The Kukkola gneiss – protolith age of an Archean metatonalite, northern Sweden

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Cover: Bog south of the lake Pitkäjärvi (7344480/906410).
Photo: Ulf Bergström.

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CONTENT

ABSTRACT
A gneissic tonalite from an area with Archean Kukkola gneiss lithodem north of Haparanda has been dated with the U-Pb SIMS method on zircon. A calculated concordia age of 2 689±3 Ma is interpreted as the best age estimate of igneous crystallization.

SAMMANFATTNING
Zirkon från ett prov av gnejsig tonalit från området med Kukkolagnejs norr om Haparanda har U-Pb-daterats med SIMS-metoden. Konkordiaåldern har beräknats till 2 689±3 miljoner år vilket bedöms vara åldern för magmatisk kristallisation.

Keywords: Fennoscandian shield, Svecokarelian orogen, radiometric age, zircon, U-Pb, Archean

INTRODUCTION

Rocks of Archean age in Sweden are mainly exposed in the northernmost part of the country. Small, scattered remnants of Archean rocks have been found in the Norrbotten county north of a line defined by Öhlander et al. (1999). This line divides juvenile crust to the south from partly Archean crust to the north, and it is defined by negative ε_{Nd} values in rocks of the Haparanda suite. One of these Archean remnants, the Kukkola gneiss, was discovered north of Haparanda in the 1970s and its Archean age was verified by dating (Öhlander et al. 1987). The reported age, 2 670±18 Ma, was considered the crystallisation age of the rock. Recent mapping in the Haparanda area has renewed the interest in these rocks which are among the oldest in Sweden. What does the old age represent and in what context can it be placed?

The Archean rocks in the Kukkola area (Fig. 1) are exposed in a north-west–south-east striking anticline. There is a complex variety of rock types including metamorphosed tonalite, trondhjemite, gabbro and granite. The rocks are variably deformed and exhibit gneissic structures, banding, veins and dykes (pegmatite, quartz-feldspar, granite), recrystallisation and alteration.

The Kukkola gneiss is unconformably overlain by younger metasedimentary and metavolcanic successions. All these rocks were intruded by rocks of the c. 1.88 Ga Haparanda suite (Bergman et al. 2015) and deformed and metamorphosed during the Svecokarelian orogeny. A general observation is that the Archean rocks have experienced more deformation and a higher degree of metamorphism than the surrounding Haparanda suite rocks.

The Kukkola gneiss has been variably affected by migmatitisation and there is a possibility that the old dating (Öhlander et al. 1987) is a mixed protolith-metamorphic age (Fig. 2). The purpose of a new dating by SIMS from the Archean metatonalite is to obtain the magmatic crystallisation age with a sample from a rock with well preserved magmatic textures.

SAMPLE DESCRIPTION

The sample was taken from a reasonably well exposed hill surrounded by bogs south of the Pitkäjärvi lake (Table 1). The sample is a grey, equigranular and medium-grained metatonalite (Fig. 3). It is gneissic, but in the sampled outcrop the rock is devoid of migmatitic veins. The metatonalite is dominated mineralogically by plagioclase, quartz, hornblende and biotite with typical geochemical features like low K_2O and Rb/Sr. In nearby outcrops on the hill, more banded tonalites and gabbroic intercalations are common.

ANALYTICAL RESULTS AND INTERPRETATION OF GEOCHRONOLOGICAL DATA

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

Table 1. Summary of sample data.

Rock type:	Gneissic metatonalite
Tectonic domain:	Svecokarelian orogen
Tectonic subdomain:	Peräpohja lithotectonic domain
Stratigraphic group:	Simo complex
Lithodem:	Kukkola gneiss
Sample number:	UJB130010A
Lab-id number:	n4824
Coordinates:	7344125/906769 (Sweref99 TM)
Map sheet:	73J SV (Sweref99 TM)
Locality:	Pitkäjärvi
Project:	Barents

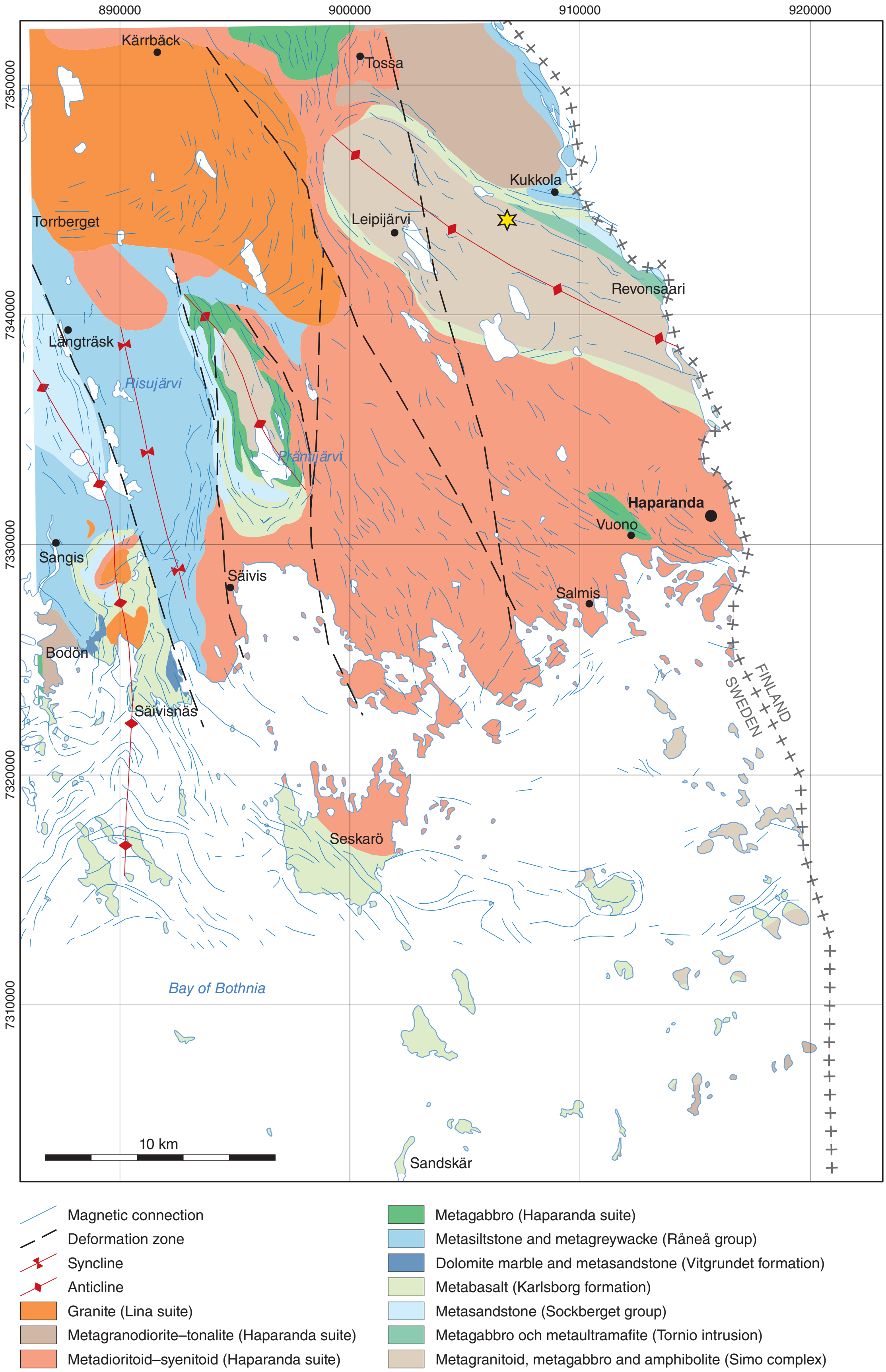

Figure 1. Preliminary bedrock map of the Haparanda-Kukkola-Sangis area. Location of the dated sample UJB130010A is shown by a yellow star.

Figure 2. Typical banded, migmatitic tonalite gneiss from the Archean Kukkola gneiss.

Figure 3. Samples of the dated Archean metatonalite (UJB130010A).

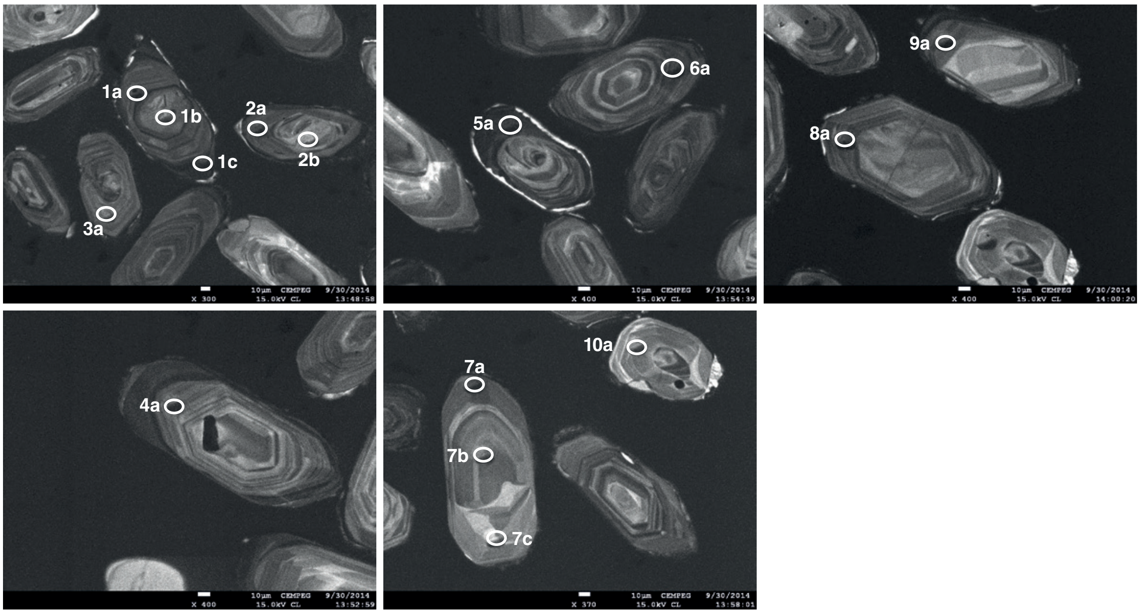

Figure 4. Cathodoluminescence images of analysed zircon grains. White ellipses mark the locations of analyses. Numbers refer to analytical spot number in Table 2.

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 electron microscopy at the Swedish Museum of Natural History in Stockholm. High-spatial resolution secondary ion mass spectrometer (SIMS) analysis was done in November 2013 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). U/Pb ratios, elemental concentrations and Th/U ratios were calibrated relative to the Geostandards zircon 91500 reference, which has an age of c. 1 065 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).

The heavy mineral concentrate is rich in zircon. Most zircon grains are turbid and cracked, but there are also transparent grains. The crystal shape is mostly subhedral and prismatic, but there are also rounded, ellipsoidal grains as well as prismatic almost euhedral grains. CL-images show oscillatory zoned zircon and in some grains there are clearly texturally older inherited cores (Fig. 4). A few grains have CL-dark rim domains with a faint oscillatory zonation parallel to the core zonation. The two analyses of CL-dark rims (1c and 5a) record somewhat lower Th/U ratios (0.22–0.29, Table 2) compared to the oscillatory zoned core analyses with Th/U ratios of 0.43–0.76. These are also slightly younger with a weighted average ^{207}Pb/^{206}Pb age of 2 667±5 Ma (2σ, MSWD = 1.7, probability = 0.20, n = 2). One oscillatory zoned rim analysis (1a) records a similar age as the CL-dark rims. The nine remaining oscillatory zoned analyses are concordant at the two sigma level, with a concordia age of 2 691±4 Ma (Fig. 5, 2σ, MSWD of concordance = 3.1, probability of concordance = 0.077, n = 9) and the weighted average ^{207}Pb/^{206}Pb age is 2 690±4 Ma (2σ, MSWD = 1.17, probability = 0.31). Including also two weakly discordant (<3.6%) analyses (2b and 6a) the weighted average ^{207}Pb/^{206}Pb age is 2 689±3 Ma (2σ, MSWD = 1.06, probability = 0.39, n = 11). There seems to be no significant difference in age

Table 2. SIMS U-Pb-Th zircon data.

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]	$^{207}Pb/^{206}Pb$ age (Ma)	±σ	$^{206}Pb/^{238}U$ age (Ma)	±σ	$^{206}Pb/^{204}Pb$ measured	f_{206}%[5]
n4824_01a	Osc zon outer core	201	103	136	0.52	12.802	0.99	1.962	0.94	0.1822	0.29	0.95	−0.8		2673	5	2655	21	304322	{0.01}
n4824_01b	Inner core	95	57	71	0.66	14.061	0.93	1.795	0.87	0.1831	0.33	0.94	8.0	5.7	2681	5	2855	20	93419	0.02
n4824_01c	CL-dark rim	363	70	245	0.22	13.646	1.04	1.831	1.02	0.1812	0.21	0.98	6.7	4.4	2664	3	2809	23	170573	{0.01}
n4824_02a	Osc zon outer core	216	93	147	0.45	13.235	1.02	1.914	0.88	0.1837	0.51	0.86	1.1		2686	8	2710	19	>1e6	0.00
n4824_02b	Inner core	67	39	48	0.61	13.473	0.95	1.875	0.87	0.1832	0.39	0.91	3.4	1.0	2682	7	2756	19	73760	{0.03}
n4824_03a	Osc zon outer core	107	51	73	0.49	13.124	0.96	1.933	0.88	0.1840	0.38	0.92	−0.0		2689	6	2688	19	604584	0.00
n4824_04a	Osc zon core	157	76	109	0.50	13.353	0.91	1.906	0.88	0.1846	0.26	0.96	1.1		2695	4	2719	19	144391	{0.01}
n4824_05a	CL-dark rim	313	90	204	0.29	12.918	0.90	1.941	0.88	0.1819	0.21	0.97	0.4		2670	4	2678	19	493397	0.00
n4824_06a	Osc zon core	294	191	201	0.65	12.671	0.91	2.002	0.89	0.1840	0.20	0.98	−3.5	−1.6	2689	3	2611	19	168626	{0.01}
n4824_07a	Rim, osc zon	214	92	144	0.44	13.107	0.91	1.945	0.87	0.1849	0.27	0.96	−1.0		2697	4	2674	19	260306	{0.01}
n4824_07b	Osc zon inner core	109	82	80	0.81	13.280	0.93	1.906	0.87	0.1836	0.32	0.94	1.5		2685	5	2719	19	337512	{0.01}
n4824_07c	Osc zon core, bright patches	68	32	47	0.49	13.295	0.97	1.911	0.88	0.1843	0.40	0.91	1.0		2692	7	2713	20	108103	{0.02}
n4824_08a	Osc zon outer core	202	106	140	0.54	13.137	1.04	1.920	0.99	0.1829	0.31	0.95	1.1		2680	5	2703	22	315366	{0.01}
n4824_09a	Osc zon outer core	157	80	109	0.52	13.176	0.93	1.924	0.87	0.1839	0.31	0.94	0.4		2688	5	2698	19	914636	{0.00}
n4824_10a	Osc zon outer core	86	55	61	0.65	13.133	0.96	1.930	0.87	0.1839	0.40	0.91	0.1		2688	7	2691	19	78726	{0.02}

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. 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. Figures in parentheses are given when no correction has been applied, and indicate a value calculated assuming present-day Stacey-Kramers common Pb.
Osc zon = Oscillatory zoned.

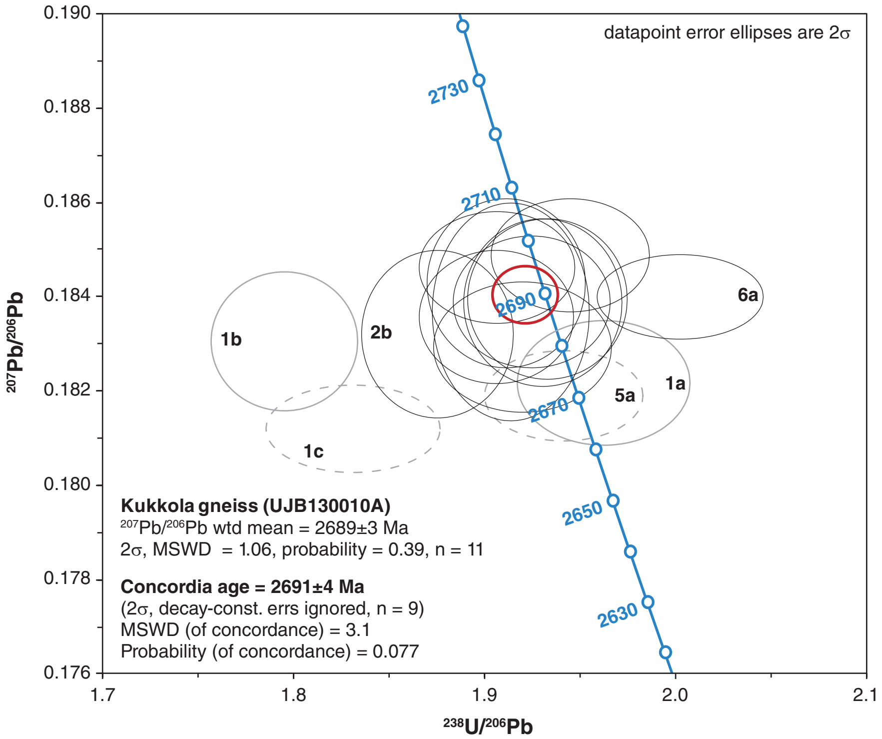

Figure 5. Tera Wasserburg diagram showing U-Pb SIMS data of zircon analyses. Analyses marked in grey are excluded. Error ellipse of calculated weighted mean age is shown in red. Dotted, grey error ellipses (1c, 5a) mark CL-dark rim analyses (see text for explanation).

between the texturally older core domains and the outer oscillatory zoned zircon domains, i.e. there is no difference in age between analyses 2a and 2b (Table 2).

All calculated ages are within error identical. The weighted average $^{207}Pb/^{206}Pb$ age of 2 689±3 Ma using eleven of the oscillatory zoned analyses is chosen as the best age estimate, and it is interpreted to date the igneous crystallisation of the metatonalite at 2.69 Ga. Analyses of secondary, CL-dark rim domains possibly date a metamorphic recrystallisation of the rock at c. 2.67 Ga, but based on only two analyses this is highly uncertain.

DISCUSSION AND CONCLUSION

Continental shield areas with a nucleus of Archean rocks are found on more or less all continents. Typically, the Archean rocks are divided into greenstone belts, dominated by basaltic volcanic rocks, and gneiss areas, dominated by meta-igneous rocks, often with a tonalitic composition (Windley 1984). The Kukkola gneiss window represents an Archean fragment of the latter type. The igneous assemblage at Kukkola includes rocks of mainly tonalitic and trondhjemitic composition, with an important mafic metagabbroic component. Volcanic rocks have not been observed. The metamorphic grade is generally high and migmatites are common. In most Archean areas, an Archean metamorphic event is recorded close in time to the intrusion of massive tonalite-trondhjemite bodies (Windley 1984).

In this study, oscillatory zoned zircons have been dated at 2 689±3 Ma and this age is interpreted to date igneous crystallisation of the Kukkola tonalite at 2.69 Ga. Two analyses of CL-dark zircon rim domains possibly date a metamorphic recrystallisation at c. 2.67 Ga. A metamorphic imprint on Kukkola gneiss close in time to the primary crystallisation (c.f. Windley

1984), would explain the similarity in obtained protolith age with the previously determined U-Pb TIMS zircon age by Öhlander et al. (1987), assuming that the latter age represents dating of mixed protolith and metamorphic zircon domains.

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