U–Pb zircon age of a granodioritic gneiss from Rimokojan at Stora Luleälven, Norrbotten County, northern Sweden

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Cover: Archaean gneisses close to Rimokojan at the northern shore
of Stora Luleälven.
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ABSTRACT

A granodioritic gneiss from Rimokojan at Stora Luleälven north of Jokkmokk in the central part of Norrbotten County, has been dated using U–Pb SIMS analyses of zircon. The sampled gneiss occurs within a massif of granodioric to tonalitic gneisses together with strongly deformed basic dykes and intrusions of almost undeformed gabbro to diorite of the Haparanda suite. This rock association occurs in the southern part of a distinct magnetic anomaly in the area of the Muddus National Park. Analyses of oscillatory zoned zircon domains from the Rimokojan gneiss sample yielded a weighted average $^{207}Pb/^{206}Pb$ age of 2668 ± 3 Ma (2σ) which is interpreted to date the protolith at c. 2.67 Ga. This figure is similar to other age determinations of Archaean rocks in southeastern Norrbotten County (2.70–2.64 Ga). Field relations suggest that the gneiss protolith has been deformed during at least two different deformational events which both predate the emplacement of the 1.91–1.87 Ga Haparanda suite. Two analyses of low Th/U, cathodoluminescence (CL)-dark unzoned zircon rims from the same sample are interpreted to date a metamorphic event at c. 2.61 Ga.

Keywords: Archaean, Svecokarelian orogeny, U–Pb, zircon, geochronology, gneiss, basic dykes

SAMMANFATTNING

En granodioritisk gnejs från Rimokojan vid Stora Luleälven norr om Jokkmokk i den centrala delen av Norrbottens län har daterats med U–Pb SIMS-metoden på zirkon. Den daterade gnejsen förekommer i ett massiv av granodioritiska till tonalitiska gnejser som uppträder tillsammans med starkt deformerade basiska gångar och mer eller mindre odeformerade intrusioner av gabbro till diorit, tillhörande Haparandasviten. Den här bergartsassociationen förekommer i den södra delen av en markant magnetisk anomali i området av Muddus nationalparken. Analyser av oscillatoriskt zonerade zirkondomäner från gnejsprovet från Rimokojan levererade en viktad genomsnittsålder ($^{207}Pb/^{206}Pb$) av 2668 ± 3 miljoner år (2σ), vilket tolkas som protolitens bildningsålder av cirka 2,67 miljarder år. Denna siffra liknar resultat från andra åldersbestämningar av arkeiska bergarter i sydöstra Norrbottens län (2,70–2,64 miljarder år). Fältförhållanden antyder att gnejsens protolit har blivit deformerad under minst två olika deformationshändelser som båda har ägt rum före bildningen av den 1.91–1,87 miljarder år gamla Haparandasviten. Två analyser av mörka (under katodoluminescens), ozonerade zirkonkanter med ett lågt Th/U förhållande från samma prov har tolkats datera en metamorfoshändelse för omkring cirka 2,61 miljarder år sedan.

Nyckelord: Arkeisk, svecokarelska orogenesen, U–Pb, zirkon, geokronologi, gnejs, basiska gångar

INTRODUCTION

Archaean rocks have been reported from different areas in the central and southeastern parts of the Norrbotten County (Fig. 1). These Archaean rocks are confirmed by radiometric age determinations or indicated by Sm-Nd analyses showing strongly negative $\varepsilon_{Nd\ (1.9\ Ga)}$ values. In the area north of Jokkmokk, strongly deformed, porphyritic granites to quartz monzonites have been dated at Mt. Ánávárre to an Archaean age of 2642 ± 38 Ma (Mellqvist 1999). These porphyritic rocks occur in a larger massif together with an association of strongly foliated felsic gneisses, deformed basic dykes and minor intrusions of isotropic to weakly foliated gabbro to diorite (Fig. 2) in the southern part of a distinct magnetic anomaly in the area of the Muddus National Park (Fig. 3). The felsic gneisses are grey to dark grey, equigranular, recrystallized, fine-grained and strongly foliated. There is a change from granitic to granodioritic compositions in the west to granodioritic to tonalitic compositions in the eastern parts of the larger massif. The association of gneisses, dykes and basic intrusions is best exposed along the northern shore of Stora Luleälven downstream of the Ligga powerstation. Here, the gneisses show a pronounced, steeply to vertically dipping foliation with a constant northeast-southwest strike (Fig. 4a).

Within the gneisses, 5 to 120 cm wide dykes of dark grey, equigranular, fine-grained and foliated basic rocks occur (Fig. 4b). These dykes are boudinaged and almost totally reorientated into the direction of the pronounced foliation in the gneisses, but truncating relationships can still be observed in places (Fig. 5). The age of these dykes is uncertain; but because of the truncating contacts with the gneisses they must be younger than the foliation in the latter. However, there are intrusions of isotropic to weakly foliated equigranular, medium-grained gabbros to diorites, which are assigned to the Palaeoproterozoic Haparanda suite, within the gneiss – dyke association, showing that the dykes must have undergone reorientation during a deformational event which predates the emplacement the Haparanda suite (Kathol et al. 2015).

The protoliths of the gneisses have therefore been deformed during at least two distinct deformational events predating the emplacement of the Haparanda suite at c. 1.91–1.87 Ga. This also suggests that the gneisses have an Archaean age, supported by the geometric occurrence with the Archaean porphyritic granites to quartz monzonites. A radiometric dating (U–Pb on zircon) of a gneiss from Rimokojan at the Stora Luleälven was therefore proposed to determine the age of the gneisses and the emplacement of the reoriented basic dykes.

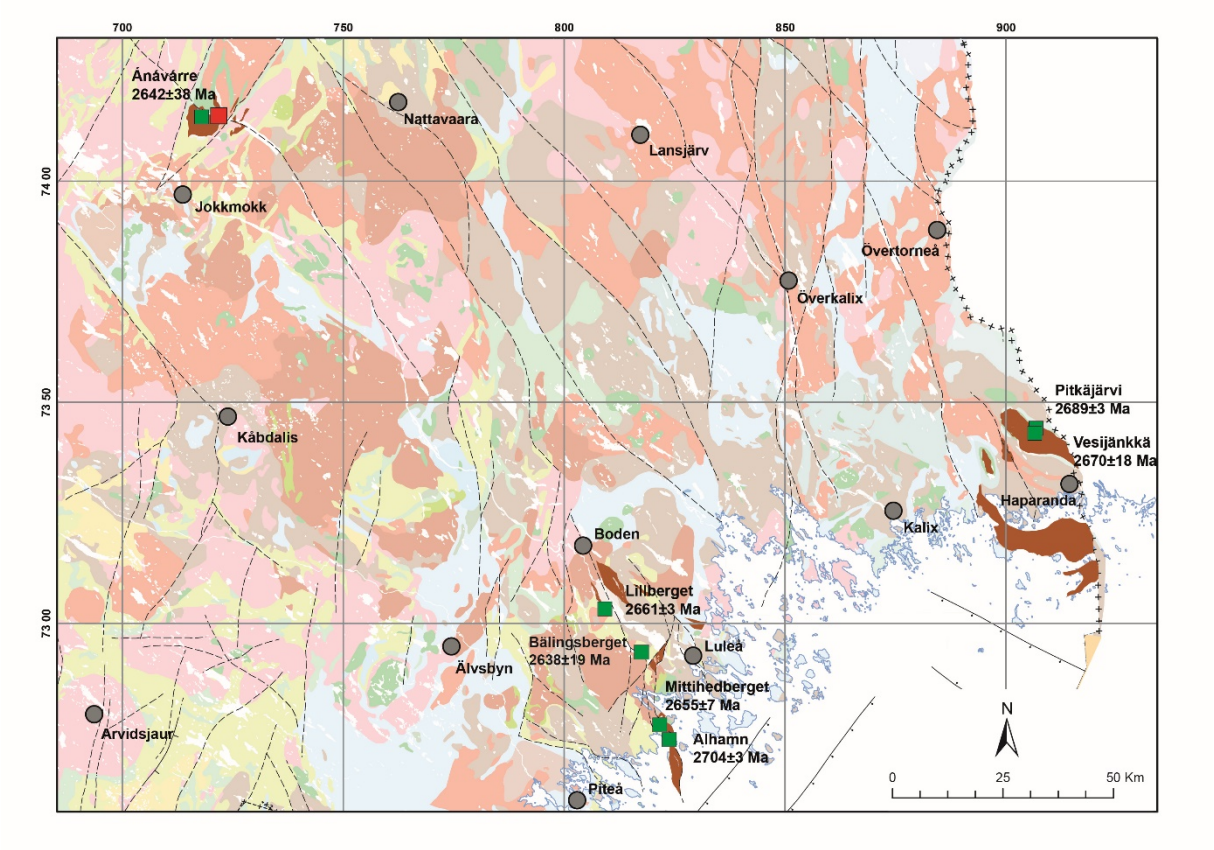

Fig. 1. Radiometric age determinations (U–Pb) and mapped occurrences of Archaean rocks in the central and southeastern parts of the Norrbotten County. The sampling sites are indicated by green squares and taken from the database of radiometric age determinations at SGU. The site for the Rimokojan sample is marked by a red square. Geological background is from the 1:1 000 000 bedrock database of SGU, and the reference grid is in SWEREF 99 TM with grid lines shown at a 50 km interval. References to age determinations: Bergström et al. (2015), Lundqvist et al. (2000), Mellqvist (1999), Öhlander et al. (1987), Sadeghi & Hellström (2018), Wikström et al. (1996).

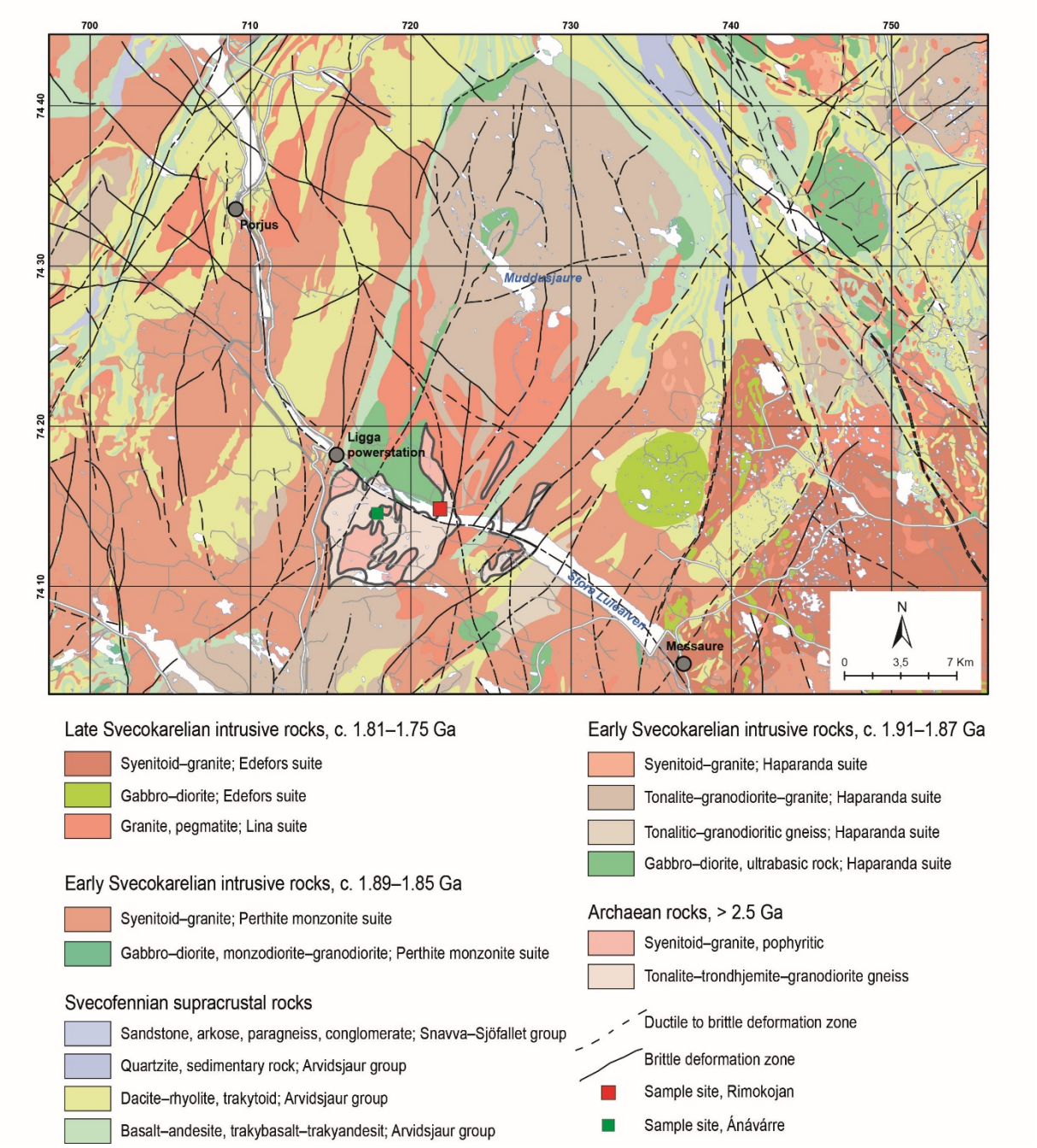

Fig. 2. Bedrock map showing the Archaean rocks in the area of Rimokojan and Mt. Ánávárre, marked with dark grey outlines. Geological background is simplified from the 1:50 000 and 1:250 000 bedrock databases of the SGU.

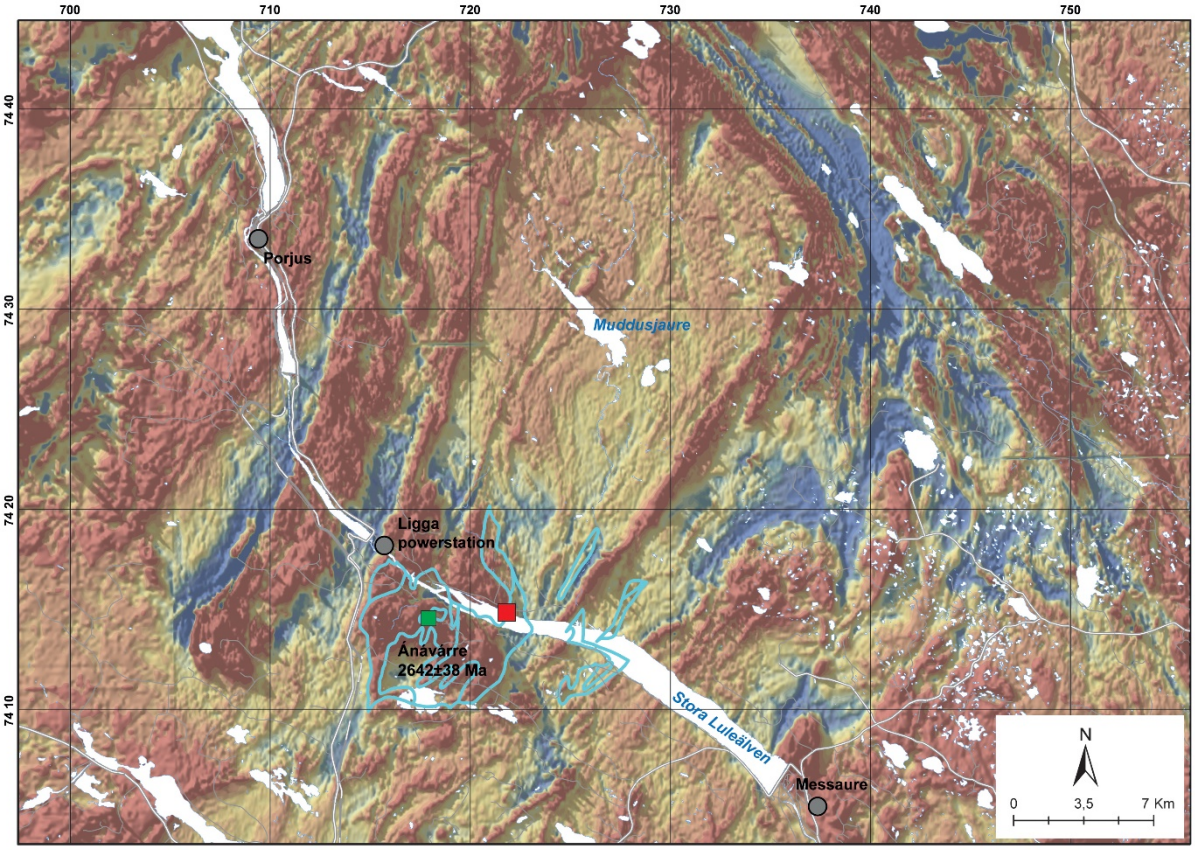

Fig. 3. Magnetic anomaly map over the same area as shown in figure 2. The Archaean rocks in the southwestern part of the magnetic anomaly in the area of the Muddus National Park are marked by green outlines.

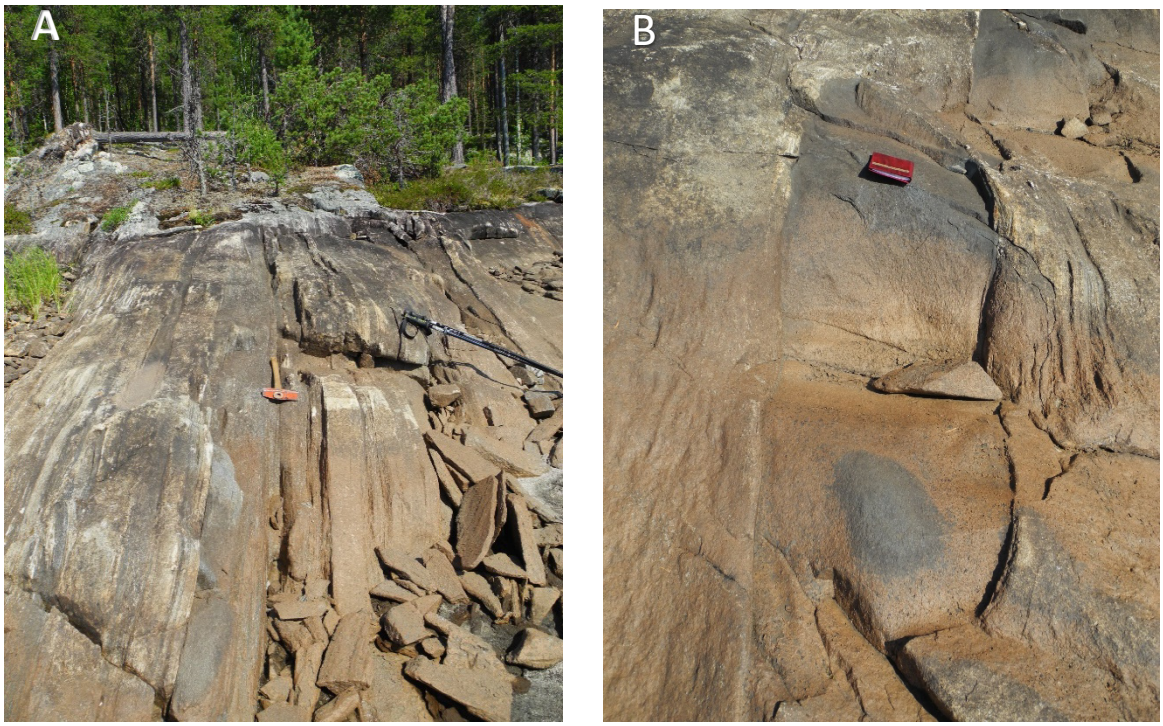

Fig. 4. A. Association of granodioritic to tonalitic gneiss and reoriented basic dykes. Rimokojan (SWEREF 99 TM; 741475/722028). **B**. Boudinaged and truncated basic dyke. Rimokojan (SWEREF 99 TM; 7414837/721822). Photos: Benno Kathol.

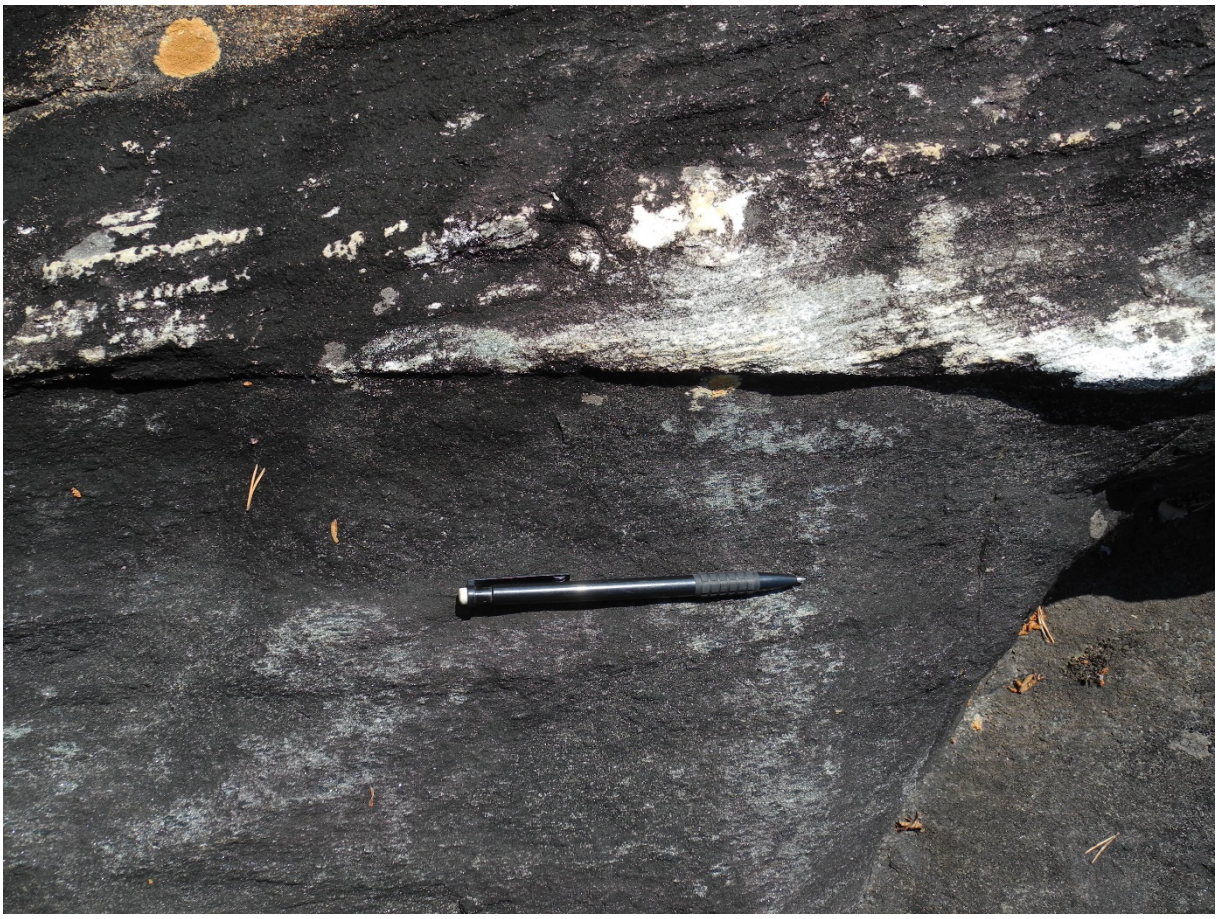

Fig. 5. Interpreted tight angular unconformity at the contact between granodioritic to tonalitic gneiss (above) and basic dyke (below). Rimokojan (SWEREF 99 TM; 7414837/721822). Photo: Benno Kathol

SAMPLE DESCRIPTION

The sampled rock is a grey, strongly foliated, recrystallized, fine-grained and relict medium-grained gneiss with a granodioritic composition (Table 1, Fig. 6). The normative composition (Granite mesonorm) according to Streckeisen & Le Maitre (1979) is granodioritic. The chemical composition is defined differently by different diagrams which give compositions from granodioritic to quartz monzonitic (Middlemost 1985), tonalitic (De la Roche et al. 1980), quartz monzodioritic to quartz monzonitic (Middlemost 1994) and quartz monzodioritic (Debon & Le Fort 1983).

Table 1. Summary of age sample data

Rock type	Granodioritic gneiss
Tectonic domain	Svecokarelian
Tectonic subdomain	Norrbotten lithotectonic unit
Stratigraphic group/suite	Archaean
Lithodemic unit	Association of felsic gneiss (informal)
Sample number	KBK140033A
Lab-id	n5414
Coordinates (SWEREF 99TM)	7414837/721822
Map sheet (SWEREF 99TM)	741-72-00
Map sheet (RT90)	27J Porjus 2h
Locality	Rimokojan, c. 7.8 km southeast of the Ligga powerstation
Project	Barents
SGU project	Syntes Södra Norrbotten

Fig. 6. Granodioritic gneiss at the sampling site at Rimokojan (SWEREF 99 TM; 7414837/721822).
Photo: Benno Kathol.

ANALYTICAL RESULTS AND INTERPRETATION OF GEOCHRONOLOGICAL DATA

Zircons were obtained from a density separate of a crushed rock sample using a Wilfley water table. Magnetic minerals were removed with 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 with Cathodoluminescence (CL) imaging using the electron microscope at the Swedish Museum of Natural History in Stockholm. High-spatial resolution secondary ion mass spectrometer (SIMS) analysis was carried out in November 2015 using a Cameca 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), 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 the modern common Pb composition (Stacey & Kramers 1975) and measured ^{204}Pb when the ^{204}Pb count rate was above the detection limit. Decay constants follow the recommendations of Steiger & Jäger (1977). Diagrams and age calculations of isotopic data were made using the Isoplot 4.15 software (Ludwig 2012). All age uncertainties are presented at the 2σ or 95% confidence level. Mixed CL-and SE-imaging of the dated zircons was performed using the electron microscopy at the Swedish Museum of Natural History in Stockholm.

The zircons are light brown and more or less rounded. Many are metamict and contain cracks, but some clear, crack-free grains were also found. Some appear to contain inherited cores. The CL-images of the crystals show oscillatory zoning, generally with rather low contrasts (Fig. 7). Many of the crystals have central areas that are markedly brighter than the rest of the grains while some crystals have dark rims. The former, which often have euhedral outline, resemble inherited cores, but where analysed, do not give older ages than the other analyses. Two analyses of dark rims, however, give distinctly younger ages.

Eight analyses are concordant and give a concordia age of 2667 ± 3 Ma (Fig. 8, 2σ, MSWD of concord. & equiv. = 1.16, probability of concord. & equiv. = 0.30). Including also a weakly discordant analysis (2a), the weighted average $^{207}Pb/^{206}Pb$ age is calculated at 2668 ± 3 Ma (2σ, MSWD = 1.13, probability = 0.34). One inner core analysis (3a) yielded a lower age at c. 2.56 Ga and was excluded from the above age calculations. The reason for this lower age is unclear. A CL-dark, rim analysis of the same grain recorded an older age of c. 2.66 Ga.

The two analyses of the dark crystal rims 1b and 2b are concordant and give a concordia age of 2610 ± 5 Ma (2σ, MSWD of concord. & equiv. = 0.52, probability of concord. & equiv. = 0.57), with an identical weighted mean $^{207}Pb/^{206}Pb$ age. The U concentration of the 2.67 Ga zircons is 108–720 ppm, and 831–939 ppm for the 2.61 Ga rims. The Th/U-ratio is 0.33–0.92 for the former, 0.11–0.14 for the latter (Table 2).

The weighted average $^{207}Pb/^{206}Pb$ age of 2668 ± 3 Ma (2σ) for the oscillatory zoned zircon is interpreted to date the gneiss protolith at c. 2.67 Ga. The low Th/U, CL-dark unzoned rims are interpreted to date a metamorphic event at c. 2.61 Ga.

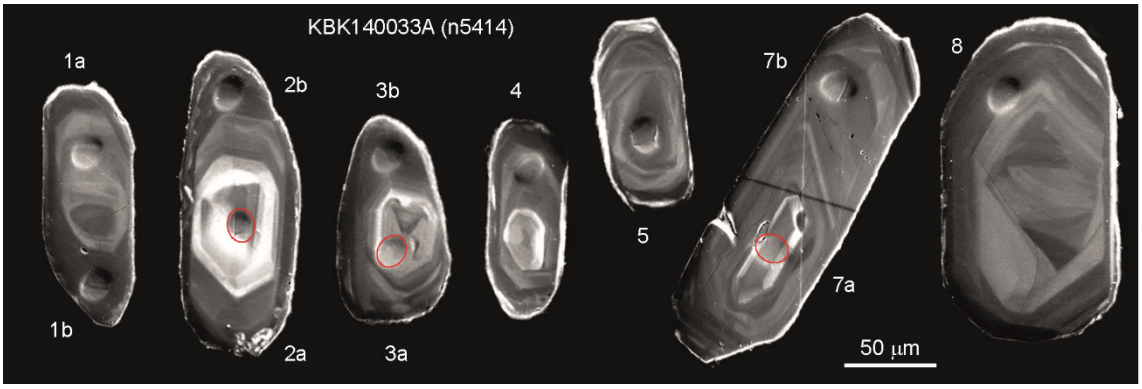

Fig. 7. Mixed Secondary Electron- (SE) and Cathodoluminescence (CL) images of analysed zircon grains. Pits/ellipses mark the locations of analyses. Numbers refer to analytical spot number in Table 2.

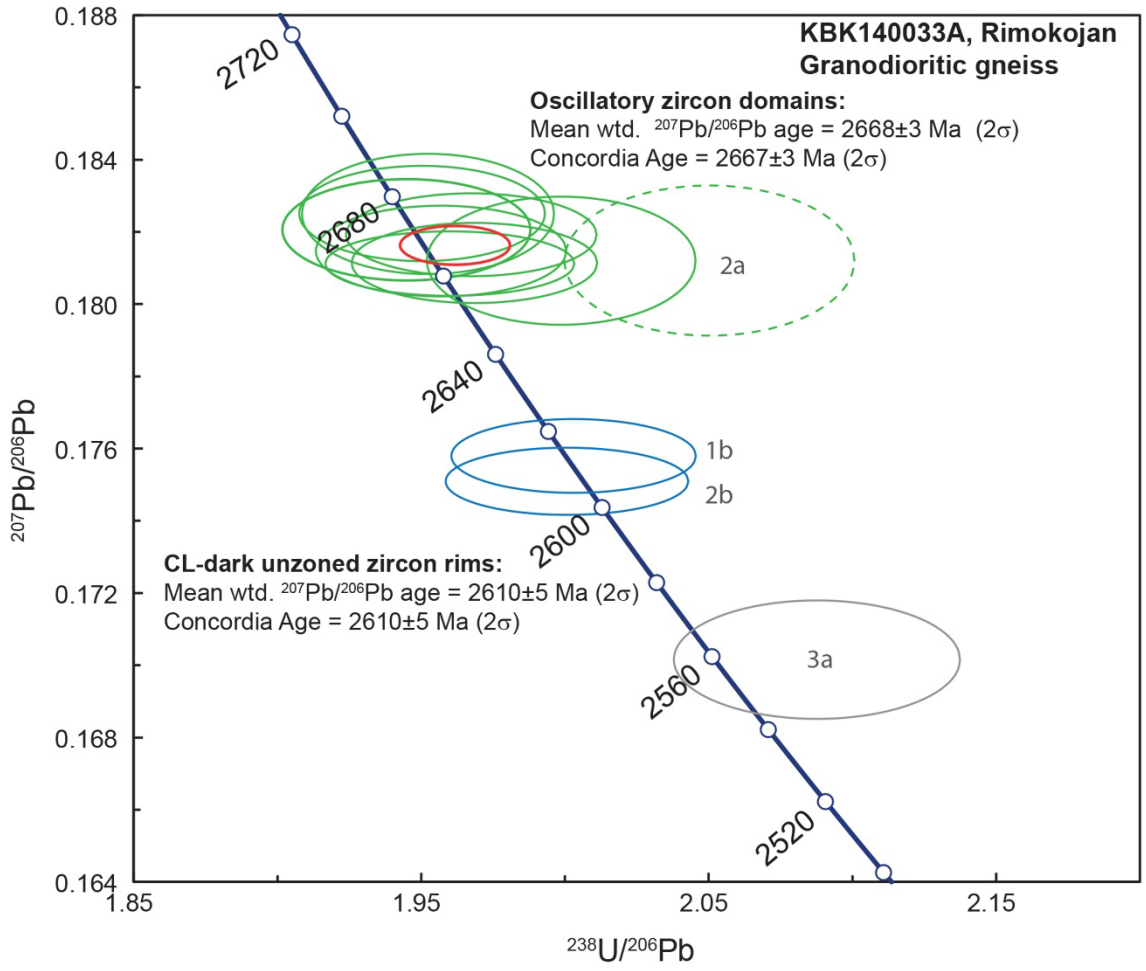

Figure 8. Tera Wasserburg diagram showing U–Pb SIMS data of zircon analyses of the Rimokojan gneiss. Analyses used in age calculation from oscillatory zoned zircons are marked in green, the discordant analysis (2a) is shown with broken lines. Analyses from CL-dark rim domains (1b and 2b) are shown in blue. Error ellipse of calculated weighted mean age for the former group is shown in red. The analysis marked in grey (3a) is from an inner core domain and was excluded from the age calculations.

Table 2. SIMS U–Pb–Th zircon data of the Rimokojan granodioritic gneiss (KBK140033A, laboratory id n5414).

		Conc. (ppm)				Ratios								Calculated ages (Ma)			
Anal. spot	Commentr	U	Th	Pb	Th/U calc [1]	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{206}Pb/^{204}Pb$	Disc. % conv. [2]	Disc. % 2σ lim. [3]	f_{206}% [4]	$^{207}Pb/^{206}Pb$	±σ	$^{206}Pb/^{238}U$	±σ
01a	osc. zon core	217	106	146	0.49	1.952	0.92	0.1825	0.37	177143	-0.4		{0.01}	2676	6	2666	20
01b	CL-dark rim	830	120	504	0.15	2.003	0.87	0.1758	0.24	251682	-0.1		{0.01}	2614	4	2611	19
02a	osc. zon core	108	93	75	0.82	2.050	1.00	0.1812	0.47	36732	-4.7	-2.0	{0.05}	2664	8	2561	21
02b	CL-dark rim	939	103	566	0.11	2.001	0.86	0.1751	0.22	89175	0.3		0,02	2607	4	2613	19
03a	osc. zon inner core	157	90	100	0.56	2.088	0.97	0.1702	0.39	>1e6	-1.7		{0.00}	2559	7	2523	20
03b	CL-dark rim	721	282	474	0.39	1.960	0.90	0.1811	0.20	97637	-0.3		0.02	2663	3	2658	20
04	osc. zon core	275	170	189	0.61	1.957	0.91	0.1815	0.28	461815	-0.2		{0.00}	2666	5	2661	20
05	osc. zon core	392	157	257	0.39	1.967	0.90	0.1819	0.26	49617	-1.0		0.04	2670	4	2649	20
06		300	177	207	0.60	1.950	0.89	0.1825	0.30	334975	-0.3		{0.01}	2676	5	2668	20
07a	osc. zon inner core	167	153	119	0.87	1.999	0.96	0.1812	0.40	2736	-2.2		0.68	2664	7	2615	21
07b	osc. zon core	258	157	178	0.59	1.945	0.91	0.1821	0.32	50482	0.1		0.04	2672	5	2674	20
08	osc. zon core	339	112	219	0.33	1.969	0.89	0.1811	0.25	410083	-0.7		{0.00}	2663	4	2648	19

osc. = oscillatory, zon = zoned, CL = Cathodoluminescence

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 corrected for Pbcom, 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 (2 level).

[4] Percent of common 206Pb in measured 206Pb, estimated from 204Pb assuming a present-day Stacey & Kramers (1975) model.

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

DISCUSSION AND CONCLUSION

A granodioritic gneiss from Rimokojan in the granodioritic to tonalitic gneiss massif at Stora Luleälven, north of Jokkmokk, has been dated using U–Pb SIMS analyses on zircon. The gneisses occur in the southern part of a distinct magnetic anomaly in the area of the Muddus National Park together with strongly deformed basic dykes and intrusions of almost undeformed gabbro to diorite belonging to the 1.91–1.87 Ga old Haparanda suite. Analyses of oscillatory zoned zircon domains from the dated gneiss sample at Rimokojan have a weighted average $^{207}Pb/^{206}Pb$ age of 2668 ± 3 Ma (2σ) which is interpreted to date the gneiss protolith at c. 2.67 Ga. This figure is like other age determinations of Archaean rocks in southeastern Norrbotten County, which return ages between 2.70 and 2.64 Ga (Bergström et al. 2015, Lundqvist et al. 2000, Öhlander et al. 1987, Sadeghi & Hellström 2018, Wikström et al. 1996). Field relations suggest that the gneiss protolith has been deformed during at least two different deformational events which both predate the emplacement of the Haparanda suite at c. 1.91–1.87 Ga. Two analyses of low Th/U, CL-dark, unzoned zircon rims from the dated Rimokojan gneiss are interpreted to date a metamorphic event at c. 2.61 Ga. This event may either be related to the generation of the strong foliation in the Archaean rocks, or the deformation and reorientation of the basic dykes, or both. More analyses are however needed to better constrain the secondary event. Mellqvist (1999) presented an Archaean age of 2642 ± 38 Ma from strongly deformed, porphyritic granites to quartz monzonites at Mt. Ánávárre, four kilometres to the west of Rimokojan. BSE- (Back-scattered electron) images of zircon from the Mt. Ánávárre sample show complex zonations within the zircons and, given that the age determination was carried out using the TIMS-technique on fractions of whole zircon grains, the results are uncertain, and the obtained age possibly constitutes a mix between protolith and secondary zircon domain ages.

Indications of two separate magmatic events during the Archaean are shown in the Luleå-Boden area, where field, geochemical and U–Pb age data separates a c. 2.70 Ga old granodiorite-tonalite-trondhjemite-gabbro gneiss from a slightly younger, 2.66–2.64 Ga old porphyritic quartz monzodiorite (Mellqvist et al. 1999 and references therein). Most of the geochronological analyses are however done by the TIMS- technique and should be reinvestigated. The Archaean lithologies in the Jokkmokk and Luleå areas are similar in composition, and a comparison between the two areas is left for future studies.

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