U-Pb zircon ages of ignimbritic and porphyritic metarhyolites in the Boden area, northern Sweden

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Cover: Quarry at Grassmyrberget. View to the NW.
Photo: Martiya Sadeghi.

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ABSTRACT
In the Luleå–Boden area of south-eastern Norrbotten, the Luleå porphyries form small segregated occurrences intruded by plutonic rocks and consist mainly of metaandesite, but also of felsic porphyritic tuffs and lavas. Two samples of metarhyolite from the Boden area were dated at 1886±4 Ma and at 1884±5 Ma using U-Pb SIMS analyses on zircon. The age and geochemical signature of these volcanic rocks suggests affinity to the Porphyrite group further north rather than the Arvidsjaur group to the west.

SAMMANFATTNING
I Luleå–Bodenområdet i sydöstra Norrbotten bildar Luleåporfyrerna små, spridda förekomster som intruderats av djupbergarter. Porfyrerna består huvudsakligen av metaandesit, men också av felsiska, porfyriska tuffer och lavor. Två prover av metaryolit från Bodenområdet har daterats till 1886±4 miljoner år och 1884±5 miljoner år genom U-Pb-SIMS-analyser på zirkon. Åldern och den geokemiska signaturen för dessa vulkaniska bergarter antyder att de tillhör porfyritgruppen, som främst förekommer längre norrut, snarare än Arvidsjaurgruppen som förekommer i väster.

Keywords: Boden, felsic volcanic rocks, rhyolite, zircon, radiometric age, Svecokarelian orogen, Svecofennian, Fennoscandian shield

INTRODUCTION

Large amounts of volcanic rocks formed in northernmost Sweden during the Svecokarelian orogeny at c. 1.9 Ga. The subaerial Kiruna–Arvidsjaur porphyries are bordered to the south by submarine volcanic rocks of the Skellefte ore district (Lundberg 1980, Wischard 1984, Perdahl & Frietsch 1993). Perdahl & Frietsch (1993) divided the subaerial volcanic rocks into different subprovinces on basis of regional differences in geochemical and lithological characteristics. In the eastern part of southern Norrbotten, the Luleå porphyries form small, segregated occurrences intruded by plutonic rocks and consist mainly of andesite, but also of felsic porphyritic tuffs and lavas (Wikström & Söderman 2000). The geochemical signature suggests that they formed in a calc-alkaline volcanic arc along an active continental margin (Perdahl & Frietsch 1993, Perdahl 1995), in similarity with the Porphyrite group further to the north. To the west, the Arvidsjaur porphyries form large volumes of subaerially erupted, dacitic to rhyolitic, in part ignimbritic ash flow tuffs and plagioclase porphyric andesitic lavas (Grip 1935, Perdahl & Frietsch 1993, Perdahl & Einarsson 1994). The Skellefte group is composed predominantly of dacite to rhyolite intercalated with andesitic to basaltic volcanic rocks (Bergman Weihed et al. 1996). Radiometric ages of 1.89–1.88 Ga have been obtained from volcanic rocks of the Skellefte group (Billström & Weihed 1996, Kathol & Triumf 2004).

Several radiometric U-Pb zircon age determinations date the extrusion of the Arvidsjaur volcanic rocks at 1.88–1.86 Ga (Skiöld et al. 1993, Lundqvist et al. 2000, Lundström & Persson 1999, Kathol & Triumf 2004, Kathol et al. 2008, Morris et al. 2015). However, there are no previous age determinations of the Luleå volcanic rocks.

In the Boden area, which is part of the Luleå subprovince (Perdahl & Fritsch 1993), a felsic to mafic sequence of volcanic rocks occurs spatially associated with intrusive rocks. Two volcanic samples, an ignimbritic metarhyolite and a porphyritic metarhyolite, have been dated to investigate if the volcanic rocks in the Luleå–Boden area are similar in age to the rocks of the Arvidsjaur group or not, and to investigate the age relationship between intrusive and extrusive rocks (Fig. 1).

The Boden area is situated close to the proposed Archean–Proterozoic transition zone delineated by extensive Sm-Nd isotope work on granitoids (Öhlander et al. 1993, Mellqvist et al. 1999). Following the Archean–Proterozoic paleoboundary to the east into Finland, gneissic tonalites and related acid metavolcanic rocks in the Savo schist record ages at 1.93–1.91 Ga (Helovuori 1979, Korsman et al. 1984, Vaasjoki & Sakko 1988, Kousa et al. 1994, Lahtinen & Huhma 1997, Vaasjoki et al. 2003, Kousa et al. 2013). It is thus even possible that the intrusive and extrusive rocks in the Boden area belong to this older suite of igneous rocks.

SAMPLE DESCRIPTIONS

Two samples of metarhyolite were taken for age determinations, one sample (MSI090039A) at Statsskölhuvudet 25 km north-west of Boden and one sample (RKN100048A) from a quarry a Grassmyrberget, 11 km east of Boden (Table 1). Whole rock geochemistry of the samples is reported in Table 2.

MSI090039A

The dated rock from Statsskölhuvudet is a metarhyolite with ignimbritic texture. The rock is light reddish grey in weathered surfaces and greyish in fresh surfaces, fine-grained and fractured. The sample was taken close to the contact to interbedded mafic metavolcanic rocks (Fig. 2A). Whole rock geochemistry diagrams show that the selected sample is located in the rhyolite field (Table 2) and it contains fine-grained aggregates composed of quartz, feldspar and biotite (Fig. 3A). The contents of TiO_2 and Zr in the dated sample are low, which suggests affin-

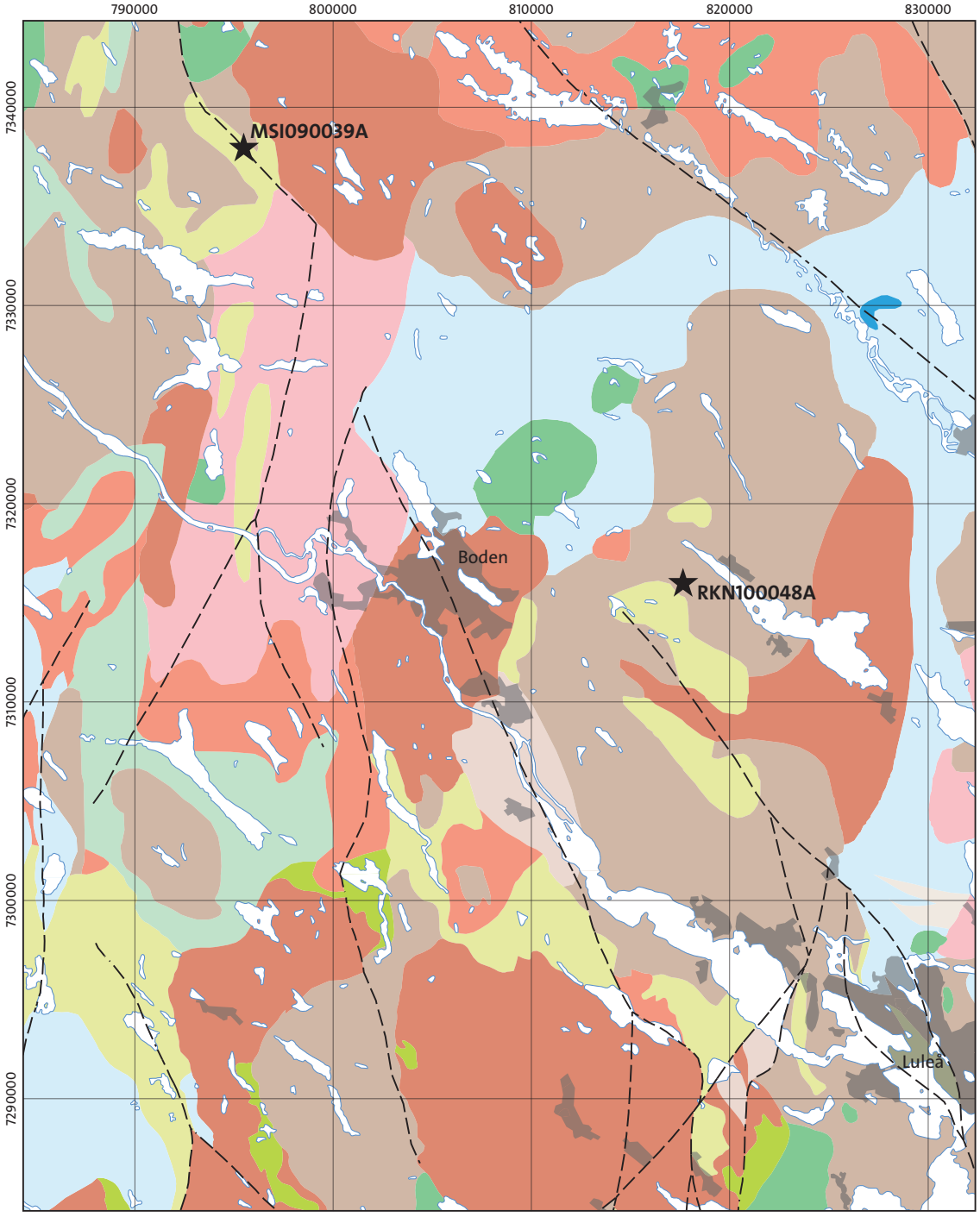

Figure 1. Geological map of the Luleå–Boden area, modified after the SGU 1:1 million bedrock geology database. Locations of dated samples are marked on the map.

Table 1. Summary of sample data.

Sample number:	**MSI090039A**	**RKN100048A**
Rock type:	Rhyolite	Rhyolite
Tectonic domain:	Svecokarelian orogen	Svecokarelian orogen
Tectonic subdomain:	Norrbotten lithotectonic unit	Norrbotten lithotectonic unit
Stratigraphic group:	Luleå porphyries	Luleå porphyries
Lab-id (Nordsim):	n3578	n4394
Coordinates	7337964/795484 (Sweref99 TM)	7316089/817673 (Sweref99 TM)
Map sheet:	73H-3jNO (Sweref99 TM)	73i, 1b NO (Sweref99 TM)
	25L Boden (RT90)	25L Boden (RT90)
Locality:	Statsskölhuvudet	Quarry, Grassmyrberget
Project:	Jäkkvik–Boden	Jäkkvik–Boden

Table 2. Whole rock geochemical data of dated samples MSI090039 and RKN100048A. The samples were analysed at ACME Labs. Major oxides and several minor elements were analysed by ICP-emission spectrometry following a lithium metaborate fusion and dilute nitric digestion. Precious and base metals were analysed by ICP-MS and digested in aqua regia.

Sample	**MSI090039A**	**RKN100048A**
x	795484	817673
y	7337964	7316089
Analyte	Rock pulp	Rock pulp
SiO_2	67.78	64.17
Al_2O_3	15.73	16.88
Fe_2O_3	3.64	4.25
MgO	0.66	1.28
CaO	2.04	3.38
Na_2O	4.51	4.7
K_2O	4.10	3.42
TiO_2	0.45	0.52
P_2O_5	0.10	0.16
MnO	0.05	0.09
Cr_2O_3	<0.002	0.003
Sc	8	13
Ba	1264	1258
Be	1	3
Co	4.2	6.5
Cs	3.3	2.3
Ga	17.6	20.5
Hf	7.8	6.8
Nb	10.8	14.8
Rb	99.9	83.2
Sn	1	2
Sr	292.1	468.1
Ta	0.6	1
Th	6.3	15.3
U	1.9	4.5
V	18	33
W	<0.5	1.4
Zr	296.3	260.6
LOI	0.7	0.9

Sample	**MSI090039A**	**RKN100048A**
La	22.1	43.5
Y	16.6	26.7
Ce	46.5	91.3
Pr	5.38	10.19
Nd	20.8	38.9
Sm	3.97	6.83
Eu	1.00	1.54
Gd	3.12	5.44
Tb	0.51	0.86
Dy	2.84	4.65
Ho	0.54	0.91
Er	1.70	2.51
Tm	0.25	0.4
Yb	1.71	2.55
Lu	0.26	0.37
TOT/C	0.04	<0.02
TOT/S	<0.02	<0.02
Mo	1.0	1.7
Cu	19.7	16.4
Pb	4.0	7.2
Zn	53	64
Ni	2.1	5.6
As	2.7	2.2
Cd	<0.1	<0.1
Sb	0.3	0.2
Bi	<0.1	<0.1
Ag	0.2	<0.1
Au	<0.5	<0.5
Hg	<0.01	<0.01
Tl	0.3	0.1
Se	<0.5	<0.5

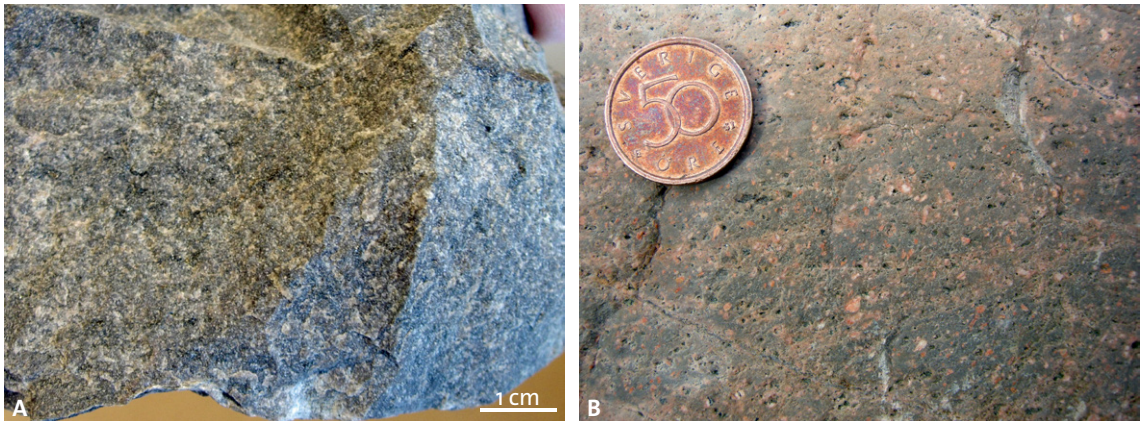

Figure 2. **A.** Dated ignimbritic metarhyolite sample (MSI090039A). **B.** Dated sample with rhyolite composition and sparsely feldspar porphyritic texture (RKN100048A).

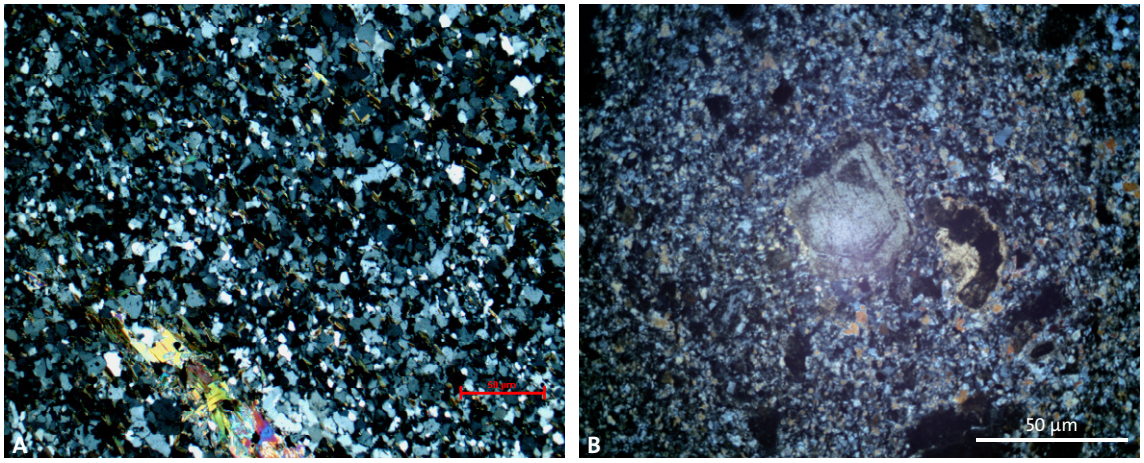

Figure 3. **A.** Photomicrograph of sample MSI090039 showing a fine grain aggregates composed of quartz, feldspar and biotite. Cross-polarized light. Scale bar is 50 µm. **B.** Photomicrograph of sample RKN100048A showing a K-feldspar megacryst and aggregates composed of feldspar and quartz. Scale bar is 50 µm.

ity to the Arvidsjaur group or Porphyrite group (Fig. 4). See Perdahl & Frietsch (1993) and Bergman et al. (2001) for more details on classification of volcanic rocks in the north of Sweden.

RKN100048A

The rock sample from Grassmyrberget is a fine-grained metarhyolite which is grey to reddish grey and has a feldspar porphyritic texture (Fig. 2B). Whole rock geochemistry of this sample is quite similar to that of the sample MSI090039 (Table 2 and Fig. 4) but the latter contains K-feldspar megacrysts and aggregates composed of feldspar and quartz (Fig. 3B). Chemically, based on Zr and TiO_2 content, the Grassmyrberget sample could also be classified as belonging to either the Arvidsjaur or Porphyrite groups (Fig. 4).

GEOCHRONOLOGY

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

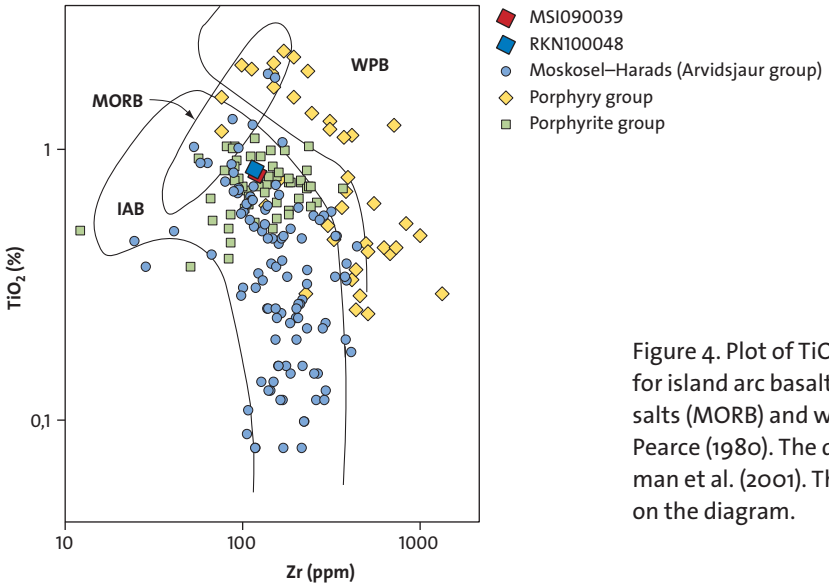

Figure 4. Plot of TiO_2 vs Zr. Discrimination fields for island arc basalts (IAB), mid-ocean ridge basalts (MORB) and within-plate basalt (WPB) from Pearce (1980). The diagram is adapted from Bergman et al. (2001). The dated samples are marked on the diagram.

mounts were polished and after gold coating examined by back-scatter electron (BSE) imaging, using standard electron microscopy at the Evolutionary Biology Centre (EBC), Uppsala University. High-spatial resolution secondary ion masspectrometer (SIMS) analysis was done in March 2010 (MSI090039) and December 2012 (RKN100048A) using a Cameca IMS 1270-1280 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). 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}Pb. Decay constants follow the recommendations of Steiger & Jäger (1977). Diagrams and age calculations of isotopic data were made using the software Isoplot 4.15 (Ludwig 2012). BSE and cathodoluminescense imaging was also done after SIMS analyses at the Department of Geology, Uppsala University.

MSI090039A

Zircon grains in the heavy mineral concentrate have mainly subhedral to euhedral, short prismatic shapes with somewhat rounded edges and tips. The zircon is transparent to semitransparent and colourless. BSE images show an internal oscillatory zonation in the zircon grains (Fig. 5). The uranium content of the analysed zircon varies between 152 and 658 ppm and Th/U ratios are 0.35–0.97 (n = 9, Table 3). Eight data points are concordant and yield a concordia age of 1886±4 Ma (2σ, MSWD of concordance and equivalence = 1.5, probability = 0.087), identical to the weighted average $^{207}Pb/^{206}Pb$ age of 1886±5 Ma (2σ, MSWD = 1.9). The concordia age of 1886±4 Ma is interpreted to date igneous crystallisation of the studied metarhyolite (Fig. 6).

RKN100048A

The heavy mineral separate is poor in zircon, and the grains or fragments of grains found are small, subhedral to euhedral and somewhat turbid. Microcracks and inclusions are common. BSE images show an internal oscillatory zonation in most zircons, although diffuse and weakly developed (Fig. 5).

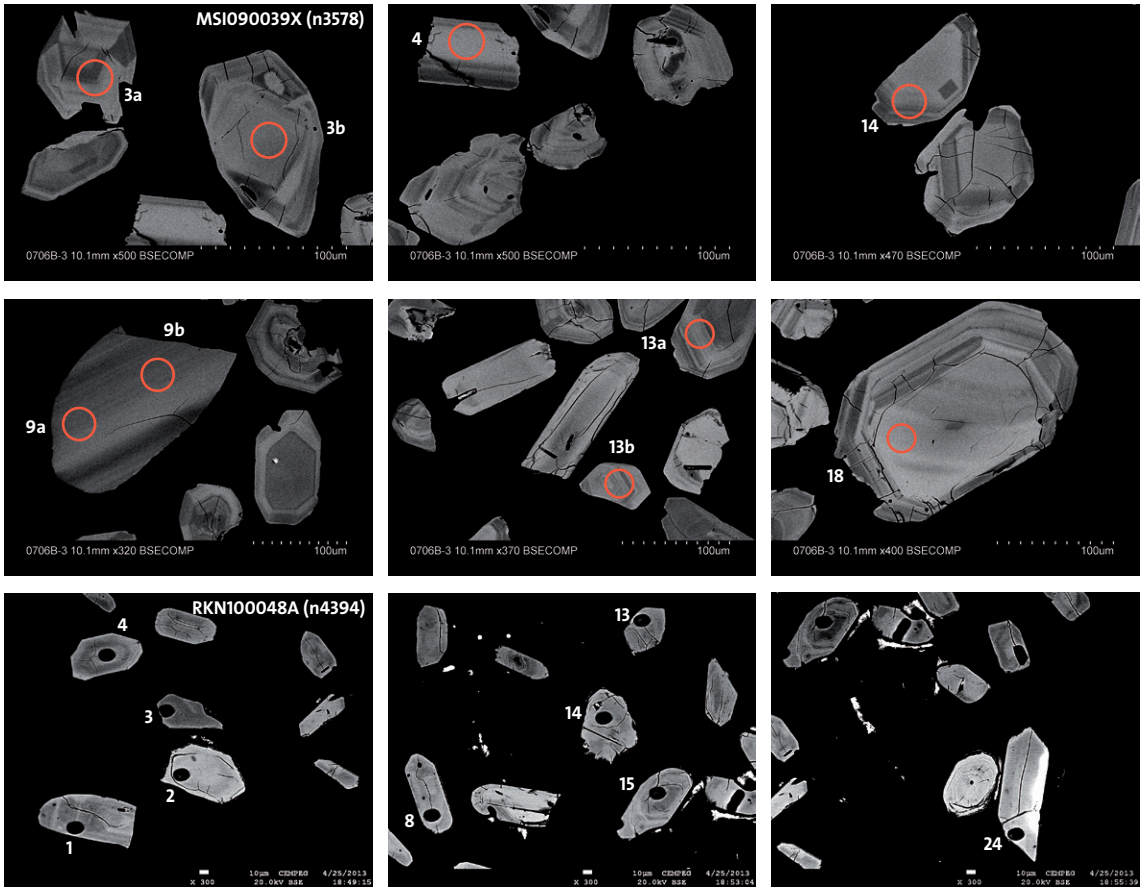

Figure. 5. BSE images of zircon from the dated samples. Red circles mark the approximate location of analysed spots. Numbers refer to analytical spot number in Table 3. Image MSI090039X: Andreas Petersson. Image RKN100048A: Fredrik Hellström.

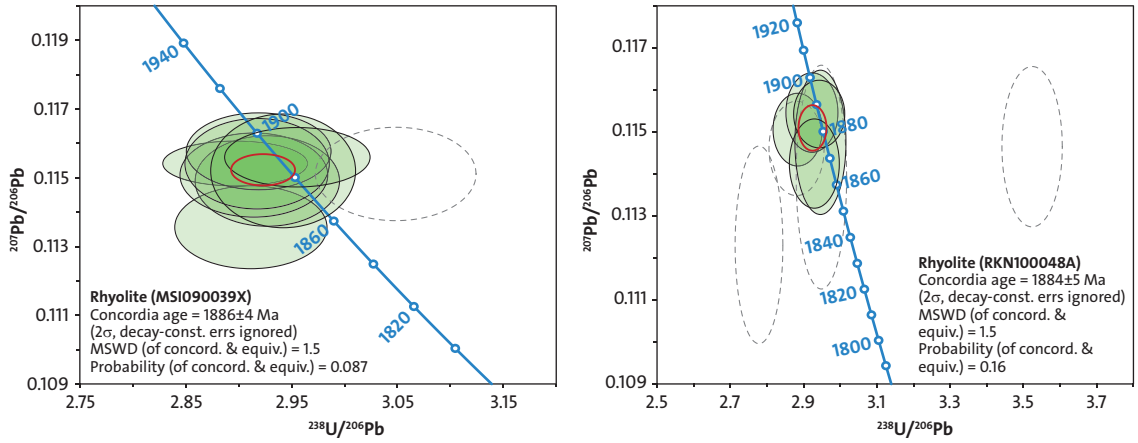

Figure. 6. Terra Wasserburg diagram showing U-Pb SIMS zircon data. Analyses marked with broken lines are discordant or have high common lead values and are not used in age calculations. Error ellipse of calculated weighted mean age is shown in red.

Table 3. SIMS U-Pb-Th zircon data for the samples MSI090039X (n3578) and RKN100048 (n4394).

Sample	U (ppm)	Th (ppm)	Pb (ppm)	Th/U calc.[1]	$^{238}U/^{206}Pb$	±σ (%)	$^{207}Pb/^{206}Pb$	±σ (%)	Disc. % conv.[2]	Disc. % 2σ lim.[3]	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	$^{206}Pb/^{204}Pb$ measured	$f_{206}\%$[4]
MSI090039X																
n3578-3a	193	100	84	0,54	2,911	1,01	0,1136	0,43	2,9		1857	8	1904	17	61093	0,03
n3578-3b	198	111	86	0,57	2,942	0,95	0,1152	0,59	0,2		1883	11	1886	16	17989	0,10
n3578-4	658	611	316	0,97	2,896	0,96	0,1154	0,23	1,6		1887	4	1912	16	36113	0,05
n3578-9b	152	109	69	0,76	2,927	0,95	0,1149	0,47	1,0		1879	8	1895	16	167300	{0.01}
n3578-9a	183	139	84	0,79	2,914	0,98	0,1151	0,43	1,3		1881	8	1902	16	55710	0,03
n3578-13a	211	77	89	0,38	2,919	0,96	0,1158	0,39	0,4		1892	7	1899	16	217091	{0.01}
n3578-13b	282	116	114	0,40	3,048	1,02	0,1151	0,48	–3,2	–0,25	1882	9	1829	16	48174	0,04
n3578-14	233	77	97	0,35	2,917	0,96	0,1154	0,47	0,8		1886	8	1900	16	72544	0,03
n3578-18	455	328	204	0,71	2,955	0,95	0,1156	0,31	–0,6		1889	5	1879	16	165140	{0.01}
RKN100048A																
n4394-01	197	62	81	0,32	2,928	0,95	0,1143	0,38	1,6		1868	7	1894	16	127003	{0.01}
n4394-02	372	214	162	0,58	2,942	0,97	0,1154	0,28	-0,0		1887	5	1886	16	143787	0,01
n4394-04	275	180	120	0,59	2,945	0,97	0,1148	0,61	0,5		1876	11	1885	16	5441	0,34
n4394-08	266	74	109	0,28	2,922	0,99	0,1155	0,33	0,6		1887	6	1898	16	527398	{0.00}
n4394-24	337	134	143	0,38	2,883	0,95	0,1151	0,31	2,4		1881	6	1920	16	50911	0,04
n4394-03	94	48	42	0,54	2,778	0,96	0,1123	0,86	9,2	4,6	1837	15	1982	16	2388	0,78
n4394-13	459	272	204	0,58	2,881	1,07	0,1146	0,40	2,9	0,0	1874	7	1921	18	2505	0,75
n4394-14	240	145	105	0,63	2,948	0,95	0,1139	0,96	1,2		1863	17	1883	16	421	4,44
n4394-15c	206	141	74	0,45	3,524	0,96	0,1146	0,68	–15,9	–12,4	1874	12	1610	14	1640	1,14
n4394-15r	307	195	131	0,34	2,709	2,24	0,0879	20,35	54,5		1381	348	2025	39	127	14,76

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, assuming a single stage of closed U-Th-Pb evolution.
2. Age discordance in conventional concordia space. Positive numbers are reverse discordant.
3. Age discordance at closest approach of error ellipse to concordia (2σ level).
4. Figures in parentheses are given when no common Pb correction has been applied, and indicate a value calculated assuming present-day Stacey-Kramers common Pb.
Analyses in gray are high in common lead and are not used in age calculations.

Ten analyses were performed and these show a uranium content of 94–460 ppm and Th/U ratios of 0.28–0.63 in (Table 3). Five analyses (3, 13, 14, 15c, 15r) record high values of common lead (f_{206} = 0.75–14.8%) and were excluded from the age calculations. The five remaining analyses are concordant at the 2σ level with a concordia age of 1884±5 Ma (Fig. 6, MSWD of concordance and equivalence = 1.5, probability = 0.16, n = 5). The weighted average age for concordant analyses is 1882±6 Ma (MSWD = 1.5, probability = 0.20, n = 5). The concordia age of 1884±5 Ma was chosen as the best age estimate interpreted to date igneous crystallisation of the metarhyolite.

DISCUSSION AND CONCLUSION

The contents of TiO_2 and Zr in the Luleå porphyries are low, which suggests an affinity to either the Arvidsjaur group or the Porphyrite group (c.f. Perdahl & Frietsch 1993, Bergman et al. 2001). In the Boden area, two samples of metarhyolites belonging to the Luleå porphyries, are dated at 1886±4 Ma and 1884±5 Ma, indicating that these subaerial metavolcanic rocks have been deposited synchronously at c. 1.89–1.88 Ga.

The Luleå porphyries in the south-eastern part of Norrbotten are thus possibly slightly older than the 1.88–1.86 Ga volcanic rocks of the Arvidsjaur group that occur to the west, but similar in age to volcanic rocks of the c. 1.88 Ga Porphyrite group to the north (Bergman et al. 2001, Edfelt et al. 2006).

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