U-Pb zircon dating of granodiorite from the Muddus structure, northern Sweden

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Cover: Muddusätno (Mottosädno), 3 km west of the dating
locality at Unna Kielas.
Photographer: Per Nysten.

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CONTENT

ABSTRACT

A Svecofennian granodiorite forming the core of the Muddus structure, has been dated to 1889±5 Ma. This is interpreted as the igneous crystallisation age of the rock. The geophysical signature and geological composition of this structure is also discussed.

Keywords: *U-Pb zircon geochronology, plutonic rock, granodiorite, Muddus, Svecofennian, Svecokarelian orogen, Fennoscandian shield, geophysical data*

SAMMANFATTNING

En svekofennisk granodiorit bildar kärnan i Muddusstrukturen och har daterats till 1889 ±5 miljoner år. Detta resultat tolkas som den magmatiska kristallisationsåldern av bergarten. Den geofysiska signaturen och geologiska sammansättningen av strukturen diskuteras också.

Nyckelord: *U-Pb zirkon geokronologi, plutonisk bergart, granodiorit, Muddus, svekofennisk, Svekokarelska bergskedjebildningen, Fennoskandiska skölden, geofysiska data*

INTRODUCTION

In the Muddus area, including the Muddus National Park, in northern Sweden there is a c. 30 × 15 km large, NNE–SSW oriented elongated geological structure, clearly outlined in the geological, as well as in the magnetic anomaly maps (Figs. 1–2). The rim of the Muddus structure consists of felsic to mafic volcanic rocks and the central part is dominated by plutonic rocks (Nisca 1980, SGU 1981). The Muddus structure was suggested by SGU (1981) as a possible result of an up-lift of a geological unit located between major deformation zones. The core of the structure was described as consisting of a 1.8 Ga granite belonging to the Lina suite.

The southern part of the structure (mainly at map sheet 27J Porjus SO) is presented on the 1:250000 bedrock map compiled by SGU (Jokkmokksprojektet 1981) while the entire structure is also described in the accompanying report (SGU 1981). The rim is briefly mentioned as "Muddus gneiss".

A minor part of the structure is shown on bedrock map sheet 27K Nattavaara NW where the above information has been interpreted mostly due to lack of relevant outcrops (Claeson & Antal Lundin, 2012). The Muddus structure is not however, evident on the Norrbotten county map (Ödman, 1957). Recent mapping by SGU (2015) suggest however, that the core consist of granodiorite to minor granite interpreted not to be part of the Lina suite (Fig. 1)

To validate our interpretation, a sample of granodiorite was chosen for age determination. Based on geological and geophysical field work together with data from gravity surveys and airborne geophysical surveys of the magnetic total field, electromagnetic very low frequency fields (VLF) and gamma ray spectrometry, we have reinterpreted part of the geological history of the Muddus structure.

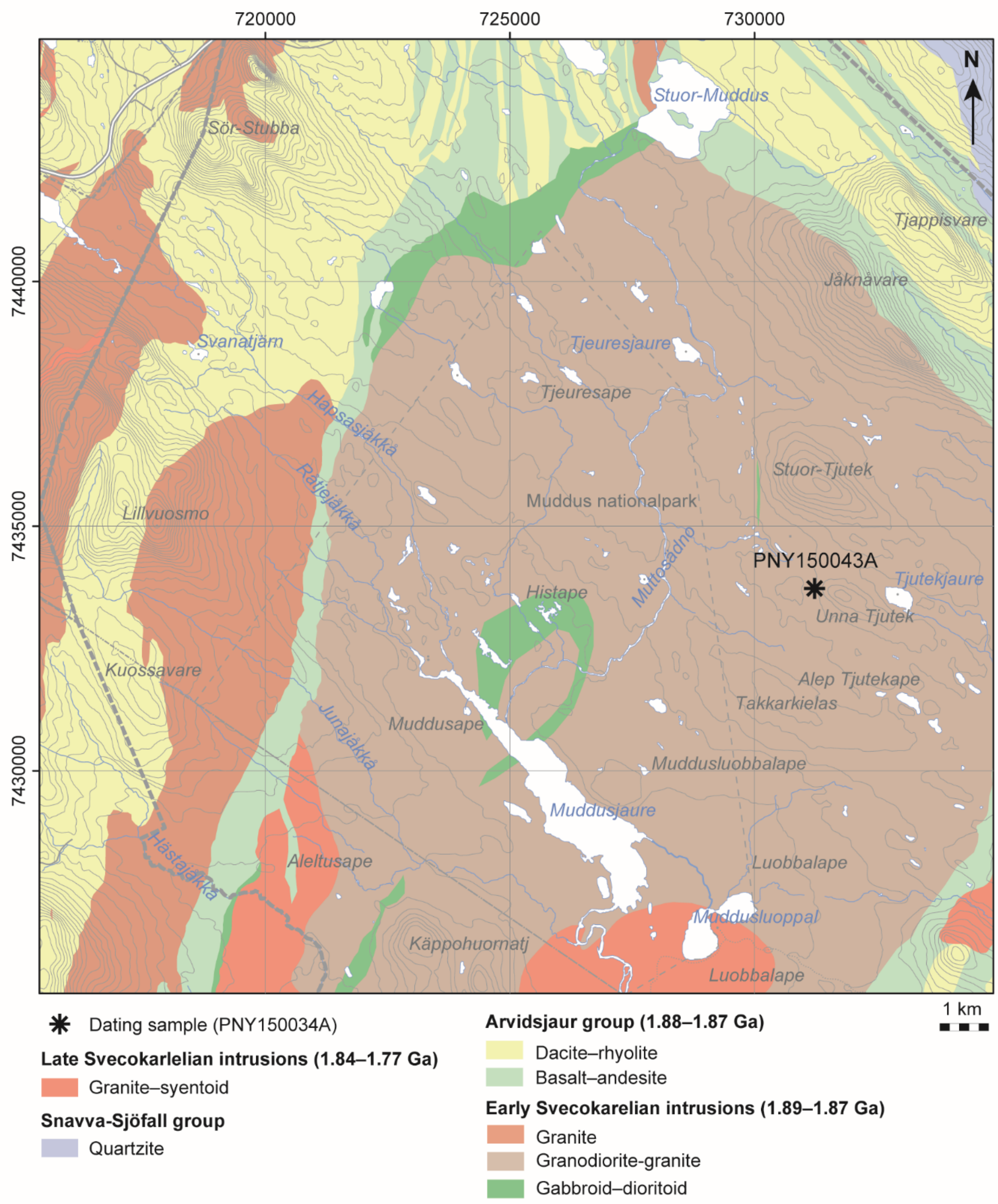

Figure 1. Geological map showing the northern part of the Muddus structure. Granodiorite (brown) and gabbro (green), belonging to the Haparanda suite, is surrounded by mafic (light green) to felsic (yellow) volcanic rocks belonging to the Arvidsjaur group. Granitic rocks are shown in red.

Figure 2. Map of the total magnetic field (vertical derivative). High magnetic anomalies are shown in light grey and low in dark grey.

SAMPLE DESCRIPTION

To validate our interpretation, a sample of granodiorite from Unna Kielas in the eastern part of Muddus was chosen for age determination (Figs. 1–3, Table 1). The sampled locality consists of a large, flat outcrop dominated by a light grey to grey, weakly foliated quartz-rich granodiorite (Fig. 3). Mafic enclaves up to 5–10 cm are present and the rock is locally K-feldspar phyric with 0.5 cm large megacrysts of microcline. The susceptibility varies from 698×10^{-5} to 1100×10^{-5} SI units.

Microscopically, the rock shows an uneven grain distribution, with microcline megacrysts up to 2 mm and coarse plagioclase partly with diffuse albite twinning, and partly totally sericitised. Coarse quartz, olive-green, fresh to slightly chloritised biotite and titanite are also present (Fig. 3C). Accessory phases are apatite, prehnite and zircon, the latter both as euhedral, zoned crystals up to 200 µm, and as small inclusions in biotite (Fig. 3D). Zircon locally shows subhedral cores with euhedral overgrowths. Magnetite with thin hematite lamellae, are also common.

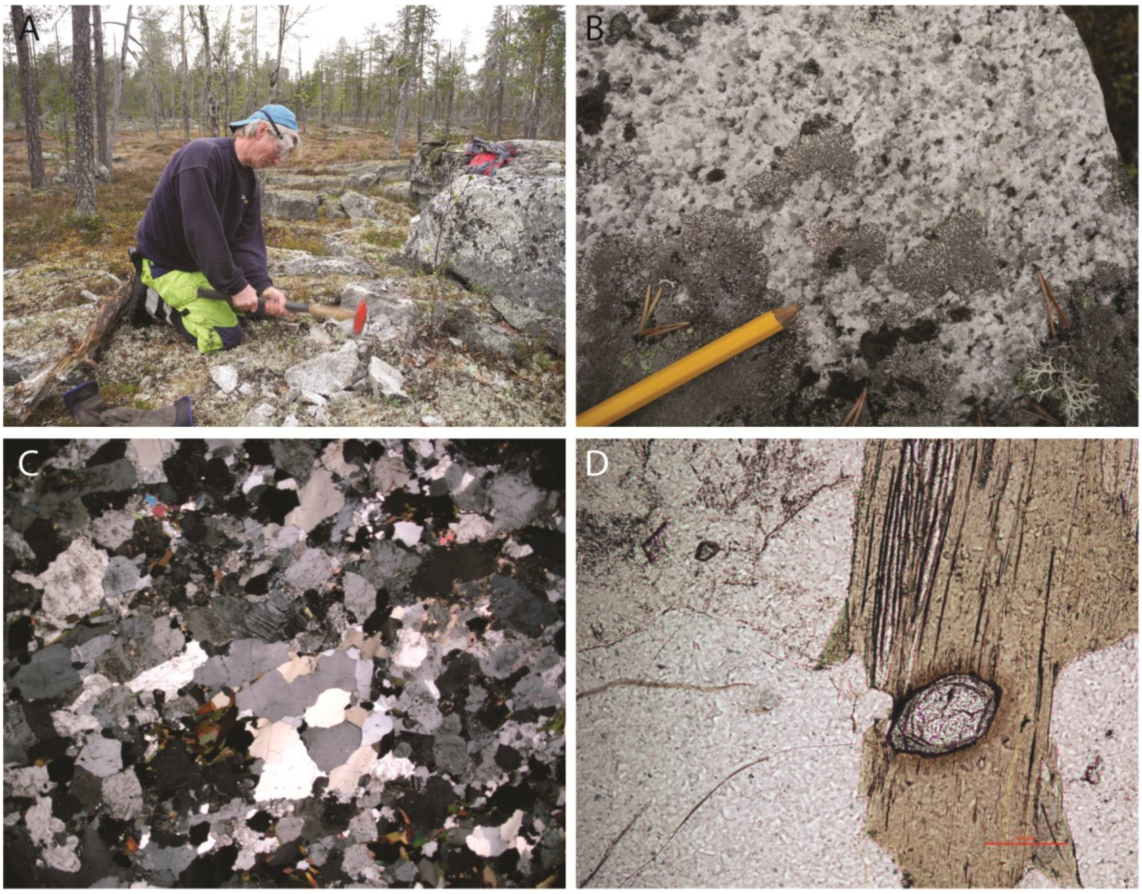

Figure 3. **A**. Sampling of granodiorite by Stefan Persson. **B.** Leucocratic granodiorite showing weak foliation. 7433738/731235 SWEREF 99TM. **C.** Recrystallised quartz in matrix of quartz, microcline, plagioclase and biotite. Transmitted light and crossed polarisers. Width of picture is 3.8 mm. **D.** Euhedral zircon crystal showing oscillatory zoned rim and homogeneous core. Associated phases are quartz and biotite. Transmitted light, parallel polarisers. All Photos: Per Nysten.

Table. 1. Sample data.

Rock type	**Granodiorite**
Tectonic domain	Svecokarelian orogen
Tectonic subdomain	Norrbotten lithotectonic domain
Stratigraphic group/suite	Haparanda suite
Sample number	PNY150043A
Lab-id	n5410
Coordinates (SWEREF 99TM)	7433738/731235
Map sheet (RT90)	27J NO
Locality	Unna Kielas
Project	Kartering Barents

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 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 carbon coating examined by Cathodoluminescence (CL) imaging using electron microscopy at the Swedish Museum of Natural History in Stockholm. Samples were then re-coated with gold. High-spatial resolution secondary ion mass spectrometer (SIMS) analysis was done in November 2015 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). In cases of a ^{204}Pb count rate above the detection limit, 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). Age calculations and diagrams of isotopic data were made using software Isoplot 4.15 (Ludwig 2012). All age uncertainties are presented at the 2σ or 95% confidence level. CL-imaging of the dated zircons was performed using electron microscopy at the Swedish Museum of Natural History in Stockholm.

The zircons are light brown or colorless and euhedral to slightly rounded. Some are clear and crack-free. The CL-images show a rather large variety (Fig. 4). Many of the crystals have oscillatory zoning. Most of those have small contrasts between lighter and darker zones whereas others have large contrast. A few of the crystals have only faint zonation pattern.

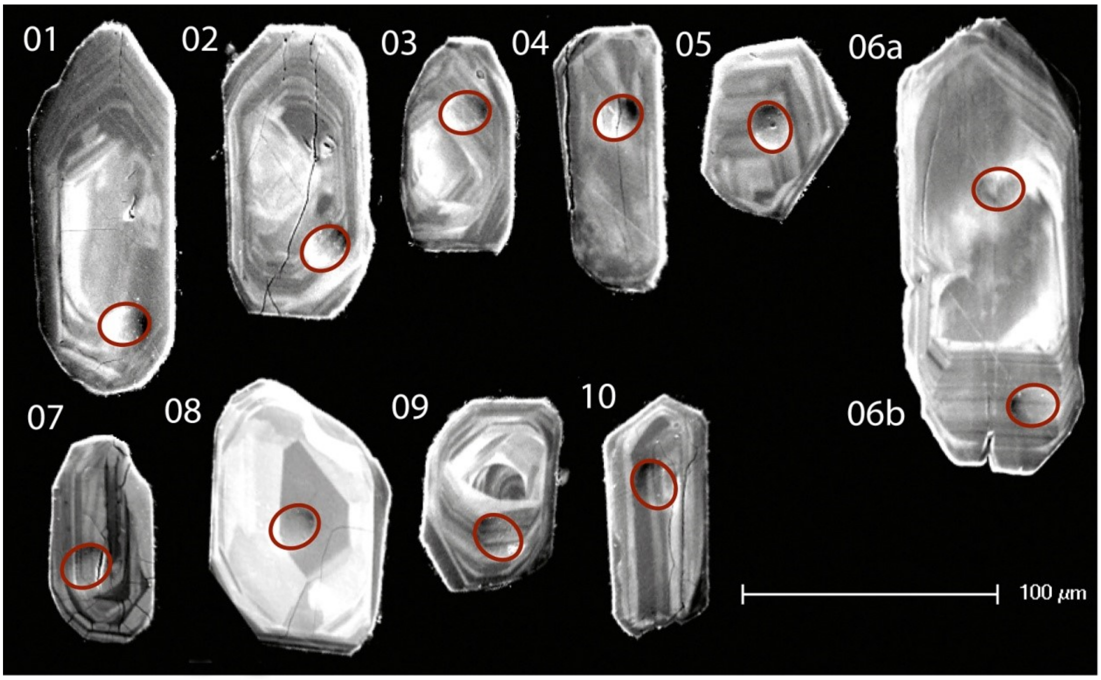

Figure 4. Cathodoluminescence (CL) image of analysed zircon grains. Numbers refer to analytical spot number in Table 2.

Ten crystals were analysed, one of them with two spots. The U concentration is 111–420 ppm and the Th/U-ratio is 0.43–0.81 (Table 2). Eight of the data points are concordant and give a concordia age of 1889 ±5 Ma (Fig. 5; 2σ, MSWD of concordance = 3.3, probability of concordance = 0.068). The weighted average of the $^{207}Pb/^{206}Pb$-ages is 1887 ±6 Ma (2σ, MSWD = 0.71; probability = 0.67). Crystal #6 was analysed both in the centre and rim with identical age results for both analyses.

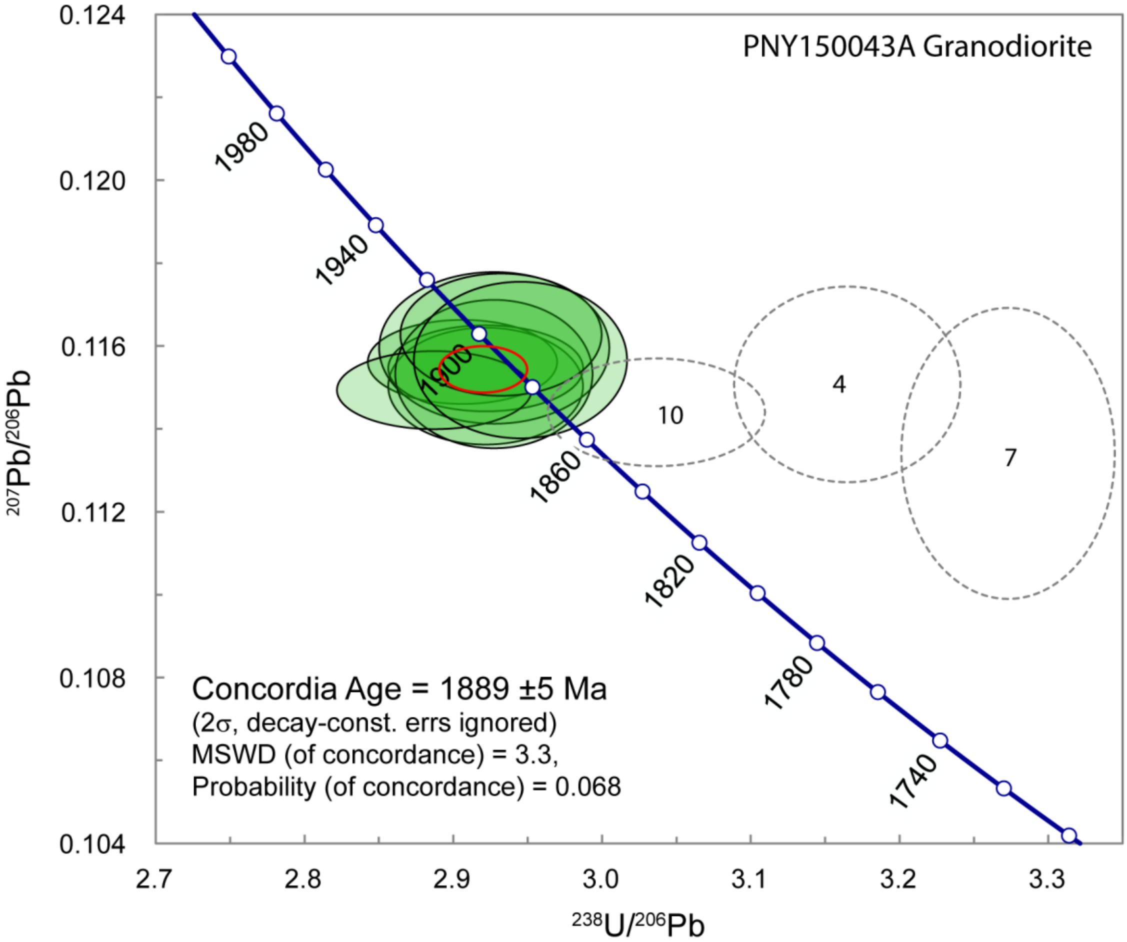

Figure 5. Tera Wasserburg diagram showing U-Pb SIMS data of zircon analyses. Three analyses (No. 4, 7, 10) with relatively high common lead values are shown with broken lines and are excluded from age calculations. Error ellipse of calculated weighted mean age is shown in red.

Table 2. SIMS U-Pb-Th zircon data (PNY150043A, laboratory id n5410).

						Isotope ratios								Calculated ages (Ma)			
No	Comment	U ppm	Th ppm	Pb ppm	Th/U calc[1]	$^{238}U/^{206}Pb$	±σ %	$^{207}Pb/^{206}Pb$	±σ %	$^{206}Pb/^{204}Pb$	f_{206}%[2]	Disc. % conv.[3]	Disc. % 2σ lim.[4]	$^{207}Pb/^{206}Pb$	±σ	$^{206}Pb/^{238}U$	±σ
1	Euhedral-subhedral. Oscillatory zoning but with a large central part with patchy zoning. Analysis point in the central part but close to the oscillatory zoned area.	420	245	187	0.60	2.888	0.92	0.1149	0.33	147561	{0.01}	2.3		1879	6	1899	8
2	Euhedral. Oscillatory zoning. Low contrast. Analysis point in the zoned, peripheral part.	361	151	154	0.43	2.907	0.89	0.1156	0.36	251680	{0.01}	1.0		1890	6	1898	8
3	Subhedral. Oscillatory zoned, outside bright central part. Analysis point in a zoned area.	241	104	102	0.43	2.922	0.91	0.1150	0.50	106207	{0.02}	1.0		1880	9	1889	9
4	Subhedral. Grey, almost homogeneous, somewhat blotchy texture.	310	167	126	0.56	3.165	0.98	0.1151	0.84	542	3.45	-6.7	-2.5	1881	15	1822	11
5	Euhedral, appears fragmented. Oscillatory zoned.	355	155	151	0.44	2.922	0.91	0.1155	0.37	>1e6	{0.00}	0.6		1887	7	1892	8
6a	Large crystal. The peripheral parts have oscillatory zoning whereas the interior is blotchy. Analysis point in the centre.	127	78	56	0.60	2.928	1.08	0.1160	0.64	>1e6	{0.00}	-0.1		1895	12	1894	11
6b	Same crystal as 6a. Analysis point in the oscillatory zoned part.	170	83	73	0.49	2.933	0.94	0.1163	0.52	367358	{0.01}	-0.5		1900	9	1895	9
7	Subhedral. Oscillatory zoning with large contrast. Analysis point in a predominantly light grey area.	368	214	144	0.55	3.273	0.90	0.1134	1.26	385	4.86	-8.4	-2.3	1855	23	1781	13
8	Subhedral, equant crystal. Very bright peripheral part with both patchy and oscillatory zoning, and a medium grey interior. Analysis point at the boundary but mostly within the grey, central part.	111	90	51	0.81	2.946	0.99	0.1157	0.67	275492	{0.01}	-0.4		1890	12	1887	10
9	Euhedral, equant crystal without termination pyramids. Oscillatory zoning but show replacement textures.	207	105	89	0.51	2.928	0.92	0.1153	0.63	31520	0.06	0.6		1885	11	1890	10
10	Euhedral. Oscillatory zoning. The analysis point is over a crack.	261	194	113	0.69	3.037	0.98	0.1144	0.46	9043	0.21	-2.2		1870	8	1852	9

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 Percent of common ^{206}Pb in measured ^{206}Pb, estimated from ^{204}Pb assuming a present-day Stacey and Kramers (1975) model.
Figures in parentheses are given when no correction has been applied.
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).

DISCUSSION AND CONCLUSION

The age obtained here, 1889 ±5 Ma, is interpreted to be the crystallisation age of the granodiorite, which is the dominating rock type in the core of the Muddus structure. This age, together with field data (composition, structure, mafic enclaves), thus fits with rocks belonging to the Haparanda suite (Bergman et al. 2001). Co-magmatic mafic rocks (gabbro) have also been found in the central core parts of the Muddus structure.

The Muddus structure was suggested by SGU (1981) as a possible result of an up-lift of a geological unit located between major deformation zones. The structure is delineated and characterised in the interpretation map by Nisca (1980) where he, inter alia, shows the magnetic patterns and levels of magnetisation.

The map of the vertical derivative of the magnetic total field (Fig. 2) shows a faint banding inside the "Muddus structure". The pattern has a wavy appearance and within it, a few smaller sub-units, of semi-circular geometry are observed. Among these one is of particular importance. It is located in the central western part of the "Muddus structure" where it forms a semi-circular complex, of banded anomalies with high levels of magnetisation coinciding with increased gravity. This sub-unit corresponds to a gabbro complex where high magnetic susceptibilities were observed in outcrops in our recent field work. We suggest that the gabbro is co-magmatic with the granodiorite (carrying mafic enclaves), although we have not observed any contact relations. Inside the northern part of the "Muddus structure", Nisca (1980) delineates an area with a banded pattern showing increased level of magnetisation. The feature consists of several thin, apparently vertical sheets, which are highly magnetised. The unit is discordant with the main magnetic pattern of the "Muddus structure" and we have, so far, not found any geological explanation. A swarm of late dykes may, however, be a possible explanation. The composition of the dykes is not possible to predict as the distance between gravity points in this area is too large.

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