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U-Pb zircon age of an Arvidsjaur group rhyolite at Makkavare in the Arjeplog area, northern Sweden

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Cover: The Bure formation at Makkavare. An outcrop of volcanoclastic rock showing cross bedding and a channel structure. Pencil (15cm) for scale.

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ABSTRACT

Felsic and intermediate volcanic rocks of the Bure formation occur in the Arjeplog–Sorsele area, north-west of the Skellefte ore district. A rhyolite at Makkavare, 20 km north of Bure, has been dated at 1869 ± 6 Ma using U-Pb SIMS zircon analyses. We propose that the Makkavare rhyolite belongs to the Bure formation and that this part of the formation itself should be dated at 1.87 Ga rather than the previously reported age of c. 1.86 Ga. This age and the subaerial character of the volcanic rocks assign the Bure formation to the 1.88–1.86 Ga Arvidsjaur group, which formed in an arc that possibly youngs and evolves to a more alkaline and zirconium-rich composition to the west. A lower intercept age of 463 ± 20 Ma, defined by a regression line of strongly discordant data, is suggested to represent episodic leaching of lead from metamict zircon domains, possibly including a regional fluid event during the Caledonian orogeny coinciding with the recently suggested age of c. 465 Ma for the Laisvall Pb-Zn deposit.

Keywords: Svecokarelian orogen, Svecofennian, Arvidsjaur group, Bure formation, radiometric age, zircon, U-Pb, Makkavare

SAMMANFATTNING

Felsisk och intermediära vulkaniska bergarter tillhörande Bureformationen uppträder i Arjeplog–Sorseleområdet, nordväst om Skelleftefältet. En ryolit på Makkavare, 20 km norr om Bure, har daterats till 1869 ± 6 miljoner år med hjälp av U-Pb-SIMS-analyser på zirkon. Vi föreslår att Makkavareryoliten tillhör Bureformationen och att bildningen av denna del av formationen bör dateras till 1,87 miljarder år, snarare än den tidigare rapporterade åldern ca 1,86 miljarder år. Denna ålder och den subaeriska karaktären av de vulkaniska bergarterna gör att Bureformationen bör föras till den 1,88–1,86 miljarder år gamla Arvidsjaurgruppen, vars bergarter bildades i en öbåge som möjligen blev yngre och utvecklades till mer basiska och zirkoniumrika sammansättningar mot väster. En lägre interceptålder av 463 ± 20 miljoner år, som definieras av en regressionslinje genom starkt diskordanta data, föreslås representera episodisk urlakning av bly från metamikta zirkondomäner. Detta kan eventuellt kopplas till en regional rörelse av fluider i samband med den kaledonska orogenen, och den lägre interceptåldern sammanfaller med den nyligen föreslagna åldern ca 465 miljoner år för bly-zinkmineraliseringen i Laisvall.

INTRODUCTION

Felsic and intermediate volcanic rocks of the Bure formation occur in the Arjeplog–Sorsole area, north-west of the Skellefte ore district in northern Sweden (Figs. 1–2, Perdahl & Einarsson 1994, Eliasson et al. 2003, Kathol & Weihed 2005). A U-Pb zircon dating of a rhyolite from the type locality at Bure, approximately 20 km south-south-west of the current sample site (Fig. 2), yielded an age of 1860 ± 7 Ma (Skiöld et al. 1993). Due to this age and the subaerial character of the volcanic rocks, Eliasson et al. (2003) and Kathol & Weihed (2005) assigned the felsic volcanic rocks at Bure to the 1.88–1.86 Ga old Arvidsjaur group. This had already been suggested by Högbom (1931, 1937), who was the first to describe the volcanic rocks of the Bure area. Perdahl & Einarsson (1994) and Perdahl (1995), however, distinguish the subaerial volcanic rocks in the Bure–Arjeplog area from the Arvidsjaur group rocks *sensu stricto* by geochemical means



Figure 1. Lithotectonic map of the Fennoscandian Shield modified from Koistinen et al. (2001).

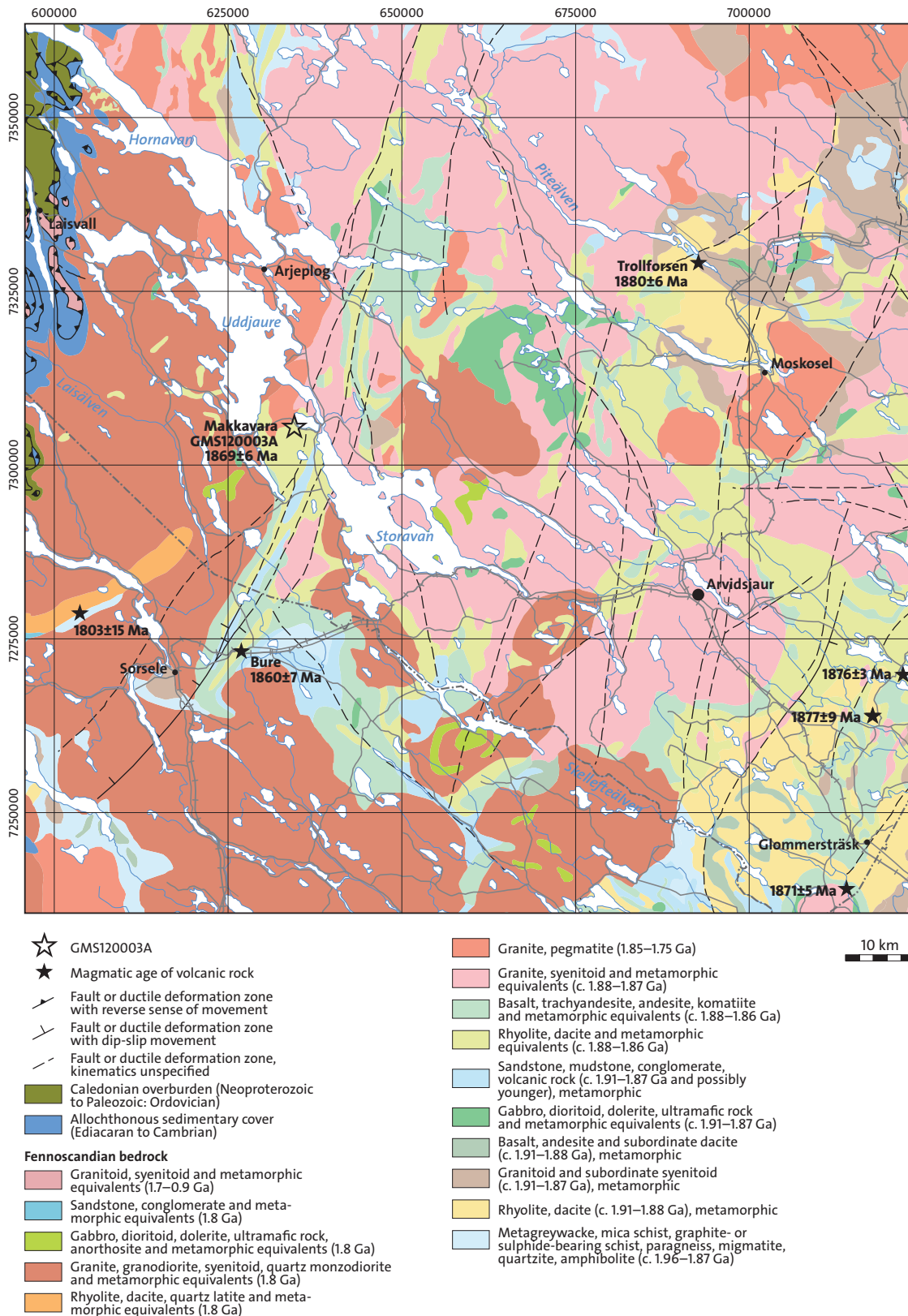


Figure 2. Bedrock geology of the Arjeplog–Arvidsjaur area, modified from the SGU 1:1 million bedrock geology database. Selected U–Pb age determinations of volcanic rocks extracted from SGU’s radiometric age database. References to the age determinations in the map: Skiöld (1988), Skiöld et al. (1993), Bergström et al. (2003), Kathol & Triumf (2004) and Kathol et al. (2008).

Table 1. Summary of sample data.

Rock type:	Rhyolite
Tectonic domain:	Svecokarelian orogen
Tectonic subdomain:	Bothnia–Skellefteå province
Stratigraphic unit:	Svecofennian supracrustal rock
Lithostratigraphic unit:	Arvidsjaur group
Sample number:	GMS120003A
Coordinates:	7305649/634580 (Sweref 99TM)
Map sheet:	25H Arjeplog 1j (RT90)
Locality:	Makkavare
Project:	Barents

and defined them as the Arjeplog porphyries. The felsic varieties of the porphyries (the Bure formation) generally have higher zirconium contents than those of the Arvidsjaur group and are mildly alkaline (Perdahl & Einarsson 1994), whereas the felsic rocks of the Arvidsjaur group are calc-alkaline. Perdahl & Einarsson conclude that the Bure formation of the Arjeplog porphyries constitutes a late-stage subunit of the Arvidsjaur porphyries, i.e. the Arvidsjaur group, but may represent a separate volcanic event.

There are, however, metavolcanic rocks situated to the north of the Arvidsjaur and Bure areas which are older than the “classic” Arvidsjaur group rocks. Felsic to intermediate metavolcanic rocks that occur at Skuppesavon c. 30–50 km north and north-east of Arjeplog have preliminary been dated at 1.89–1.88 Ga (Hellström & Berggren 2014). At Trollforsen in the Abmoälven area, c. 60 km east-north-east of Makkavare, an age of 1880 ± 6 Ma (Kathol et al. 2008) has been obtained from a coherent, feldspar-porphyrific rhyolite within a mainly volcanoclastic sequence (Fig. 2, Falk 1973). This sequence has been distinguished from the rocks of the Arvidsjaur group in the 25J Moskosel map areas (Hartvig & Aaro 2012a, b, Kathol & Aaro 2012).

The rhyolite from Makkavare in the north-western part of the Bure volcanic sequence has been dated to give additional information about whether the volcanic rocks in the Bure formation are constrained to a volcanic event around 1.86 Ga, or at a time in the wider time spectrum of 1.89–1.86 Ga volcanic events. In the latter case, correlation with the 1.88–1.89 Ga old rocks at Skuppesavon and Trollforsen is possible. Together with the dating of a rhyolite from Tjåresvare in the north-eastern part of the 26H Jäkkvik map area (SGU, unpublished), the result will give a better understanding of the volcanic rocks in the map areas 24H Sorsele, 25H Arjeplog, 25I Stensund and 26H Jäkkvik.

SAMPLE DESCRIPTION

The sample was collected from a small outcrop on the north-eastern slope of Makkavare, c. 220 m south-west of the road between Aspberg and Lappheden (Fig. 2). The sampled rock is a quartz-porphyrific, red volcanoclastic rhyolite with 2–5 mm phenocrysts (Fig. 3). A foliation is defined by the orientation of small quartz phenocrysts.

ANALYTICAL RESULTS AND INTERPRETATION OF GEOCHRONOLOGICAL DATA

Zircons were obtained from a density separate of a c. 0.5 kg crushed rock sample using a Wilfley water table, and magnetic minerals were removed with hand magnet. Hand-picked crystals were mounted in transparent epoxy resin together with chips of the reference zircon 91500. The zircon mount was polished and, after gold coating, examined by back-scatter electron (BSE) and cathodoluminescence (CL) imaging using the electron microscope at the Department of Geology, Uppsala University. High-spatial resolution secondary ion mass spectrometer (SIMS)

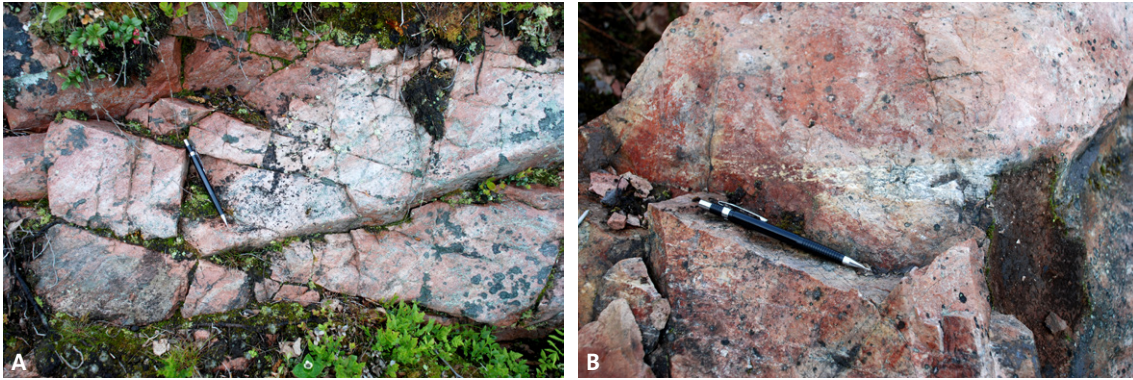


Figure 3. Volcaniclastic rhyolite from Makkavare. A. Relic cross-bedding, thought to be part of a channel structure, from the pyroclastic deposition of this rock. B. Small channel structure in outcrop.

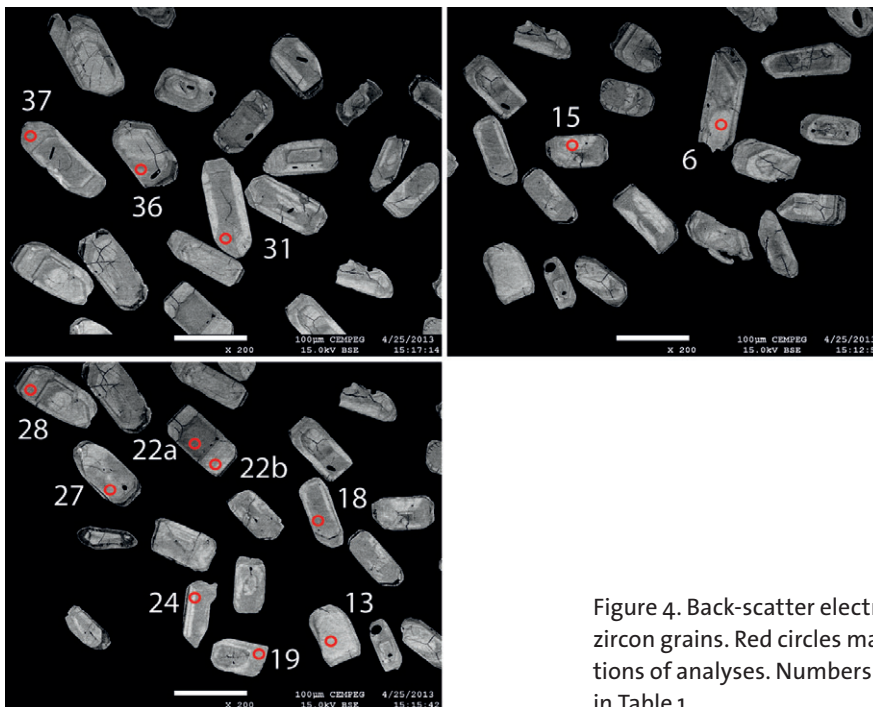


Figure 4. Back-scatter electron images of analysed zircon grains. Red circles mark the approximate locations of analyses. Numbers refer to analytical spots in Table 1.

analysis was carried out in May 2013 using the Cameca IMS 1270 (upgraded to an IMS 1280) at the Nordsim facility of 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 lead corrected isotope values were calculated using modern common lead composition (Stacey & Kramers 1975) and measured ^{204}Pb . Decay constants follow the recommendations of Steiger & Jäger (1977). The analytical spot size was c. 15–20 μm . Diagrams and age calculations of isotopic data were made using the Isoplot 4.15 software (Ludwig 2012).

The heavy mineral concentrate contained small, subhedral to euhedral, prismatic zircons. Most grains are turbid and contain microcracks, but there are also transparent, colourless crystals that were selected for analysis. BSE and CL images reveal an internal oscillatory zonation in most zircon grains, and in some grains there may be inherited cores (Figs. 4–5). Microcracks

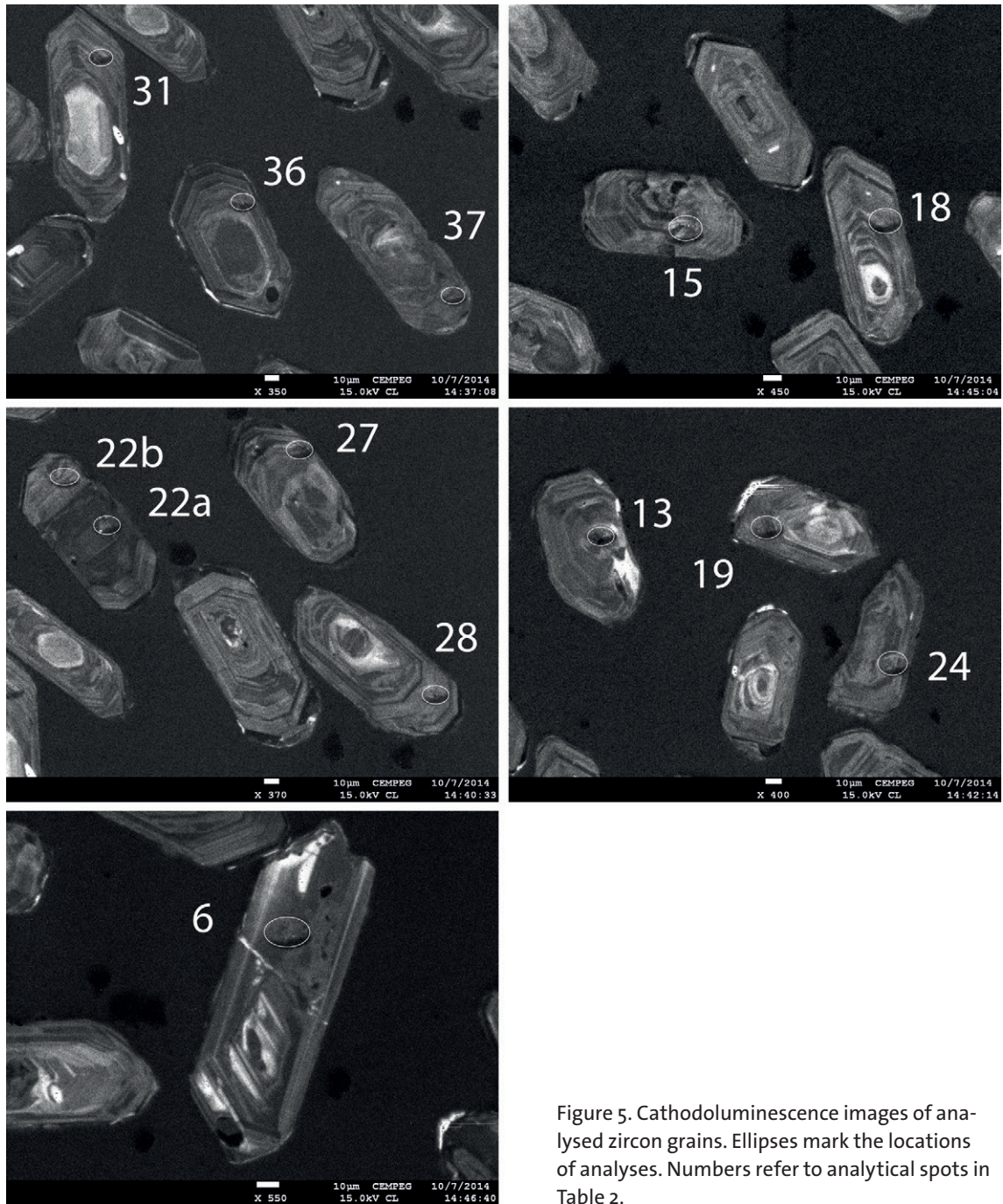


Figure 5. Cathodoluminescence images of analysed zircon grains. Ellipses mark the locations of analyses. Numbers refer to analytical spots in Table 2.

are common in most grains. The uranium content of analysed zircon varies between 330 and 1546 ppm and the Th/U ratios vary between 0.18 and 0.87.

Most analyses are highly discordant and record high values of common lead (Table 2). The degree of discordance is positively correlated with the uranium content, suggesting lead loss from metamict zircon domains, i.e. the degree of radiation damage is controlled by the amount of uranium in the zircons. Only three analyses (no. 6, 13, 27) are near concordant, i.e. 0.6%, 2.1% and 4.8% reversely discordant (Fig. 6, Table 2). The weighted $^{207}\text{Pb}/^{206}\text{Pb}$ average age of these analyses is 1872 ± 7 Ma (2σ , MSWD = 2.1, probability = 0.12, $n = 3$). Two of these (no. 6 and 13) are concordant at the 2σ limit, with a concordia age of 1870 ± 8 Ma (MSWD of concord-

Table 2. SIMS U-Pb-Th zircon data (GMS120003A).

Analysis	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 age (Ma)	²⁰⁶ Pb/ ²³⁸ U ±σ age (Ma)	²⁰⁶ Pb/ ²⁰⁴ Pb measured	f ₂₀₆ %
n4593-06	Osczon	469	406	215	0.87	5.279 0.93	2.972 0.85	0.1138 0.38	0.91	0.6		1861 7	1870 14	74269	0.03
n4593-13	Osczon	330	175	144	0.55	5.437 1.08	2.905 1.04	0.1146 0.31	0.96	2.1		1873 6	1907 17	102189	0.02
n4593-15	Osczon	875	301	243	0.25	3.402 0.92	4.329 0.88	0.1068 0.27	0.96	-25.7	-23.9	1746 5	1340 11	4581	0.41
n4593-18	Osczon	888	290	238	0.28	3.185 1.09	4.542 1.06	0.1049 0.26	0.97	-27.7	-25.7	1713 5	1283 12	19281	0.10
n4593-19	Osczon	893	324	276	0.29	3.840 0.92	3.929 0.90	0.1094 0.20	0.97	-20.5	-18.8	1790 4	1462 12	18647	0.10
n4593-22a	Osczon, centre	1546	789	199	0.28	1.136 2.58	9.705 2.20	0.0800 1.36	0.85	-49.5	-40.7	1197 27	632 13	900	2.08
n4593-22b	Osczon	745	150	249	0.18	4.377 1.03	3.502 1.00	0.1112 0.26	0.97	-12.4	-10.3	1819 5	1619 14	7977	0.23
n4593-24	Osczon	738	224	199	0.22	3.287 2.37	4.412 2.27	0.1052 0.68	0.96	-25.7	-21.1	1717 12	1317 27	6440	0.29
n4593-27	Osczon	571	191	246	0.37	5.612 1.06	2.822 1.02	0.1149 0.27	0.97	4.8	2.3	1878 5	1955 17	43103	0.04
n4593-28	Osczon	880	248	220	0.20	3.044 1.02	4.746 0.98	0.1048 0.27	0.96	-30.6	-28.7	1710 5	1233 11	8013	0.23
n4593-31	Osczon	752	220	251	0.25	4.277 1.02	3.590 0.98	0.1114 0.25	0.97	-14.7	-12.7	1822 5	1584 14	19436	0.10
n4593-36	Osczon	703	443	223	0.44	3.734 1.08	4.023 1.03	0.1089 0.32	0.95	-21.9	-19.7	1782 6	1431 13	3025	0.62
n4593-37	Osczon	932	284	202	0.19	2.508 1.06	5.499 1.01	0.1000 0.33	0.95	-36.5	-34.4	1624 6	1077 10	8998	0.21

Isotope values are common Pb corrected using modern common Pb composition (Stacey & Kramers 1975) and measured ²⁰⁴Pb.

1. Th/U ratios calculated from ²⁰⁸Pb/²⁰⁶Pb and ²⁰⁷Pb/²⁰⁶Pb ratios, assuming a single stage of closed U-Th-Pb evolution.

2. Error correlation in conventional concordia space.

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).

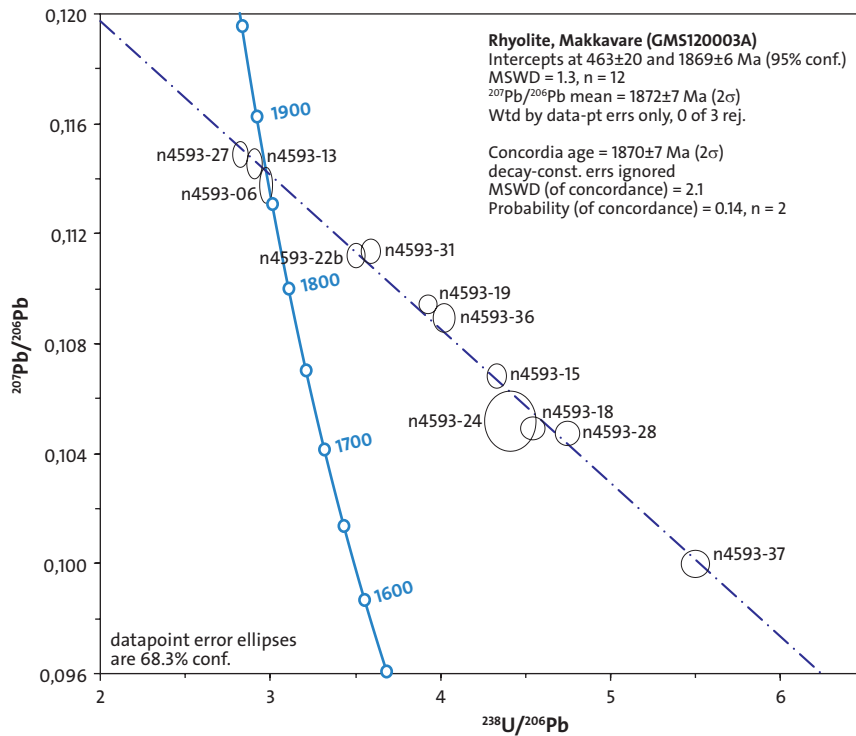


Figure 6. Tera Wasserburg diagram showing U-Pb SIMS data of zircon analyses. One highly discordant analysis, with high common lead (no 22a), plots outside the extent of the diagram and is excluded from the age calculations, see Table 1 and discussion in the text.

ance = 2.1, probability = 0.14, n = 2). Using all but one analysis, the exception being one highly discordant analysis with high common lead content (no. 22a, Table 2), a discordia line through data points gives upper and lower intercept ages at 1869 ± 6 Ma and 463 ± 20 Ma (95% confidence, MSWD=1.3, n=12).

All calculated ages give, within error, the same age and suggest an igneous crystallisation age of the rhyolite at c. 1.87 Ga. The upper intercept age of 1869 ± 6 Ma (95% confidence) is chosen as the best age estimate. Discordance, which results in a lower intercept of the regression line in the concordia diagram at an age of 463 ± 20 Ma (MSWD=1.3), suggests that episodic leaching of lead from metamict zircon domains has occurred.

DISCUSSION AND CONCLUSION

An upper intercept age of 1869 ± 6 Ma is within error of the age obtained from the Bure formation at Bure, 20 km south-south-west of this location (1860 ± 7 Ma, Skiöld et al. 1993). It should be noted, however, that this date was determined by bulk zircon separate analysis using solution chemistry and TIMS analysis. The resultant isochron gives a negative lower intercept indicating disruption of the U-Pb system and the authors freely admit that the date is probably too young.

A somewhat older age of 1880 ± 6 Ma has been reported from U-Pb zircon SIMS analysis from a volcanoclastic rhyolite at Trollforsen, 30 km north of Arvidsjaur (Kathol et al. 2008). The errors from this age determination overlap with the date reported here, possibly indicating that the Bure formation constitutes a younger member of the Arvidsjaur group as a whole.

We propose that the Makkavare rhyolite belongs to the Bure formation and that this part of the formation should be dated at 1869 ± 6 Ma rather than the previously reported age of 1860 Ma. The Bure formation itself could constitute a younger subunit of the Arvidsjaur group, which suggests that the Arvidsjaur group represents a long-lived volcanic event (1.88–1.87 Ga) and that the Svecofennian volcanic rocks possibly young and evolve to more alkaline and zirconium-rich compositions to the west. This conclusion agrees with that of Perdahl & Einarsson (1994).

An interesting additional note concerns the lower intercept of discordant data, which forms a reasonably tight linear array with a lower intercept at 463 ± 20 Ma. Avoidance of turbid crystals probably biased the analytical results in favour of less discordant zircons, increasing the error on the lower intercept. The coincidence of this age with the recently suggested age for the Laisvall deposit (467 ± 5 Ma, Saintilan et al. in press) is, however, striking. A similar lower intercept age (453 ± 19 Ma) was recorded by highly discordant U-Pb zircon analyses in the 1.79 Ga Hoting gabbro, located c. 10 km east of the present Caledonian front. This lower intercept age was suggested to represent an episodic leaching of lead from metamict zircon domains related to Caledonian orogenic activity (Hellström & Larsson 2003). These trends of discordant data lend credence to the notion of a major fluid event occurring in the region at approximately 465 Ma.

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