke metasediments of the Bothnian Basin constituted the source for the investigated leucogranite. This is consistent with the work of Claesson et al. (1993), who showed that zircon detritus in Svecofennian metaturbidites are dominated by c. 60% Proterozoic (1.9–2.1 Ga) and 30% Archaean (2.6–3.0 Ga) crystals. The maximum age of the metasedimentary rock protolith to the leucogranite dated in this study is set by the youngest xenocrystic zircon component, here dated at about 1.87 Ga.

Secondary zircon in the meta-leucogranite is dated at between 1.86 and 1.84 Ga. The inheritance of the zonation pattern of the xenocrystic zircon cores also in the secondary formed zircon domains may indicate a process of in situ recrystallisation of zircon during metamorphism. This may have resulted in an incomplete resetting of the U–Pb–Th isotopic system during formation of secondary zircon domains (Hoskin & Black 2000) and may explain the apparent spread in  $^{207}\text{Pb}/^{206}\text{Pb}$ -ages of the secondary formed domains in the analysed sample. More petrological, textural and analytical data is needed to evaluate the geological significance of this time interval. The secondary formed zircon is interpreted to have formed in response to interaction of a fluid (melt) aggressive to zircon available during partial melting of the metasedimentary rock protolith, melt extraction and subsequent crystallisation of the leucogranite. The age of the leucogranite is dated at between 1.86 and 1.84 Ga. This time interval overlaps with ages of partial melting in the Sundsvall–Härnösand area presented by Högdahl et al. (2008). The investigated granite is foliated and has been exposed to metamorphism after melt crystallisation. The subhedral morphology of secondary formed zircon rims may reflect surficial modification of zircon during a younger metamorphic event.

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