Age of migmatisation in the Boden area, northern Sweden

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Cover: View from outcrop which the dated sample was taken.
Fold axial planes oriented in north-westerly direction in stromatic, metatexitic migmatite.
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CONTENT

ABSTRACT

The Archaean and Palaeoproterozoic rocks in the south-eastern Norrbotten County show in part migmatisation with varieties of metatexite to diatexite migmatites. Metamorphic alterations within map area 25L Boden vary from low- to high metamorphic grade and is generally of lower grade in the western part compared to the eastern part. A stromatic, metatexite migmatite sample from the south-eastern part of the map area was dated by U-Pb zircon SIMS geochronology. The variable ages of the oscillatory zoned zircon core domains suggest a detrital origin of the zircon, and a sedimentary precursor to the dated migmatitic gneiss. Clastic material was derived from several; differently aged igneous source rocks, one older group with Archaean ages at 2.92−2.70 Ga and a younger group with ages between 2.08 and 1.93 Ga. U-Pb isotopic analyses of secondary BSE-bright zircon rim domains give an age of 1878 ±4 Ma, which is interpreted to date migmatisation. These zircon rims have very low Th/U ratios compared to cores, which gives support to a metamorphic origin of the zircon rims. The results show that the Boden area underwent early Svecokarelian migmatisation and deformation at c. 1.88 Ga.

Keywords: *Svecokarelian orogen, migmatisation, U-Pb, geochronology, Boden*

SAMMANFATTNING

De arkeiska och paleoproterozoiska bergarterna i sydöstra Norrbottens län är delvis migmatitiserade med olika varianter av metatexitiska till diatexitiska migmatiter. Metamorfosen inom kartområdet 25L Boden varierar från låg- till höggradig och är i allmänhet av lägre metamorf grad i den västra delen jämfört med den östra. Ett stromatiskt, metatexitiskt migmatitprov från den sydöstra delen av kartområdet daterades med U-Pb zirkon SIMS geokronologi. Varierande åldrar hos oscilliatoriskt zonerade kärndomäner av zirkon föreslår att zirkonerna är detritiska och att den daterade migmatitiska gnejsen har ett sedimentärt ursprung. Det klastiska materialet har sin källa i magmatiska bergarter med olika åldrar, en äldre grupp med arkeiska åldrar vid 2,92–2,70 miljarder år och en yngre grupp med åldrar mellan 2,08 och 1,93 miljarder år. U-Pb-isotopanalyser av sekundära, BSE-ljusa kantdomäner av zirkon ger en ålder på 1878 ±4 miljoner år, vilken tolkas datera migmatitiseringen. Dessa zirkonkanter har mycket låga Th/U-kvoter jämfört med kärndomänerna, vilket ger stöd för ett metamorft ursprung för zirkonkanterna. Resultaten visar att Bodenområdet genomgick tidig svekokarelsk migmatitisering och deformation vid ca 1,88 miljarder år.

Nyckelord: svekokarelska bergskedjebildningen, migmatitisering, U-Pb, geokronologi, Boden

INTRODUCTION

The interplay between regional metamorphism, magmatism and local deformation is not understood in any detail in Norrbotten although it seems that the time span c. 1.89 to 1.75 Ga involves a complex evolution of rock formation and subsequent deformation episodes (Bergman et al. 2006; Wikström et al. 1996). Bergman et al. (2006) recognized two different structural domains in north-eastern Norrbotten separated roughly along a N–S trending structural boundary defined by the western margin of the Pajala deformation belt (PDB, see Luth et al. *in press*, Hellström *in press*). The eastern domain occurs within the Pajala deformation belt, and is characterized by NNE- to NNW high-strain zones with high-grade metamorphic alterations. The area west of the Pajala deformation belt is structurally heterogeneous with both medium- and high-grade metamorphic areas. Metamorphic monazite and titanite as well as zircon overgrowths in the Pajala deformation belt verify deformation and high-grade metamorphism in the 1.83–1.78 Ga interval, while rocks of west of the Pajala deformation zone have preserved an older phase of deformation and high-grade metamorphism (Bergman et al. 2006, Luth et al. 2016, Hellström & Bergman 2016). U-Pb SIMS analyses of metamorphic, low Th/U zircon rims from a migmatitic paragneiss in the Masugnsbyn area (west of PDB), is dated at 1878±3 Ma (Hellström *in press*), while metamorphic monazite is dated at c. 1.86 Ga (Bergman et al. 2006). Evidence of an older phase of migmatisation and shearing was also reported from the south-eastern part of Norrbotten, where the 1881±9 Ma Bläsberget felsic-mafic dykes cut migmatites occurring immediately west of the Pajala deformation belt (Baltic-Bothnian mega shear; Wikström et al. 1996). In the north-eastern part of the Skellefte ore district, 1.88 Ga old plutons also crosscut deformed metasedimentary rocks (Lundström et al. 1997, 1999).

The Archaean and Palaeoproterozoic rocks in the south-eastern Norrbotten County have in part undergone migmatisation from metatexite to diatexite. The metamorphic grade within map area 25L Boden varies from low-grade metamorphism to garnet-andalusite facies (Sadeghi et al. *in press*). In general, the metamorphic overprinting in the western part of the map area 25L Boden is lower compared to the eastern part. Higher degree of metamorphism is seen in rocks of the Bothnian Supergroup and the Råneå group, where migmatitic greywacke, paragneiss, and gneissic volcanic rocks are documented. The Svecokarelian intrusive rocks, especially in the southern part of the map area around Sunderbyn, show somewhat higher grade of metamorphism compared to those in the western part. To the west of Boden area (25L), in the map area 25K Harads, well-preserved rocks show commonly low-grade metamorphism. Higher grade of metamorphism in the 25L Harads is only seen in rocks of the Bothnian Supergroup, with migmatised greywacke and paragneiss and in the gneissic volcanic rocks. In the map area 26L Pålkem north of the Boden area (25L), there is a distinct contrast in the metamorphic grade, with a central area with diatexitic migmatitic rocks and areas to the east and west with lower-grade metamorphism, where preserved primary structures in the supracrustal rocks are evident (Bergström et al. 2015).

In this study, zircon was dated from a stromatic, metatexite migmatite sample taken from a quarry close to E4 north of Rutvik in the south-eastern part of the Boden map area (Fig. 1). The main question to answer is the timing of migmatisation within this area.

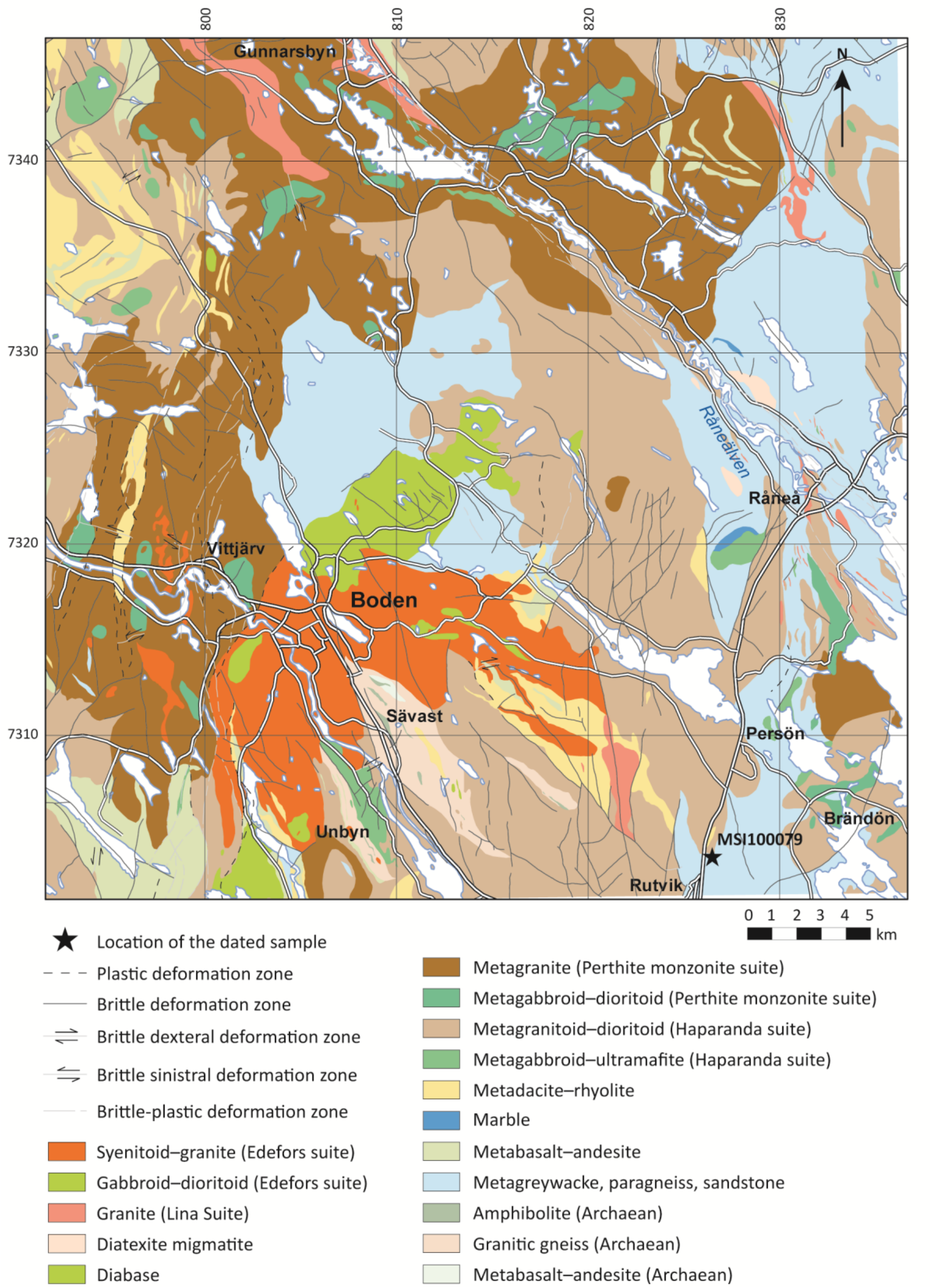

Figure 1. Geological map of the Boden area, modified after the SGU 1:50 000 bedrock geology (Sadeghi et al. in press). Location of dated sample is marked with black star on the map.

SAMPLE DESCRIPTION

The sampled rock from the Rutvik quarry is a stromatic, metatexitic migmatite with greywacke to arkose protolith. The sample is fine- to finely medium grained and consist of quartzo-feldspathic gneiss (mesosome), biotite-rich bands (melanosome), and granitic to granodioritic leucosome (Fig. 2 and Table 1). The leucosome and mesosome occur in parallel layers, which vary from mm to several cm up to 30 cm in width. All of the layers are strongly foliated with transposed quartz veins and melt lenses. The gneissosity, including melt veins, is isoclinally folded in places and is later sheared along a conjugate system indicating NW–SE compression.

Table 1. Summary of sample data (MSI100079).

Rock type	Migmatite
Tectonic domain	Svecokarelian orogen
Tectonic subdomain	Norrbotten lithotectonic unit
Stratigraphic group	Råneå group
Sample number	MSI100079
Lab-id (Nordsim)	n4061
Coordinates (Sweref 99TM)	7303669/ 826489
Map sheet	73i, 0c SO (Sweref99TM)
Locality	Quarry northeast of Rutvik
Project	Jäkkvik-Boden

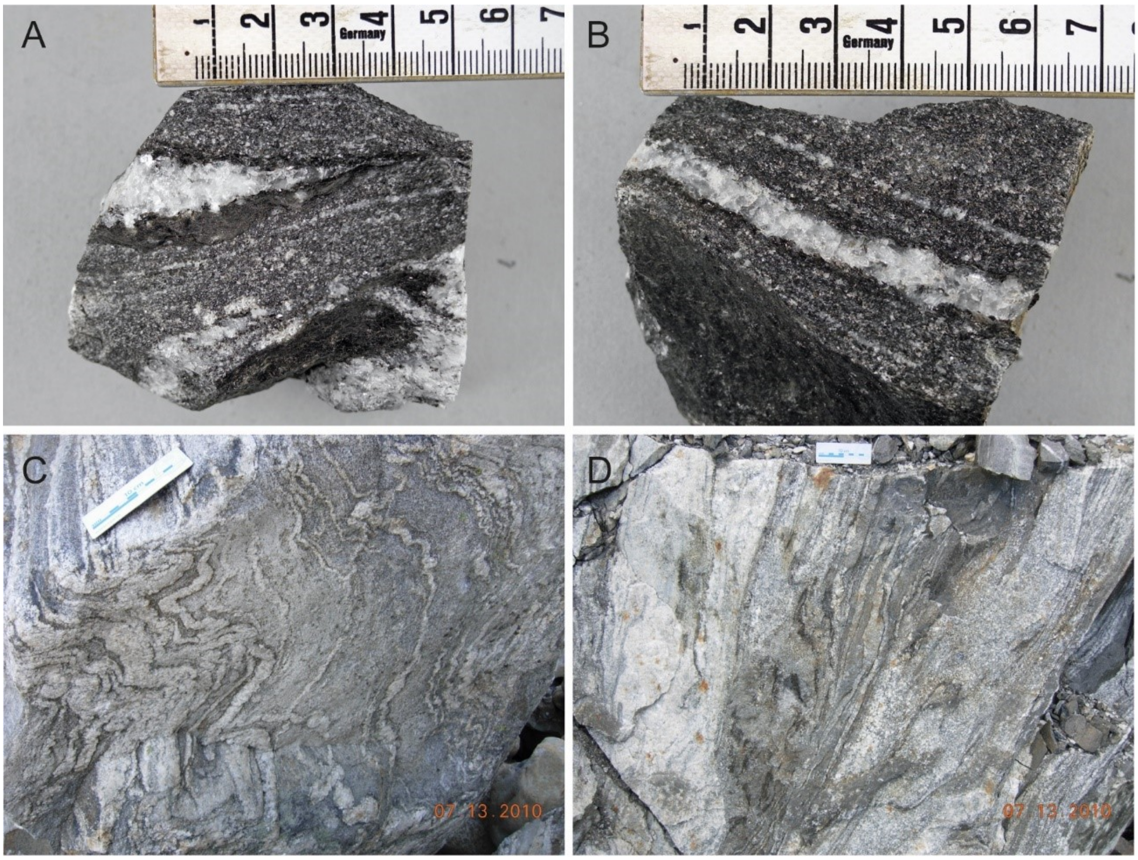

Figure 2. **A–B.** The dated sample shows prominent layering with mesosome, melanosome and leucosome. **C–D.** View from outcrop which the dated sample was taken. **C.** Fold axial planes oriented in north-westerly direction in stromatic, metatexitic migmatite. **D.** The migmatite is folded and rich in fine-medium to medium grained leucosome of granitic to granodioritic composition interlayered with biotite schist bands. Photo: Fredrik Hellström (A–B). Martiya Sadeghi (C–D).

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 2011. The analytical results are shown in Table 2.

Zircons were obtained from a density separate of a 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 Back scattered electron (BSE) using electron microscopy at the department of geology, Lund University. High-spatial resolution secondary ion mass spectrometer (SIMS) analysis was done using a Cameca IMS 1280 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). A c. 6 nA O^{2-} primary ion beam was used, yielding spot sizes of c. 10–15 µm. U/Pb 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}Pb, in cases of a ^{204}Pb count rate above the detection limit. Decay constants follow the recommendations of Steiger & Jäger (1977). Diagrams and age calculations of isotopic data were made using software Isoplot 4.15 (Ludwig 2012). All age uncertainties are presented at the 2σ or 95% confidence level. BSE-imaging of the dated zircons was performed using electron microscopy at the Department of Geology, Uppsala University.

The heavy mineral concentrate from 775 g of processed sample contains abundant zircon grains with subhedral to anhedral prismatic shapes with somewhat rounded edges. Most zircons are turbid and probably metamict, but there are also clear crystals, which were selected for analysis. BSE images show weakly oscillatory zoned or homogeneous crystals (Fig. 3). Some crystals have unzoned (?) BSE-bright, seemingly texturally younger, outer domains surrounding the BSE-dark core domains (Fig. 3).

Analyses of core domains show 80−483 ppm U, and Th/U ratios of 0.13−1.43, except analysis 14c that recorded a ratio of 0.03. Analyses of BSE-bright rim domains show high U content, 666−1108 ppm, and low Th/U ratios, 0.01−0.04 (4r1, 4r2, 5r1, 5r2, 13r2), except rim analyses 10r, 11r and 25r, which also record much older ages (Table 2, Fig. 4). All analyses are concordant or near concordant, except the rim analysis 11r which is 11% discordant (Table 2).

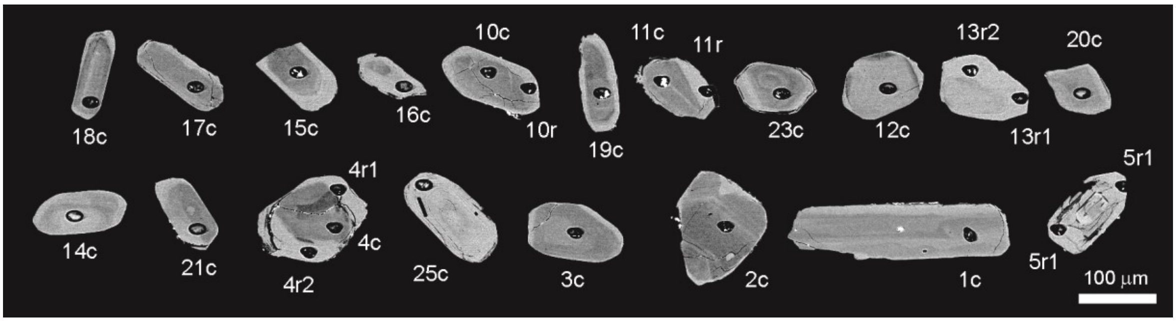

Figure 3. BSE-images of analysed zircon grains. Numbers refer to analytical spot number in Table 2.

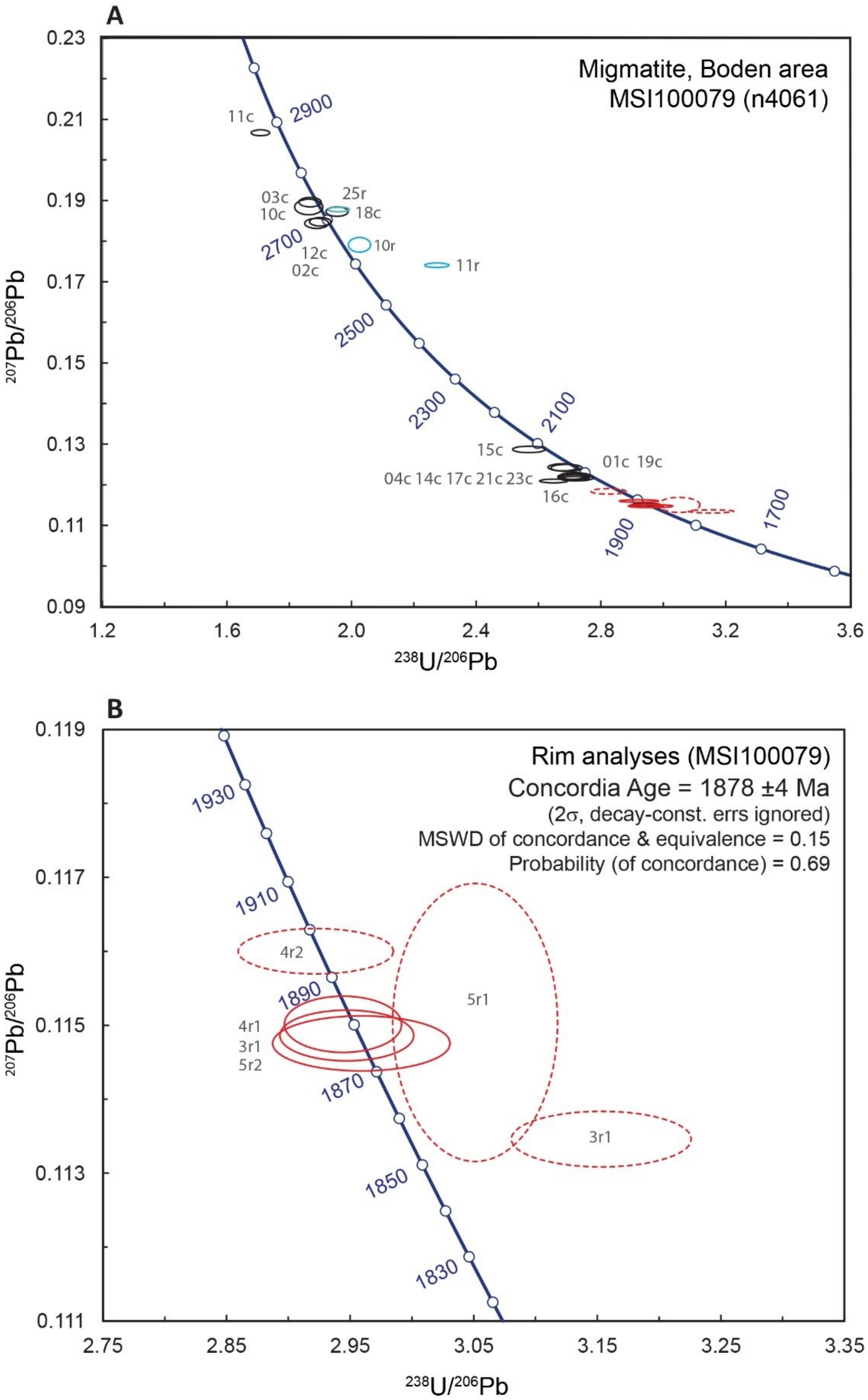

Figure 4. Tera Wasserburg diagram showing U-Pb SIMS zircon data. **A.** All data with core analyses in black, old rim analyses in blue and young rim analyses in red. **B.** Young rim analyses. Analyses not used in age calculation are shown with dotted lines, see text for explanation.

Table 2. SIMS U–Pb–Th zircon data (MSI100079, Lab id: n4061).

		Element conc.				Isotopic ratios									Calculated ages (Ma)					
Anal.	Comment	U ppm	Th ppm	Pb ppm	Th/U Calc[1]	^{207}Pb/^{235}U	±σ %	^{238}U/^{206}Pb	±σ %	^{207}Pb/^{206}Pb	±σ %	ρ [2]	Disc. % conv. [3]	Disc. % 2σ lim. [4]	^{207}Pb/^{206}Pb	±σ	^{206}Pb/^{238}U	±σ	^{206}Pb/^{204}Pb	f_{206}% [5]
01c	core, osc zon	170	49	77	0.29	6.399	1.28	2.678	1.19	0.1243	0.46	0.93	1.5		2019	8	2045	21	160872	{0.01}
02c	core, osc zon	79	40	56	0.53	13.464	1.41	1.888	1.33	0.1843	0.44	0.95	2.2		2692	7	2740	30	74155	{0.03}
03c	core, osc zon	99	138	84	1.43	14.001	1.33	1.867	1.27	0.1896	0.41	0.95	1.2		2739	7	2765	29	>1e6	{0.00}
04c	core, osc zon	129	79	62	0.62	6.200	1.28	2.716	1.20	0.1222	0.46	0.93	1.9		1988	8	2021	21	182988	{0.01}
04r1	rim, BSE-bright	666	16	254	0.03	5.386	1.08	2.944	1.06	0.1150	0.22	0.98	0.3		1880	4	1885	17	348135	{0.01}
04r2	rim, BSE-bright	1032	10	395	0.01	5.473	1.43	2.922	1.42	0.1160	0.17	0.99	0.1		1895	3	1897	23	880367	{0.00}
05r1	rim, BSE-bright, partly outside	779	14	286	0.02	5.198	1.80	3.051	1.44	0.1150	1.08	0.80	-3.2		1880	19	1827	23	9779	0.19
05r2	rim, BSE-bright, mixed with core?	797	6	301	0.01	5.347	1.62	2.959	1.60	0.1148	0.21	0.99	0.0		1876	4	1877	26	306670	{0.01}
10c	core, unzon	153	45	104	0.31	13.946	1.74	1.863	1.60	0.1884	0.67	0.92	1.9		2728	11	2770	36	>1e6	{0.00}
10r	rim, BSE-bright	294	69	181	0.25	12.190	1.35	2.026	1.17	0.1791	0.66	0.87	-2.6		2644	11	2587	25	330242	{0.01}
11c	core, unzon-osc zon	181	192	160	1.14	16.687	1.18	1.708	1.15	0.2067	0.24	0.98	4.0	1.4	2880	4	2971	27	138448	{0.01}
11r	rim, BSE-bright, partly outside	829	69	437	0.08	10.555	1.15	2.274	1.13	0.1741	0.22	0.98	-11.4	-9.2	2597	4	2350	22	278212	0.01
12c	core, weakly osc zon-unzon	246	51	161	0.23	13.409	1.25	1.900	1.19	0.1848	0.37	0.96	1.4		2696	6	2726	27	182352	0.01
13r1	rim, BSE-bright	1108	43	395	0.04	4.961	1.54	3.153	1.52	0.1135	0.22	0.99	-4.9	-1.9	1856	4	1776	24	504454	0.00
13r2	rim, BSE-bright	684	5	259	0.01	5.373	1.23	2.947	1.21	0.1149	0.20	0.99	0.3		1878	4	1883	20	233869	0.01
14c	core, osc zon	483	13	201	0.03	6.174	1.14	2.717	1.12	0.1217	0.20	0.98	2.3		1981	4	2020	19	858984	{0.00}
15c	core, osc zon	111	28	52	0.27	6.909	1.41	2.569	1.35	0.1287	0.41	0.96	2.2		2081	7	2119	24	292988	{0.01}
16c	core, BSE right	326	39	142	0.13	6.295	1.15	2.648	1.12	0.1209	0.25	0.98	5.7	3.0	1970	4	2065	20	153209	0.01
17c	core, weakly osc zon-unzon	107	45	49	0.45	6.203	1.22	2.709	1.13	0.1219	0.46	0.93	2.5		1984	8	2025	20	44898	0.04
18c	core, osc zon	185	56	121	0.30	13.217	1.27	1.954	1.20	0.1873	0.41	0.95	-2.4		2718	7	2665	26	338316	{0.01}
19c	core, weakly osc zon		40	44	0.44	6.365	1.31	2.690	1.23	0.1242	0.47	0.93	1.2		2017	8	2038	21	34614	0.05
20c	core, osc zon	149	66	66	0.47	5.778	1.37	2.825	1.32	0.1184	0.38	0.96	1.3		1932	7	1954	22	98330	{0.02}
21c	core, osc zon	138	68	65	0.53	6.219	1.12	2.706	1.06	0.1220	0.37	0.94	2.4		1986	7	2028	18	395993	{0.00}
23c	core, osc zon	111	47	51	0.46	6.170	1.43	2.720	1.37	0.1217	0.42	0.96	2.2		1982	8	2018	24	46079	0.04
25r	margin, osc zon, fractures	707	438	493	0.63	13.218	1.16	1.959	1.14	0.1878	0.21	0.98	-2.9	-0.5	2723	3	2659	25	53116	0.04

Isotope values are common Pb corrected using modern common Pb composition (Stacey & Kramers 1975) and measured ^{204}Pb.
1 Th/U ratios calculated from ^{208}Pb/^{206}Pb and ^{207}Pb/^{206}Pb ratios corrected for Pb_{com}, assuming a single stage of closed U-Th-Pb evolution
2 Error correlation in conventional concordia space. Do not use for Tera-Wasserburg plots.
3 Age discordance in conventional concordia space. Positive numbers are reverse discordant.
4 Age discordance at closest approach of error ellipse to concordia (2σ level).
5 Percent of common ^{206}Pb in measured ^{206}Pb, estimated from ^{204}Pb assuming a present-day Stacey & Kramers (1975) model. Figures in parentheses are given when no correction has been applied.

Spots aimed at core domains record variable ages. The oldest analysis is 4% reversely discordant and has a $^{207}Pb/^{206}Pb$ age at 2880 ±8 Ma (2σ, 11c). The other core analyses record concordia ages at 2738 ±11 Ma (n=2; 3c, 10c), 2697 ±9 Ma (n=2; 2c, 12c), 2084 ±14 Ma (n=1; 15c), 2021 ±11 (n=2, 1c, 19c), 1986 ±8 Ma (n=5, 4c, 14c, 17c, 21 c, 23c), and 1934 ±13 Ma (n=1; 20c).

The spots aimed at texturally young BSE-bright rim domains are characterized by high U content and low Th/U ratios. Two of these analyses (5r1, 13r are slightly discordant (-4.9%, -3.2%). The other four analyses are concordant with a concordia age at 1884 ±7 Ma (MSWD of concordance and equivalence = 3.1, probability of concordance = 0.84, 95% confidence level). However, obvious from the concordia diagram, one of the analyses (4r2) has a slightly older age ($^{207}Pb/^{206}Pb$ age at 1895 ±6 Ma, 2σ) compared to the other analyses, possibly due to mixing with an older age component. Excluding that analysis will lower the concordia age to 1878 ±4 Ma (MSWD of concordance and equivalence = 0.15, probability of concordance = 0.69, 2σ, n=3), which is identical to the weighted $^{207}Pb/^{206}Pb$ mean age at 1878 ±4 Ma (MSWD = 0.27, probability = 0.76). The concordia age at 1878 ±4 Ma is suggested to date metamorphic, secondary formed zircon domains during migmatisation.

DISCUSSION AND CONCLUSION

The variable ages of the oscillatory zoned zircon core domains suggest a detrital origin of the zircon, and a sedimentary precursor to the dated migmatitic gneiss. One older group with Archaean ages at 2.92−2.70 Ga and a younger group with ages between 2.08 and 1.93 Ga (n = 14) reveals that clastic material was derived from several, differently aged igneous source rocks. The youngest concordant analysis sets the maximum age for deposition of the sediments at c. 1.93 Ga (concordia age of the youngest analysis, no 20c).

U-Pb analyses of secondary BSE-bright zircon rim domains from the stromatic, metatexitic migmatite are interpreted to date migmatisation at 1878±4 Ma. These rim analyses have very low Th/U ratios in contrast to core analysis, which give support to a metamorphic origin of the rims. The results show that the Boden area underwent early orogenic Svecokarelian migmatisation and deformation at c. 1.88 Ga, similar to the Masugnsbyn area, c. 175 km to the north (c.f. Hellström *in press*). The 1.88 Ga migmatisation is suggested to be caused by heat transfer from large volumes of contemporaneous early orogenic Svecokarelian intrusions (Hellström et al. 2015, Hellström *in press*).

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