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Cover: Granodiorite pebble in the Pite conglomerate on Degerberget, 3 km ESE of the town of Piteå (coordinates of the Swedish National Grid c. 725600-177135). Length of the penknife 9 cm. See paper by Persson & Lundqvist (pp. 41–49).

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EDITOR´S PREFACE

This paper is the third of a series of publications comprising radiometric age determinations carried out as an integral part of the bedrock mapping programme of the Geological Survey of Sweden.

The good cooperation with the isotope laboratories involved in the present investigations is gratefully acknowledged: the Unit for Isotope Geology, Geological Survey of Finland, Espoo (head Dr. Hannu Huhma; analyses performed under the supervision of Dr. Matti Vaasjoki), and the Laboratory for Isotope Geology, Swedish Museum of Natural History, Stockholm (head Prof. Stefan Claesson). In each of the papers of this volume information is given on which laboratory is responsible for the isotopic analyses.

For the analytical procedure of the **Unit for Isotope Geology, Geological Survey of Finland**, the reader is referred to Suominen (1991) and Vaasjoki *et al.* (1991).

Analytical methods for the U-Pb datings performed at the **Laboratory for Isotope Geology in Stockholm** can be summarized as follows. The zircons were separated using standard magnetic and heavy liquid techniques. Some fractions were abraded according to the Krogh (1982) method. They were dissolved in $HF:HNO_3$ in Teflon® capsules in autoclaves according to the method of Krogh (1973). A $^{233\text{-}235}U$ tracer was added to the capsules prior to decomposition. After decomposition and evaporation, 3.1N HCl was added after which the solution was aliquotted. One aliquot was spiked with a ^{208}Pb tracer. The sample aliquots were loaded onto anion exchange columns with 50 µl resin volume for extraction of Pb and U, using HCl ion exchange technique. One sample (Ripa & Persson, pp. 57–62) was spiked with a mixed ^{205}Pb and $^{233\text{-}235}U$ tracer due to the small zircon amounts that were analysed. The isotopic abundances were measured in the static mode on a Finnigan MAT 261 mass spectrometer equipped with five Faraday cups. The calculation of the corrected isotope values and the error propagation were made using the PBDAT program of Ludwig (1991a), and the decay constants recommended by Steiger & Jäger (1977) were used. The calculation of the intercept ages and the drawing of the concordia plot were made with the ISOPLOT-program by Ludwig (1991b). The total Pb blank was 7–12 pg and the U blank less than 2 pg. The assigned composition of common Pb is calculated according to the Pb evolution model of Stacey & Kramers (1975). The mass fractionation for Pb is 0.1% per a.m.u. U mass fractionation was monitored and corrected for by means of the $^{233\text{-}235}U$ ratio of the spike. All analytical errors are given as 2σ.

Monazite was decomposed in 6N HCl bombs. The ensuing procedure was identical to that for zircon.

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Uppsala, February 1997

Thomas Lundqvist

U–Pb zircon dating of the Antak granite, northeastern Västerbotten County, northern Sweden

By

Benno Kathol and Per-Olof Persson

INTRODUCTION

The bedrock in northeastern Västerbotten and southeastern Norrbotten Counties is dominated by Svecofennian volcanic rocks which are informally divided into a subaqueous (marine) succession belonging to the Skellefte group in the south and volcaniclastic and coherent rocks, formed in a terrestrial environment in the north, the Arvidsjaur group (Lundberg 1980; Allen *et al.* 1996). During the Svecokarelian orogeny these rocks have been intruded in several phases and at several levels by early orogenic granites, granodiorites, diorites and gabbros. According to U-Pb zircon datings (Wilson *et al.* 1987; Skiöld *et al.* 1993) these plutonic rocks formed in a time span ranging from c. 1890 Ma to 1870 Ma. In a later stage of the Svecokarelian orogeny, these early orogenic rock assemblages were intruded by late orogenic and postorogenic granites belonging to the Härnö and Revsund suites, respectively.

Most of the plutonic rocks of the area, especially the Arvidsjaur and Antak granites, show no or very weak evidence of Svecokarelian penetrative deformation. Thus, the Arvidsjaur and Antak granites were considered to be of postorogenic or late orogenic age (Claesson 1986; Kathol 1995). However, a U-Pb zircon dating yielded an early orogenic age (1877+8/-7 Ma) for the Arvidsjaur granite (Skiöld *et al.* 1993). Field observations and geochemical data (Ehrenborg 1987; Kathol & Triumf 1996; Kathol & Rapp 1996) suggest a close relationship between the Antak granite and the surrounding Hej volcanic rocks (1878±2 Ma; Skiöld *et al.* 1993), which could imply an early orogenic emplacement even for the Antak granite. In order to understand the relationship between the Arvidsjaur and the Antak intrusions and to get a minimum age for the Arvidsjaur group, the Antak granite has been chosen for a U-Pb zircon dating in the context of the regional mapping by the Geological Survey of Sweden (SGU).

GEOLOGICAL SETTING

The Antak granite is situated within a major, north–northeast trending synform, folding mainly felsic and subordinate intermediate volcanic rocks here called the Hej volcanic rocks (Fig. 1). Together with some epiclastic intercalations (see below) the entire succession is called the Hej subgroup (Ehrenborg 1987). This subgroup belongs to the terrestrial Arvidsjaur group and is situated close to the transition zone between

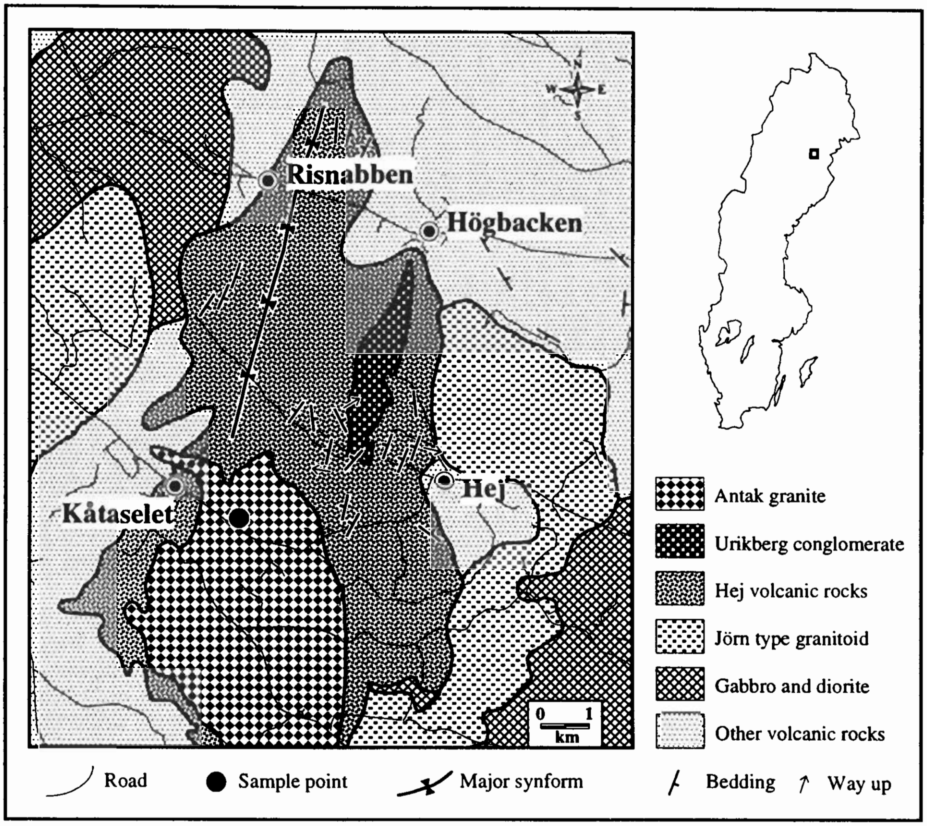

Fig. 1. Simplified geological map of the Hej area. "Other volcanic rocks" includes volcanic rocks of the Skellefte and Arvidsjaur groups undifferentiated. Coordinates (RT 90) of the map corners: 7250000/1687500, 7250000/1700000, 7265000/1700000, 7265000/1687500.

the subaqueous and the subaerial volcanic successions of the Skellefte and the Arvidsjaur groups, respectively.

The Hej volcanic rocks consist of rhyolitic to dacitic, quartz- and/or feldspar-porphyritic lavas and volcaniclastic rocks, intermediate plagioclase porphyries and volcanic breccias, rhyolitic ash-fall tuffs, non-welded ignimbrites and typically violet, welded ignimbrites. The ash-fall tuffs and the ignimbrites are considered to form a 400-500 m thick compound cooling unit, emplaced in an intra-caldera setting (Rapp 1996).

Intercalations of epiclastic sedimentary rocks, mainly polymict conglomerates and subordinate impure sandstones occur at several stratigraphic levels within the volcanic succession. The most extensive of these conglomerate lenses, here referred to as the Urikberg conglomerate, has a north–south extension of more than 4 km and a thickness exceeding 100 m. The fragments range from 1 to 50 cm in size and consist of lavas, volcaniclastic rocks and granodiorites from the GI intrusion of the Jörn suite (Ehrenborg 1987; Kathol 1995; Rapp 1996), all these rocks being derived from the east. Due to the lack of argillaceous material in the matrix and the occurrence of thick massive beds, this conglomerate is considered to represent the result of mass flows initiated by slope wasting in areas with relatively high relief and unweathered volcanic rocks.

Emplacement of the Hej subgroup in a terrestrial environment is indicated by the occurrence of eutaxitic textures, lithophysae, fiamme and welding within the rhyolitic ignimbrites, as well as by the red colours of most of the felsic rocks. Further evidence for the terrestrial nature of the Hej subgroup is given by the nature of the Urikberg conglomerate and the occurrence of drying cracks within an intercalated sandstone lens (I. Antal, I. Lundström, SGU, Uppsala, pers. comm.).

The metamorphic grade within the Hej subgroup does not exceed lower greenschist facies. Primary textures are well preserved, apart from epidote alteration of feldspar phenocrysts and epidote growth within lithophysae.

To the east and west, the Hej subgroup overlies minor massifs of granodiorite and diorite (Fig. 1) which are correlated with the GI intrusion (1888+20/-14 Ma; Wilson *et al.* 1987) of the Jörn suite. To the north and west, the Hej subgroup mainly overlies felsic to intermediate volcanic rocks of the Arvidsjaur group. In its eastern part, the rocks of the Hej subgroup dip at moderate angles to the west and northwest, and minor overturned limbs indicate a deformation style with tight to isoclinal folds with vergences to the east and southeast. However, no foliation related to these folds has been observed. The western part of the Hej volcanic rocks dips steeply to the east and southeast. In general, rocks of the Hej subgroup lie right way up with the violet, welded ignimbrite at the top of the succession, occupying the core of the major synform.

In its south-central parts the Hej subgroup is intruded by the even grained, fine to medium grained, light red or reddish Antak granite. By geophysical modelling, the thickness of the elliptic Antak intrusion (c. 5 x 8 km) is estimated to be between 200 and 500 metres at the present erosional level. Porhyritic varieties of this granite occur locally as a marginal facies of the main Antak intrusion and as minor intrusions within and outside the Hej subgroup. Evidence for the intrusive relationship of the Antak granite to the surrounding volcanic rocks is given by map scale relationships, i.e. the granite boundary cuts general features such as bedding in the Hej subgroup. In one place, the intrusive nature of the granite – volcanic rock contact has directly been observed in the field. A comagmatic origin of the Antak granite, the minor granitic intrusions and the ignimbrites and rhyolites of the Hej subgroup is indicated by REE and trace element patterns of these rocks (Fig. 2).

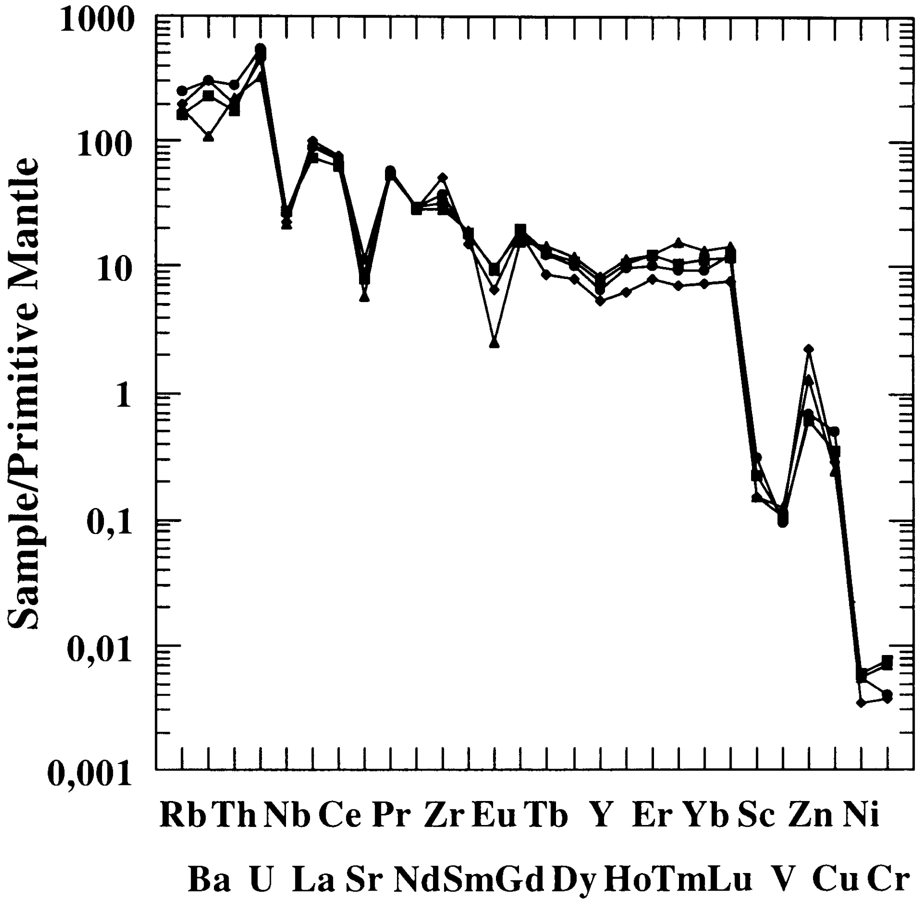

Fig. 2. REE and trace element patterns from chemical data of the Antak granite (square), a minor granitic intrusion (diamond) an ignimbrite (circle) and a rhyolite (triangle) of the Hej area. Normalization according to Taylor and McLennan (1985).

SAMPLING

One granite sample of c. 35 kg was collected on the southwestern slope of the Antak hill c. 1.5 km southeast of Kåtaselet (Fig. 1), map-sheet 24J Arvidsjaur SO. The coordinates of the sampling outcrop are 7254650/1691940 on the national grid (RT 90).

ZIRCON DESCRIPTION AND ANALYTICAL RESULTS

The granite is very poor in zircon. The crystals are colourless or pale yellow. Most of them are euhedral but some have rounded terminations. The length/width ratio is generally less than 3 but more elongated crystals are also present. The zircons are strongly metamict, and it was not possible to avoid metamict grains when selecting grains for analysis. All analysed zircons were strongly abraded. The following four fractions were analysed:

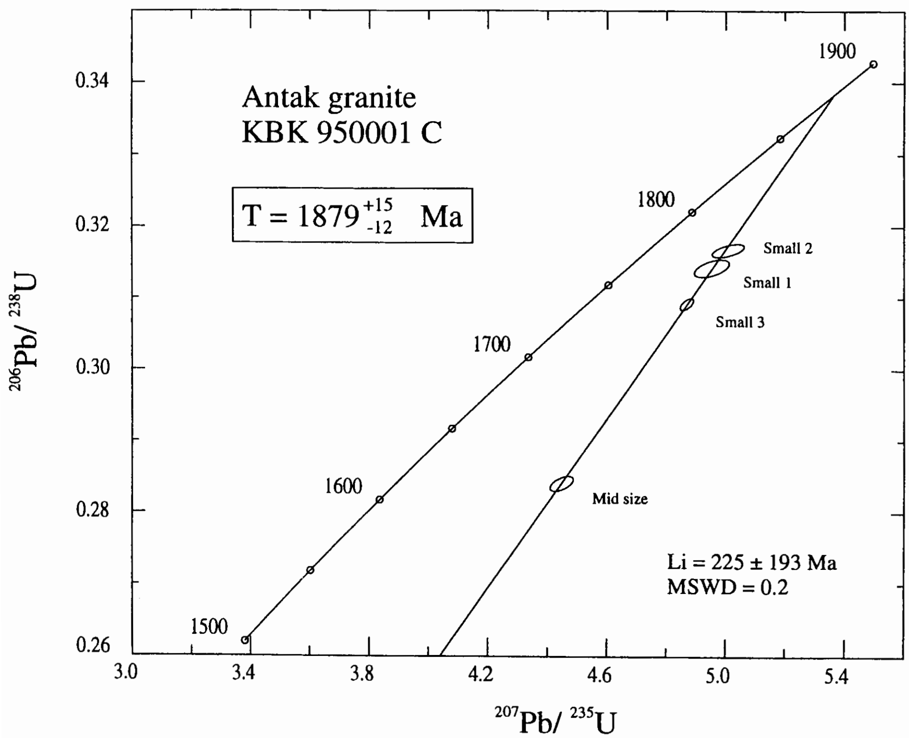

Fig. 3. Concordia diagram for analysed zircons from the Antak granite.

Small 1: 23 crystals. Colourless, short prismatic. Good quality even though cracks, inclusions and turbid domains are present.

Small 2: 18 crystals. Colourless. Four are elongated; the others are short. The quality is somewhat poorer than for the previous fraction.

Small 3: 29 crystals. The appearance is the same as for the fractions above but the zircons are more metamict.

Mid size: 5 crystals. Colourless, short. Cracks and inclusions are present in all grains.

The data points are moderately discordant and define a straight line with an upper concordia intercept of 1879 +15/-12 Ma (Fig. 3). Three of the analysed fractions have remarkably low $^{206}Pb/^{204}Pb$ ratio. These zircons are obviously rich in common lead. The fraction consisting of the most fractured crystals shows a much lower common lead content, implying that the common lead resides in lead-rich inclusions rather than in the zircon crystal lattice or in the cracks. The isotopic composition of the common lead used for correction was calculated according the growth model of Stacey & Kramers (1975). Since all four points yield a good linear array, the model is evidently appropriate in this case. We interpret the obtained age as the crystallization age of the granite.

TABLE 1. U-Pb isotopic data for the Antak granite (KBK 950001 C).

Analysis fraction	Weight (μg) (μg)	U (ppm)	Pb tot. (ppm)	Common Pb (ppm)	$^{206}Pb^{a}/^{204}Pb$
Small 1	10.2	266.8	123.7	36.1	145
Small 2	12.1	242.2	98.9	18.6	241
Small 3	12.2	478.5	155.2	1.4	3702
Mid size	9.7	340.9	109.2	8.7	577

Analysis fraction	^{206}Pb - ^{207}Pb - ^{208}Pb Radiog. (atom %)^{b}	$^{206}Pb/^{238}U^{b}$	$^{207}Pb/^{235}U^{b}$	$^{207}Pb/^{206}Pb$ age (Ma)
Small 1	82.3 - 9.4 - 8.3	0.3143±10	4.953±49	1869±15
Small 2	82.3 - 9.4 - 8.3	0.3167±8	5.008±45	1875±14
Small 3	82.7 - 9.4 - 7.8	0.3092±7	4.868±18	1867±5
Mid size	82.9 - 9.4 - 7.7	0.2841±9	4.447±32	1857±11

a) corrected for mass fractionation (0.1% per a.m.u).

b) corrected for mass fractionation, blank and common Pb.

CONCLUSIONS

The received U–Pb age (1879 +15/-12 Ma) from the analysed zircons places the Antak granite in a suite of early orogenic, granitic intrusions, comprising the Arvidsjaur granite (1877+8/-7 Ma; Skiöld *et al.* 1993) and the Jörn GIII granite (187 +18/-14 Ma; Wilson *et al.* 1987). This granitic suite postdates another early orogenic intrusion phase with the generation of the Jörn GI (1888+20/-14 Ma; Wilson *et al.* 1987) and related granodiorites, tonalites and subordinate diorites and gabbros. Furthermore, the age of the Antak granite and that of the Jörn GI granitoid bracket the time interval embracing the uplift of the Jörn GI intrusion into an erosional position, the emplacement of the Hej volcanic rocks and the deposition of the Urikberg conglomerate. In addition to this, the Antak intrusion yields a minimum age for the Hej subgroup, corresponding with the age of the violet, welded ignimbrites (1878±2 Ma; Skiöld *et al.* 1993) which represent the upper part of the Hej volcanic rocks. Considering the Hej subgroup as the uppermost part of the Arvidsjaur group (Ehrenborg 1987) this minimum age is even relevant for the evolution of the entire Arvidsjaur group.

In volcanological terms, the Antak granite is considered to be formed in a shallow level magma chamber inside its own extrusive equivalents. The granite probably represents the position of the eruptive centre of the Hej volcanic rocks. Thus, the Antak granite and the Hej volcanic rocks can be considered to form a terrestrial volcanic system. A similar, more or less coeval granite which may be related to a similar volcanic system occurs to the east of the Jörn intrusion at Hobergsliden (Lundström *et al.* 1997). Further investigations of the relationships between the Arvidsjaur granite and parts of the Arvidsjaur terrestrial volcanic rocks will possibly reveal that these rocks form a comparable system.

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^{40}Ar–^{39}Ar ages of ultramafic lamprophyres from the Kalix area, northern Sweden

By

Peter Kresten, David C. Rex and Phil G. Guise

ABSTRACT

Four samples of ultramafic lamprophyres from the Kalix area have yielded a rather consistent Ar-Ar plateau age of 1141±6.8 Ma. In Scandinavia, this age is unique among lamprophyres, carbonatites, and alkaline rocks. Ultramafic lamprophyres of corresponding age occur in Greenland and Canada, while the Tajno carbonatite in Poland is apparently somewhat younger.

INTRODUCTION

On the mainland around Kalix in the northernmost part of the Gulf of Bothnia, and in the archipelago south of Kalix and east of Luleå, about one hundred lamprophyre dykes occur, along with some carbonatite dykes. The lamprophyre dykes have been termed "alnöitic, picrite-porphyritic and carbonatitic kimberlites" (Larsson 1943), or "kimberlites" (Åhman 1950) which most certainly is not correct. Kresten *et al.* (1981) have subdivided the Kalix dykes into carbonatites (beforsites), silico-carbonatites, and lamprophyres (micaceous, picritic, and breccia dykes). Major element discrimination diagrams (Rock 1991) applied to the analyses of lamprophyric dykes from the area (Larsson 1943; Kresten *et al.* 1981) show that the majority plots within the ultramafic lamprophyre (UML) field while two analyses (nos. 4 and 5 in Kresten *et al.* 1981) plot in the overlap between UML and AL (alkaline lamprophyres). Available trace element data (Kresten *et al.* 1981) cannot be used in the few discrimination diagrams that have been constructed (Rock 1991). Trace element levels are in accordance with those found in UMLs.

The dykes occur as roughly north-south trending dyke swarms with vertical to steep westward dip directions. They have been intruded into Palaeoproterozoic supracrustal rocks (mafic lavas, tuffites, and sedimentary rocks) belonging to the Karlsborg formation of the Kalix group (Wikström & Åhman 1990). The lamprophyre dykes are commonly highly altered. Fresh olivine is quite rare (Åhman 1950; Kresten *et al.*1981) but the phlogopite seems unaffected by the alteration processes.

The only radiometric age published so far for the dykes is by K-Ar (Kresten *et al.* 1977) on a biotite separate from a breccia dyke at Uddskär, about 30 km east of Luleå, giving an age of 1142±35 Ma. Successively, the present authors (unpublished data) obtained a K-Ar age of 1668±67 Ma (whole rock; 1.96% K, 932×10^{-7} ml/g ^{40}Ar, 98.7% Ar rad.) for the picritic lamprophyre dyke KA 9 on Storön southwest of Kalix (Kresten *et al.* 1981). In order to resolve the apparent discrepancy of ages obtained, four samples were analysed using Ar-Ar techniques on initiative by Dr. Th. Lundqvist, Geological Survey of Sweden. Economic support was given by the inter-Nordic Mid-Norden Project.

SAMPLES AND ANALYTICAL METHODS

Sample KA 7 (map-sheet 25M Kalix SO, Swedish National Grid: 731112/183310). Centre of a 20 cm wide dyke at Storön southwest of Kalix, classified as "picritic lamprophyre" (Kresten *et al.* 1981), with chilled margins, "horned dykes" and apophyses. It contains phenocrysts of altered olivine and some phlogopite in a matrix of these minerals and titanomagnetite, serpentine, and calcite. Sample KA 9 (K-Ar age above) is an apophysis of the same dyke.

Sample KA 10 (map-sheet 25M Kalix SO, 731008/183305). Dyke at Storön southwest of Kalix, classified as "picritic lamprophyre" (Kresten *et al.* 1981), about 10 cm wide, *en échelon*. Phenocrysts of altered olivine and some phlogopite are set in a matrix of these minerals and titanomagnetite, serpentine, and calcite.

Sample KA 15 (map-sheet 25M Kalix SO, 730880/183350). Dyke at southern Storön, southwest of Kalix, classified as "picritic lamprophyre" (Kresten *et al.* 1981), about 60 cm wide, in composition similar to sample KA 10, with accessory ilmenite, picotite, and anatase (analyses given by Kresten *et al.* 1981).

Sample KA 17 (map-sheet 25M Kalix SO, 731530/182620). Dyke on the mainland north of Storön, southwest of Kalix, classified as "micaceous lamprophyre" (Kresten *et al.* 1981), about 20 cm wide, with phenocrysts of phlogopite in a matrix of carbonate, mica, serpentine, chlorite, opaque minerals, and arfvedsonite (analysed by Kresten *et al.* 1981). Occasional ultramafic nodules that have been completely altered into serpentine occur.

Analytical techniques have been described in detail by Rex *et al.* (1993).

RESULTS

Three of the samples give consistent ages between 1140.6 and 1141.3 Ma (Table 1, Fig. 1), average 1141±6.8 Ma, while the fourth sample yielded an age of 1127.9 ± 6.7 Ma. All four data are, however, within the 1 σ error range. The K-Ar age of 1668±67

TABLE 1. Isotope data and calculated ages of the investigated samples.

KA 10 Bio, run 1765, weight =0.03664 g, J value =0.00459 +/- 0.8 %

Temp °C	$^{39}Ar_K$ {	$^{37}Ar_{Ca}$ vol. x 10^{-9} cm^3	$^{38}ArCl$ }	Ca/K	$^{*}40/^{39}Ar_K$	% Atm. ^{40}Ar	Age { Ma	Error }	$\%^{39}Ar_K$
670	1.5	2.22	0.06	2.98	178.86	7.6	1081.3	1.9	1.5
745	5.9	0.26	0.11	0.09	197.81	0.3	1165.5	0.6	6.1
800	12.1	0.17	0.20	0.03	194.07	0.1	1149.2	0.4	12.4
850	16.4	0.17	0.26	0.02	193.02	0.1	1144.6	0.5	16.8
950	22.4	0.26	0.37	0.02	191.92	0.2	1139.7	0.4	23.1
1050	23.1	0.44	0.39	0.04	190.89	0.4	1135.2	0.3	23.7
1155	11.9	0.34	0.19	0.06	192.56	0.1	1142.6	0.4	12.3
1320	4.0	0.13	0.06	0.06	193.09	0.1	1144.9	1.1	4.1

Total gas values.		Analytic & J errors.		
Age(Ma)	1141.9	0.6	6.8	Wt %K = 8.2
$^{*}40/^{39}Ar_K$	192.41	0.07%		$^{*}40 = 510 \times 10^{-6}\ cm^3g^{-1}$

Age derived from steps 3 - 8 : 1141.3 ± 6.8

KA 7 Bio, run 1766, weight =0.04010 g, J value =0.00459 +/- 0.8 %

Temp °C	$^{39}Ar_K$	$^{37}Ar_{Ca}$	$^{38}ArCl$	Ca/K	$^{*}40/^{39}Ar_K$	% Atm. ^{40}Ar	Age	Error	$\%^{39}Ar_K$
640	0.4	0.92	0.01	4.53	234.88	47.7	1319.6	7.4	0.4
735	1.9	1.58	0.03	1.62	217.42	3.6	1248.6	1.4	1.8
795	4.6	0.18	0.07	0.08	200.40	0.7	1176.7	0.4	4.2
850	9.8	0.11	0.14	0.02	194.06	0.3	1149.2	0.3	9.0
955	34.6	0.32	0.52	0.02	189.57	0.2	1129.4	0.4	31.7
1055	24.4	0.23	0.36	0.02	189.10	0.3	1127.3	0.4	22.3
1170	23.8	0.81	0.37	0.07	188.77	0.3	1125.8	0.4	21.8
1330	9.8	0.71	0.15	0.14	189.52	0.3	1129.2	0.6	9.0

Total gas values.		Analytic & J errors.		
Age(Ma)	1134.8	0.6	6.8	Wt %K = 8.5
$^{*}40/^{39}Ar_K$	192.80	0.07%		$^{*}40 = 520 \times 10^{-6}\ cm^3g^{-1}$

Age derived from steps 5 - 8 :1127.9 ± 6.7

Errors are 1 sigma, *40 is volume of radiogenic ^{40}Ar, gas volumes corrected to STP.

Ma determined for sample KA 9, a small dykelet, is probably too high due to excess argon from the Proterozoic wall-rock. The published age of 1142±35 Ma (Kresten *et al.* 1977) on a breccia dyke at Uddskär agrees very well with the present determinations.

TABLE 1, cont.

KA 15 Bio, run 1763, weight =0.03114 g, J value =0.00459 +/- 0.8 %

Temp °C	$^{39}Ar_K$ {	$^{37}Ar_{Ca}$ vol. x 10^{-9} cm^3	$^{38}ArCl$ }	Ca/K	$*40/^{39}Ar_K$	% Atm. ^{40}Ar	Age {	Error Ma }	$\%^{39}Ar_K$
670	1.2	0.74	0.04	1.27	178.49	12.7	1079.6	2.6	1.5
740	0.4	0.00	0.00	0.00	207.21	0.2	1205.9	4.8	0.5
780	8.3	0.05	0.12	0.01	195.31	0.2	1154.6	0.4	10.3
860	20.6	0.16	0.31	0.02	193.03	0.1	1144.6	0.6	25.8
960	17.8	0.10	0.28	0.01	192.28	0.1	1141.3	0.3	22.3
1025	11.4	0.11	0.17	0.02	191.58	0.3	1138.2	0.4	14.3
1175	17.8	0.32	0.27	0.04	191.34	0.2	1137.2	0.4	22.3
1325	2.4	0.24	0.04	0.20	191.35	0.1	1137.2	1.0	3.0

Total gas values. Analytic & J errors.
Age(Ma) 1141.5 0.7 6.8 Wt %K = 8.0
$*40/^{39}Ar_K$ 192.32 0.08% $*40 = 492 \times 10^{-6}$ cm^{3}g^{-1}

Age derived from steps 4-8 : 1140.6 ± 6.8

KA17 Bio, run 1764, weight =0.02848 g, J value =0.00459 +/- 0.8 %

665	1.5	2.46	0.05	3.31	142.76	8.1	909.2	1.7	2.0
735	4.5	1.38	0.12	0.62	196.03	0.4	1157.8	0.6	6.0
790	8.6	0.16	0.22	0.04	193.54	0.1	1146.9	0.4	11.7
865	18.8	0.19	0.44	0.02	192.84	0.1	1143.8	0.5	25.5
960	15.3	0.13	0.36	0.02	194.05	0.2	1149.1	0.2	20.7
1030	10.8	0.07	0.26	0.01	195.42	0.3	1155.1*	0.3	14.6
1180	13.6	0.30	0.31	0.04	192.28	0.5	1141.3	0.5	18.4
1330	0.8	0.12	0.02	0.28	191.91	1.8	1139.7	5.8	1.1

Total gas values. Analytic & J errors.
Age(Ma) 1140.7 0.6 6.8 Wt %K = 8.1
$*40/^{39}Ar_K$ 192.15 0.08% $*40 = 500 \times 10^{-6}$ cm^{3}g^{-1}

Age derived from steps 3 - 8 (omit 6*) :1141.3 ± 6.8

* step 6, minor technical fault, shown for completeness, not used in age calculations

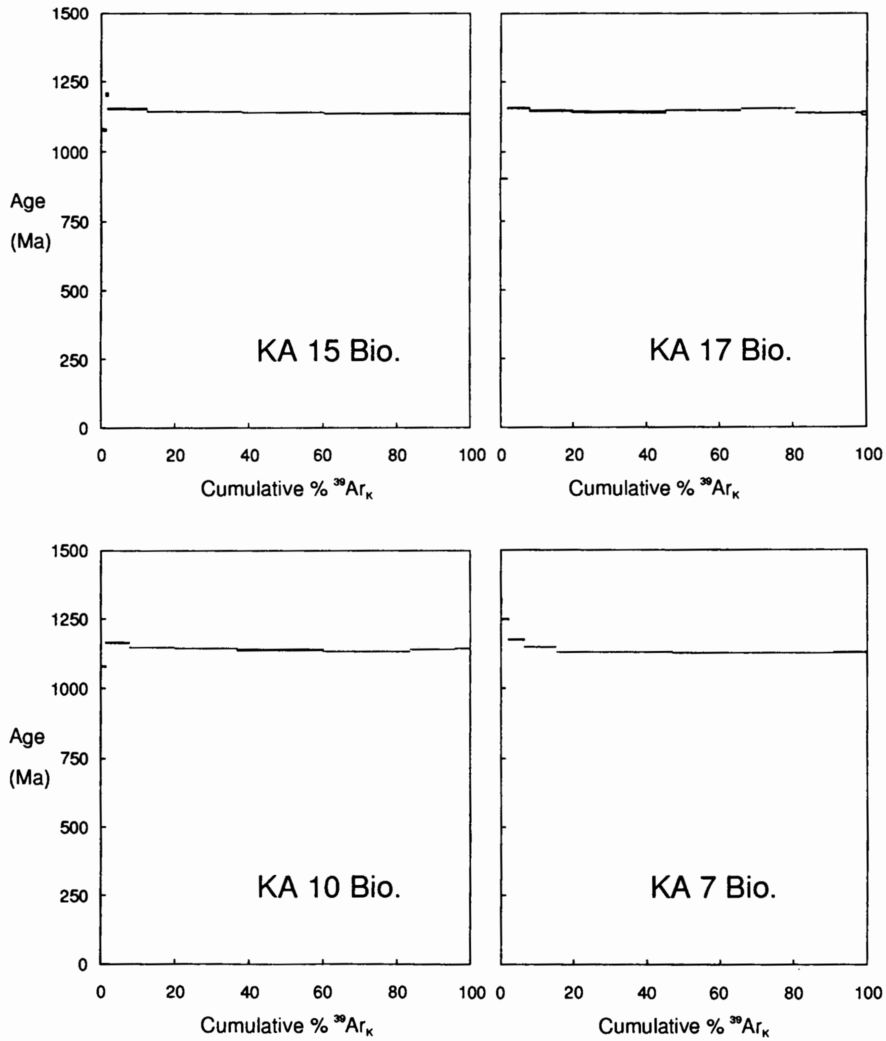

Fig. 1. $^{40}Ar/^{39}Ar$ release spectra for the investigated samples.

DISCUSSION

In Sweden, only dolerite intrusions and some supracrustal rocks (mainly sandstones) have ages comparable to those of the Kalix dykes (Lundqvist 1979). The age of the Kalix dykes is unique among carbonatite and lamprophyre intrusions in Scandinavia

(Kresten *et al.* 1977; Woolley 1989; Rock 1991). Similar rocks of the Gardar province in south Greenland, and of the Borden and Bachelor Lake districts in Ontario, Canada, also have Grenville ages (Rock 1991; Woolley 1989). A possible relation between the activity at the Tajno carbonatite in Poland, thought to be about 900 Ma, and the Kalix dykes has been indicated by Woolley (1989, p. 27). The Alnö alkaline and carbonatite complex, accompanied by various lamprophyric rocks, is situated some 500 km southwest of Kalix, apparently along the same zone of crustal weakness. However, it is much younger than the Kalix dykes (Pb-Pb isochron age of 584±13 Ma; Andersen *et al.*, unpublished).

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Radiometric age determinations of plutonic rocks in the Boliden area: the Hobergsliden granite and the Stavaträsk diorite

By

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Ildikó Antal and Fredrik Strandman

INTRODUCTION

The Boliden area is situated in the easternmost part of the Skellefte mining district (Weihed *et al.* 1992) and displays a wide variety of rock types. Thus, the southwestern part of the Boliden quadrangle (Fig. 1) is dominated by volcanic, partly hydrothermally altered, ore-bearing rocks, which are overlain in the east by black schists and metagreywackes. The metamorphic grade varies from greenschist facies in the west to amphibolite facies in the east. In the easternmost part of the area, the rocks are thoroughly migmatized. The volcanic rocks are c. 1880 Ma old and are intruded by the c. 1870–1890 Ma old Jörn granitoids. The metasedimentary rocks in the east are migmatized and rich in heterogeneous, pegmatitic-aplitic, leucogranitic neosomes which are probably related to the c. 1810 Ma old Skellefte–Härnö granites. Such granites as well as c. 1780 Ma old Revsund granites intrude the metasediments. For references, see Weihed *et al.* (1992). Cf. also Antal & Lundström (1995) and Lundström & Antal (1996).

The Jörn granitoid complex, half of which is found in the northwestern part of the Boliden map-sheet (Fig. 1), was thoroughly described by Wilson *et al.* (1987). They subdivided the Jörn granitoids into four varieties ("Jörn GI, II, III and IV", respectively). This subdivision was primarily based on the various aeromagnetic anomaly patterns displayed by the different varieties but was also found to be of petrographic and geochronologic significance. Thus, the main, GI phase was found to be granodiorite-dominated and yielded a U-Pb zircon age of 1888+20/-14. The other main phase, the mainly granitic GIII, was found to give an U-Pb zircon age of 1873+18/-14. Thanks to the thorough description by Wilson *et al.* (1987) the Jörn granitoids are easily used as "age discriminants" in the area.

During the mapping of the Boliden map-sheet, the Jörn granitoid complex was mostly easily recognized as described by Wilson *et al.* (1987). However, several bodies of plutonic rocks were also encountered (cf. Fig. 1), which lack obvious field relations or petrographic/geophysical similarities to the Jörn or other well known complexes. Thus, their ages and settings remained enigmatic and some were sampled for radiometric dating. This contribution reports the results from the dating work on two of these rocks.

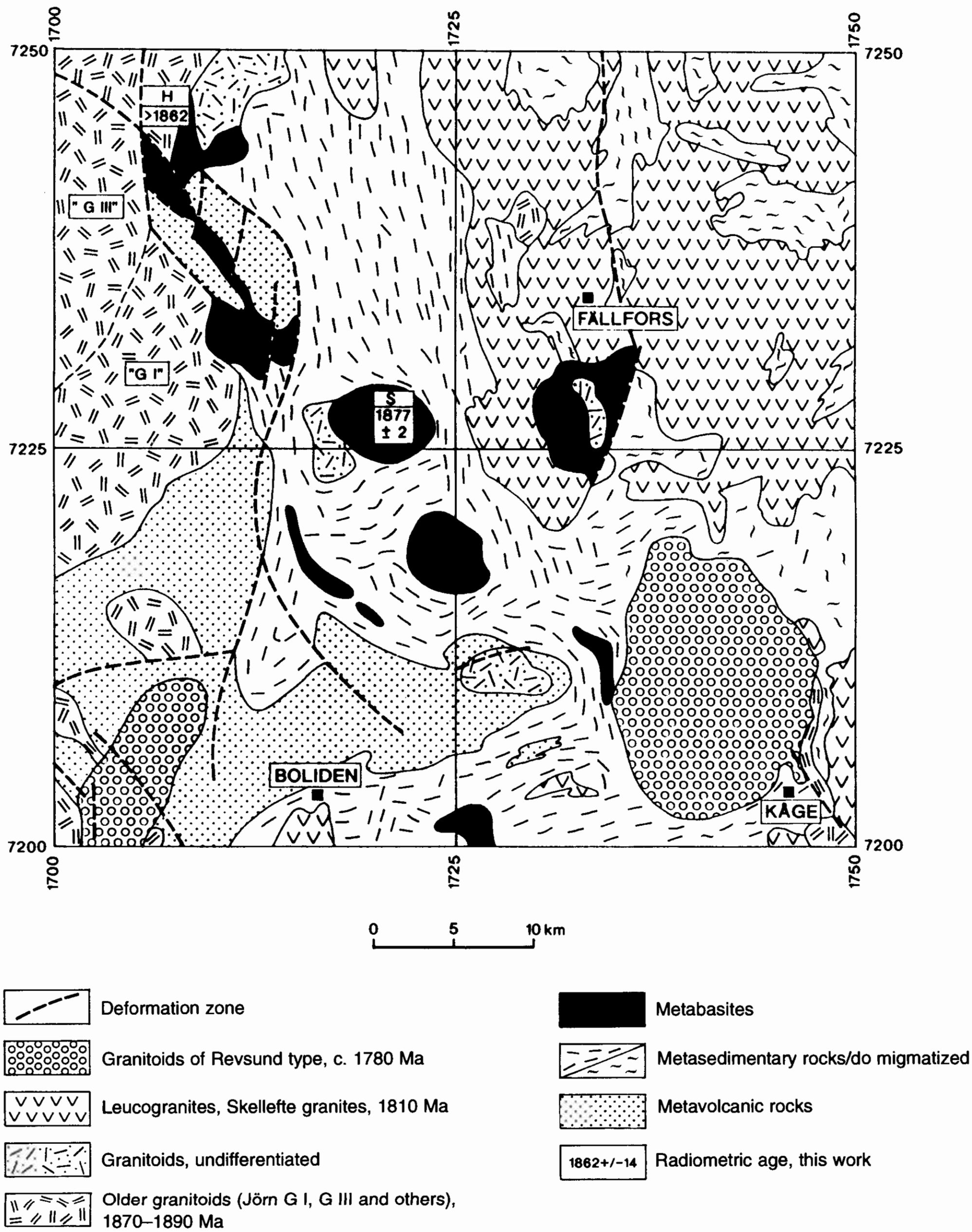

Fig. 1. Preliminary sketch map of the geology on the Boliden map-sheet. H: Hobergsliden, S: Stavaträsk.

THE HOBERGSLIDEN GRANITE

Around the Hobergsliden hill (see Fig. 1) a reddish granite is found which looks fairly similar to the GIII type of the Jörn complex, which it also abuts on. Consequently, both Högbom (1937), Gavelin & Kulling (1955) and Wilson *et al.* (1987) suggested it to be a Jörn granitoid. According to Kathol (oral communication 1996) it is very similar to the Antak granite, which is found to be a subvolcanic intrusion of GIII age (Kathol & Rapp 1996; Kathol & Persson, 1997)

Description and geological setting

The area occupied by the Hobergsliden granite is, however, found to have a significantly less distinct aeromagnetic anomaly pattern (cf. Fig. 2) than the adjoining GIII area. The susceptibility of the GIII is also clearly higher than that of the Hobergsliden granite. The latter furthermore seems to be richer in thorium than the GIII as evi-

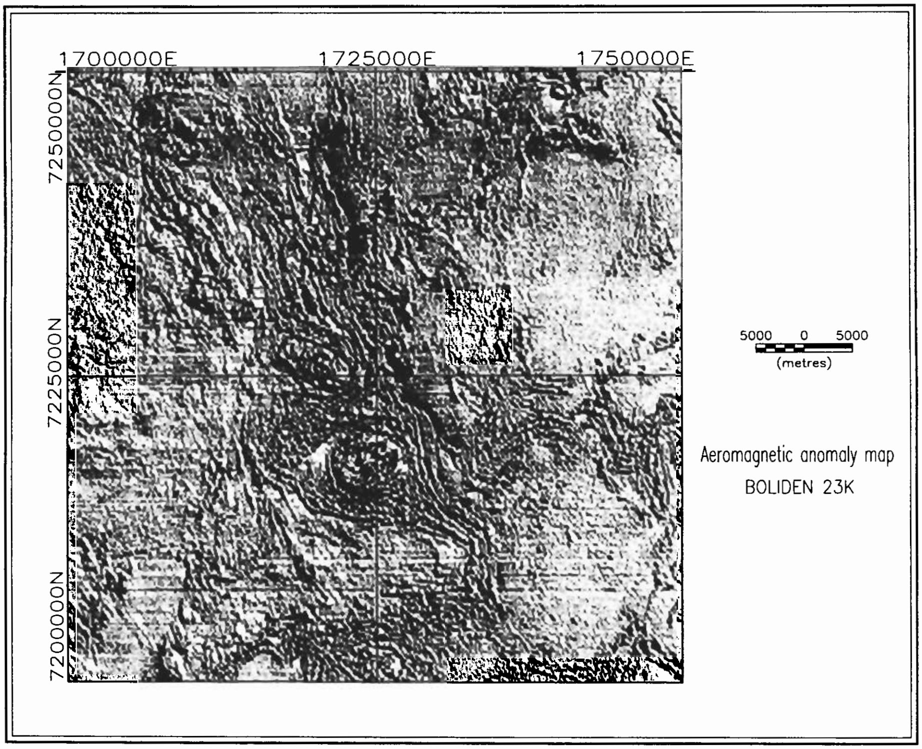

Fig. 2. Aeromagnetic anomaly map of the Boliden map-sheet. H: Hobergsliden, S: Stavaträsk.

TABLE 1. Chemical analyses of dated samples.

Sample no.	FRS940255A	MAF9400003A	HCA930060
Location	Hobergsliden	3 km NE Stavaträsk	3 km W of Stavaträsk
Nat. grid coordinates:	724760/170680	722638/172190	722318/171670
SiO_2 (wt.%)	77.4	46.3	71.9
Al_2O_3	12.6	16.9	15.4
TiO_2	0.087	1.88	0.25
Fe_2O_3	0.98	13.1	2.47
MgO	0.11	5.00	0.68
CaO	0.21	7.90	2.45
Na_2O	3.82	3.35	4.69
K_2O	4.73	1.61	2.12
MnO	0.01	0.11	0.04
P_2O_5	<0.01	1.09	0.10
LOI	0.35	0.60	0.94
Total	100.3	98.2	101.0
Ba (ppm)	<50	917	1212
Ce	23	106	43.1
Co	71	49	6
Cr	<10	20	12
Cs	3	<3	-
Dy	-	-	1.30
Er	-	-	0.64
Eu	<7	3.0	1.11
Gd	-	-	2.20
La	10	49	20.4
Lu	0.23	0.16	-
Mo	<5	<5	-
Nb	16	7	5
Nd	10	40	16.6
Ni	<100	<100	9.4
Rb	157	67	62
Sc	1.5	20.4	2
Sm	2.1	9.4	1.59
Sr	44	1690	673
Tb	<5	<5	-
Th	26.0	1.1	-
U	6.2	1.4	-
V	-	-	24
W	540	78	-
Y	16	33	4.9
Yb	1.3	0.8	0.384
Zn	<50	<50	50
Zr	109	82	90

denced by gamma radiation spectra. This is corroborated by Table 1 which shows that the dated Hobergsliden sample contains 26.0 ppm thorium as compared to about 12–15 ppm, commonly found in the GIII according to Wilson *et al.* (1987, Table 1). The gamma radiation spectra of the Hobergsliden granite also show it to be richer in U than the normal GIII type.

Furthermore, the Hobergsliden granite does not have the well preserved magmatic texture, typical of the GIII in the area, but is somewhat more recrystallized. Thus, in the Hobergsliden type, the quartz grains are always surrounded by small subgrains, which are lacking in the GIII type. Furthermore, it is locally rich in aplite dikes, which are wanting in the GIII. Consequently, the nature of the Hobergsliden granite was found dubious and a sample was taken in an attempt to date the granite radiometrically.

The sample, which was taken at the Hobergsliden hill, is a fairly typical, reddish, weakly recrystallized granite with a hypidiomorphic-granular, medium-grained, even-grained, homogeneous, isotropic texture. The rock consists of about equal amounts of undulatory quartz, perthitic microcline and a sodic oligoclase as main minerals. Biotite is a leading accessory mineral, among which muscovite, chlorite, zircon, sphene and opaques have also been found. The chemical composition is demonstrated by Table 1.

Result

The sample contained a surprisingly small amount of very fine-grained (<70 μm) and extremely heterogeneous zircons. Consequently a conventional U-Pb study of the zircons was not feasible.

However, the sample contained fairly abundant brown, anhedral titanite, on which a U-Pb determination was carried out. The results (Table 2) show that the titanite is reversely discordant (Fig. 3). Thus, the $^{207}Pb/^{206}Pb$ age of 1862+/-14 Ma indicates a minimum age for the closure of the titanite U-Pb system, often interpreted as the last cooling below 500°C.

TABLE 2. U-Pb titanite data from sample FRS940255A, Hobergsliden.

U conc	Pb conc	206/204	206/238	207/235	207/206	Apparent age in Ma		
ppm	ppm	meas.	Corrected for blank			206/238	207/235	207/206
168.7	99.34	244.6	.3749	5.886	.1139	2052	1959	1862

Common lead correction: $^{206}Pb/^{204}Pb$: 15.7; $^{207}Pb/^{204}Pb$: 15.4; $^{208}Pb/^{204}Pb$: 35.2.

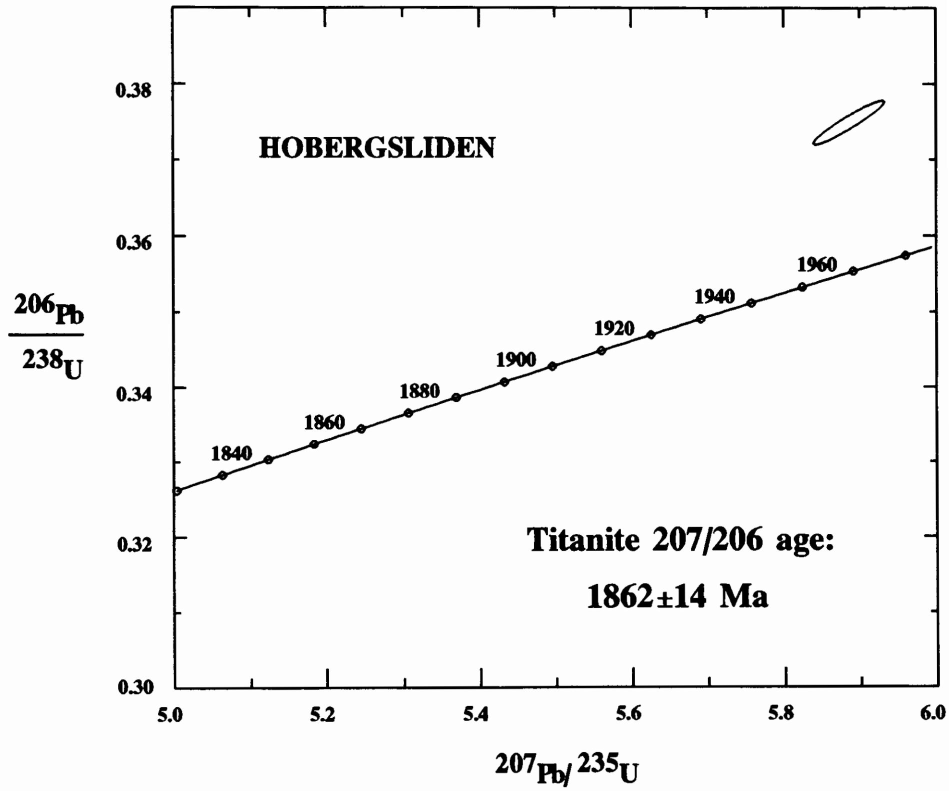

Fig. 3. Concordia plot for the Hobergsliden titanite.

Conclusions

Although the Hobergsliden granite deviates somewhat from a typical Jörn GIII granite, its titanite age is apparently consistent with the original idea that it is a variety of the Jörn GIII granites.

THE STAVATRÄSK DIORITE

Just north of Stavaträsk village in the central part of the Boliden map-sheet, a pluton occurs, which consists essentially of a diorite and a trondhjemitic tonalite, cf. Fig. 1. The diorite was interpreted by Högbom (1935) to be a variety of the Jörn granitoids, which apparently was also the opinion of Gavelin & Kulling (1955). On the map of

Grip & Frietsch (1973), it is suggested to be of Revsund granitoid age. The tonalite/trondhjemite has been interpreted as a fine-grained Revsund granite (Högbom 1937; Gavelin & Kulling, 1955; Grip & Frietsch 1973).

The Stavaträsk and other basic plutons, for example the Storkågeträsk gabbro, c. 5 km to the southeast of Stavaträsk, form a distinct group of intrusions with unknown relations to the Jörn granitoids. Therefore a radiometric age determination was found desirable.

Geological setting

The Stavaträsk pluton is hosted by a N–S-trending belt of metasedimentary rocks, cf. Fig. 1. To the east, the metamorphic grade of the metasedimentary succession increases rapidly and the rocks are transformed into migmatites. Particularly on the western, lower-grade metamorphic side of the pluton, contact metamorphism is evident. Thus, andalusite porphyroblasts, that overprint the cleavage of the metasedimentary rocks, occur there.

The core of the Stavaträsk pluton is rich in hornblende gabbro, which is surrounded by the diorite and the tonalite/trondhjemite.

The diorite has a high magnetic susceptibility and stands out as a distinctive (high) magnetic anomaly on the aeromagnetic map, Fig. 2. Current interpretations of gravimetric and magnetic data indicate that the dioritic part of the pluton is c. two kilometres deep and has steep western and moderately east-dipping eastern contacts.

The diorite is clearly intrusive along its eastern contact, where it contains more or less resorbed and hornfelsic roof pendants of the metasedimentary rocks. Thus, hornfelsic and contact metamorphic phenomena seem to have overprinted the cleavage of the host rocks also here. Furthermore, as the diorite itself has a completely unfoliated, isotropic, unrecrystallized magmatic texture, it seems to be of post-tectonic age.

The tonalite/trondhjemite has an unknown contact relation with the diorite. Consequently, the diorite and the tonalite/trondhjemite need not be related at all. However, both the tonalite/trondhjemite and the diorite are Sr-enriched and have characteristically fractionated REE patterns without negative Eu anomalies (cf. Table 1 and Fig. 4), suggesting a plagioclase-enriched, tholeiitic trend. The rocks therefore seem to be geochemically related. Furthermore, the tonalite/trondhjemite cross-cuts the foliations in the metasedimentary rocks southwest of Stavaträsk and is therefore post-tectonic as well.

The exact extension of the tonalite/trondhjemite in the low magnetic areas northeast and southeast of the diorite is unclear due both to the low magnetic susceptibility of the rock and to lack of outcrops.

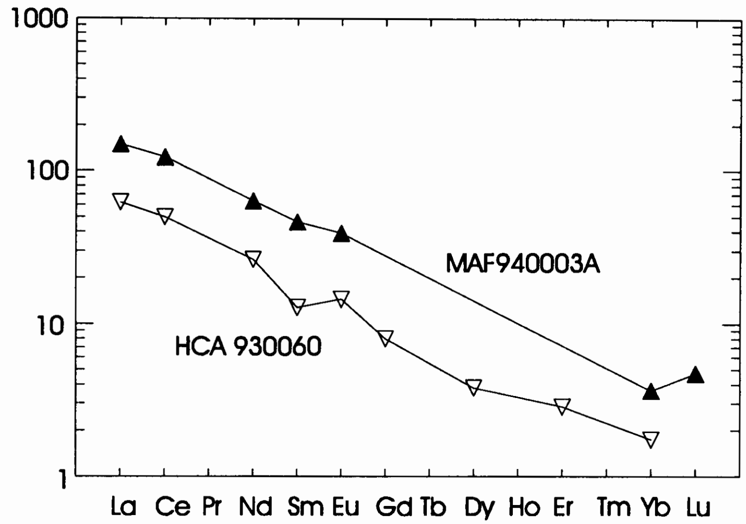

Fig. 4. REE plot for the Stavaträsk diorite and tonalite/trondhjemite. Normalization according to Sun (1982).

Description

The diorite was sampled at the Yttre Brandbergen hill, some three kilometres north-east of Stavaträsk village and close to the eastern contact of the pluton. There, a rather light grey variety occurs, which is suggested to have formed in a fractionated roof zone, which could be expected to be rich in zircons. The sampled diorite is a medium grey, fine- to medium-grained, even-grained, homogeneous, isotropic rock with a well preserved hypidiomorphic-granular texture with somewhat lath-formed plagioclase crystals. Its main minerals are plagioclase (andesine, anorthite content 40–45 %) and greenish hornblende in approximately equal amounts. Brownish biotite and apatite are essential minerals and ilmenite, titanite, chlorite and epidote are common accessories. The chemical composition is demonstrated in Table 1. Relative to the dark, normal diorite variety, the sampled, light grey diorite is enriched in incompatible elements and REE, as can expected for a fractionated rock from a roof zone.

The diorite contains fairly abundant zircons, which are pale brown in colour. The crystals are generally roundish and subhedral. No marked zonation has been observed. About 5% are turbid and these were removed by hand-picking before analysis.

Result

The analysed fractions exhibit a normal discordancy pattern, i. e. the degree of discordance increases as the uranium contents increase and the density decreases. The common lead contents are low, as is demonstrated by the high $^{206}Pb/^{204}Pb$ ratios, and thus, the estimated value of the common lead composition has no bearing on the results. All analyses are relatively concordant, which results in a quite precise age estimate of 1877+/-2 Ma, see Fig. 5 and Table 3.

TABLE 3. U-Pb zircon data from sample MAF940003, Stavaträsk.

Sample	Fraction	U conc ppm	Pb conc ppm	206/204 meas.	206/238	207/235	207/206	Apparent age in Ma 206/238	207/235	207/206
					Corrected for blank					
A	+4.5/ABR	210.1	73.33	12412	5.286	.3343	.1147	1859	1866	1875
B	+4.5	214.0	73.52	13514	5.215	.3230	.1146	1838	1855	1874
C	4.3-4.5	519.2	181.90	11439	5.020	.3188	.1142	1784	1822	1867
D	4.2-4.3	901.6	314.85	8732	4.857	.3092	.1139	1736	1794	1863

Common lead correction: $^{206}Pb/^{204}Pb$: 15.7; $^{207}Pb/^{204}Pb$: 15.4; $^{208}Pb/^{204}Pb$: 35.2.

Conclusions

The age obtained indicates that the Stavaträsk diorite is coeval with the Jörn GIII granitoids. This is somewhat surprising because the Jörn GIII phase is hitherto only known to contain granitic varieties.

A common origin for the diorite and the tonalite/trondhjemite of the Stavaträsk intrusion is suggested by the coexistence of the two rocks in the pluton, by their similar relations to the fabrics of the host rocks as well as by their similar geochemistry. However, a radiometric age determination of the tonalite/trondhjemite is also highly desirable but may be difficult to accomplish because of poor outcrops. Nevertheless, the presently available data indicate that the Stavaträsk pluton intruded into a setting upon which an early fabric of unknown age and significance had been imposed already 1877+/-2 Ma ago.

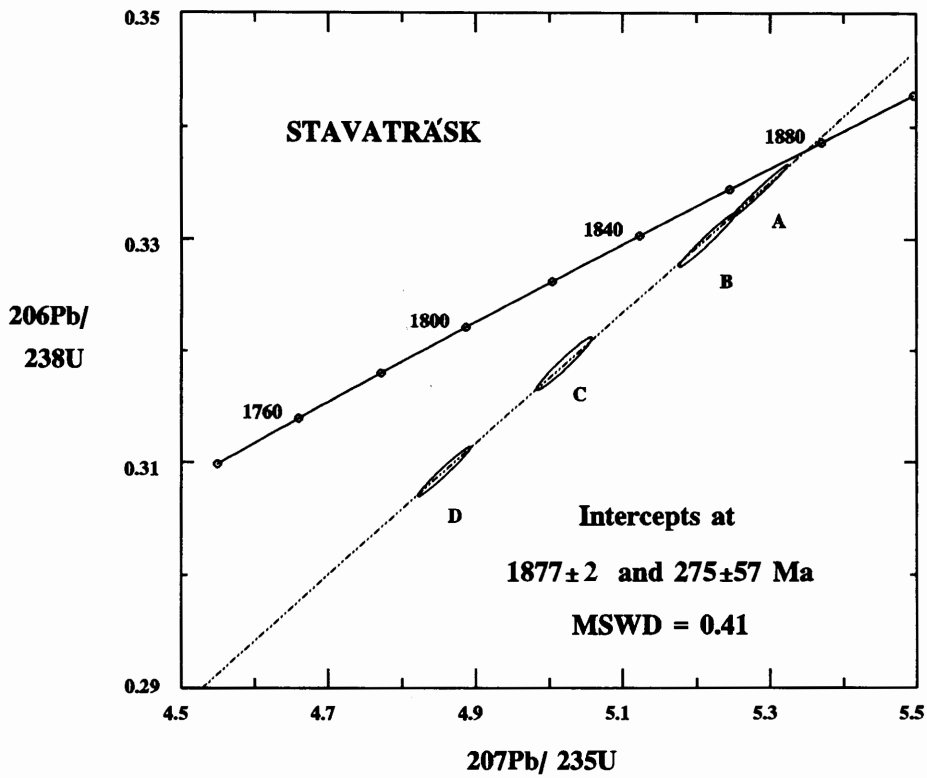

Fig. 5. Concordia plot for the zircons of the Stavaträsk diorite.

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U-Pb zircon ages of two Småland dyke porphyries at Påskallavik and Alsterbro, southeastern Sweden

By

Magnus Nilsson and Hugo Wikman

INTRODUCTION

The main part of the bedrock in southeastern Sweden is made up of so-called Småland-Värmland granites and associated volcanic rocks, mainly porphyries. These rocks comprise a belt extending from Blekinge in the southeast through Småland and Värmland into Norway, where it disappears under the much younger Caledonian cover (Fig. 1). This vast lithological block, together with granites further to the north, forms the Transscandinavian Igneous Belt (TIB). Within the Småland part of the belt there also occur minor sections of mainly older rocks, e.g. the Västervik formation (Gavelin 1984) and the Oskarshamn–Jönköping Belt (OJB; Mansfeld 1995, 1996).

The intrusive rocks within the Småland–Värmland region consist of different types ranging from gabbroic plutonic rocks to felsic, red granites. The volcanic rocks are dominated by felsic porphyries of which many exhibit ignimbritic structures. The rocks within the TIB were previously believed to be postorogenic in relation to the Svecokarelian orogeny and should, according to this, crosscut the regional structures. It has, however, been demonstrated that in some areas the TIB granites are folded and deformed conformably with the older bedrock (e.g. Wikström 1989). These intrusions are thus not postorogenic in the general meaning of the term.

Age data from the TIB show that the intrusions span over a very long time. Larson & Berglund (1992) proposed a threefold division of the intrusions with age intervals at 1810–1760, 1710–1690, and 1670–1650 Ma, respectively. According to this division the oldest, TIB 1 rocks, are found in the east and the youngest, TIB 3 rocks, in the west. Recently a fourth, older generation at 1850 Ma has been dated within the Askersund area (Persson & Wikström 1993; Wikström 1996). Within the Växjö region there are new datings indicating an intrusive period at c. 1680 Ma (Wikman, this volume, pp. 63–72). This period probably corresponds to TIB 2.

Both age data and structure observations thus indicate a long and complex history of the TIB rocks and the onset of the TIB magmatism is clearly related to the late Svecokarelian development. The intrusions have probably been formed continuously from the later phases of an orogenic activity extending into a postorogenic stage. Designations such as syn- to postorogenic or syntectonic, instead of postorogenic, should therefore be more correct in many cases.

Whereas the granitoids vary much in age, the ages of the corresponding volcanic rocks in Småland seem to be restricted to a narrow time-interval just above 1800 Ma.

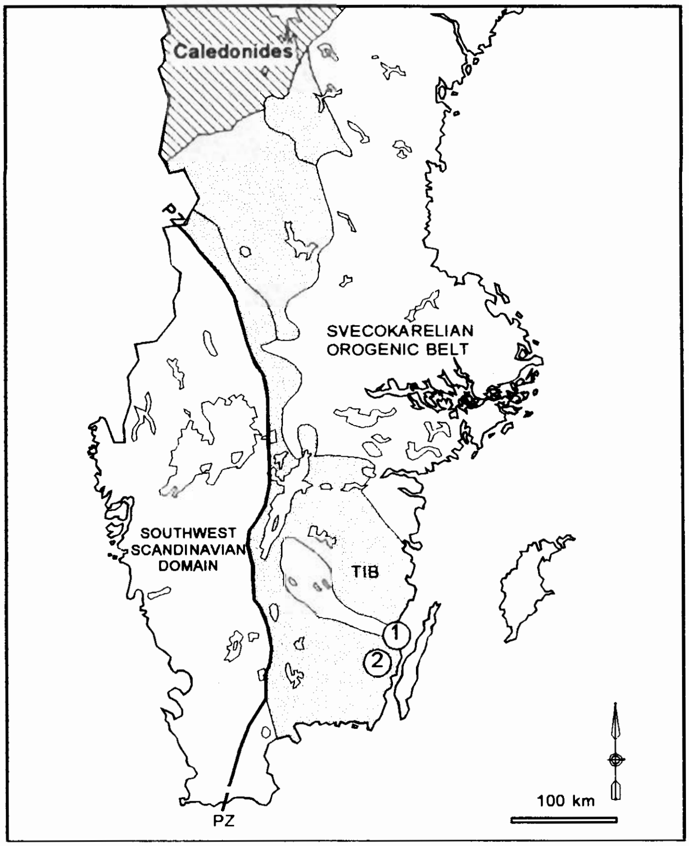

Fig. 1. Simplified map of southern Sweden showing the major Precambrian units. Stippled area represents the Transscandinavian Igneous Belt (TIB). Location of the investigated samples 1, MHW 94024 and 2, OSSV:02c.

This means that the volcanic rocks were probably formed very early in the evolution of the TIB. Field observations also indicate that the volcanic rocks are older than the granite intrusions (e.g. Persson 1974). New results from the Växjö region (this volume, pp. 50–56) indicate ages c. 20 Ma younger than 1800 Ma, the lower limit for earlier datings of the volcanic suite.

The main part of the postorogenic activity in southeastern Sweden was followed by the intrusion of different kinds of dykes which cut the Småland granites as well as the volcanic rocks. There are both mafic and felsic dykes as well as composite mafic-felsic types. The different mafic dykes have been discussed by, among others, Nilsson (1992) and Wikström (1992). Persson (1973, 1974) suggested that the felsic dykes, often called Småland dyke porphyries, are genetically linked to the Småland porphyries. Åberg (1978) got a seemingly reasonable Rb-Sr age of c. 1655 for dyke porphyries from three different areas. In another work by Åberg & Persson (1984) an enigmatic maximum age of c. 1837 for one dyke was obtained.

In southeastern Sweden there also occur young granites, which have intruded during an anorogenic phase of the Precambrian evolution. Jungfrun, Götemar, Uthammar, Virbo, Vånevik and Brånhult granites are all examples of small anorogenic bodies which have been described by various authors (Lundegårdh 1971; Kresten & Chyssler 1976; Åberg *et al.*,1983, 1984; Åberg 1986 and Lundqvist *in* Lindström *et al.* 1991). The age of these intrusives has been estimated at c. 1350–1400 Ma (Åberg 1986).

Different occurrences of the dyke porphyries have been mentioned by Lundegårdh *et al.* (1985). Among these the so-called Påskallavik porphyry is probably the best known. In a new road-cut north of Påskallavik a dyke porphyry cuts the Vånevik granite which is believed to belong to the anorogenic granites (Lundqvist op. cit.). In order to determine the age of the Påskallavik porphyry, and consequently also a minimum age of the Vånevik granite, a U-Pb zircon age dating of the dyke was made. The analysis has been performed at the Unit for Isotope Geology, Geological Survey of Finland, by Dr. Matti Vaasjoki, and the text concerning the analytical data is based on his report.

Many of the dyke porphyries in southeastern Småland have mafic margins. Field relationships and chemical analyses of these composite dykes indicate semi-simultaneous intrusions of genetically unrelated basaltic and rhyolitic magmas (Nilsson 1992). In order to determine the age of this magma interaction, and thereby relate it to some granitic igneous event in the region, a U-Pb zircon age dating of the felsic core of a composite dyke was performed. The text concerning the analytical data is based on a report from Hans Schöberg at the Laboratory for Isotope Geology in Stockholm to Magnus Nilsson.

SAMPLE DESCRIPTION AND ISOTOPIC RESULTS

Reddish grey dyke porphyry, Påskallavik porphyry, MHW 94024

The sample, MHW 94024, was collected in a road-cut at S.Vånevik, 2 km NNW of Påskallavik, map-sheet 5G Oskarshamn NO (7h), coordinates 633930/143875. The vertical dyke is 10 m wide and runs approximately N 40° E. In the easternmost section of the outcrop there is another dyke, which is not entirely exposed in its eastern part. At both contacts of the exposed, coarse-grained dyke porphyry there are c. 4 dm broad marginal zones of fine-grained reddish brown porphyry with sharp contacts towards the enclosing granite. The inner contacts between the coarse-grained and the fine-grained porphyry seem to be somewhat gradational rather than sharp. The sur-

TABLE 1. U-Pb zircon data from sample MHW 94024, reddish grey dyke porphyry, Påskallavik porphyry.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected for blank	207/235	206/207	Apparent age in Ma 6/8	7/5	7/6
A	+4.5/ABR	224.9	97.56	275.4	.3161	4.744	.1088	1770	1775	1780
B	+4.5	228.6	96.22	306.8	.3120	4.673	.1086	1750	1762	1776
C	4.3-4.5	370.6	163.28	162.3	.2847	4.233	.1079	1614	1680	1763
D	4.2-4.3	670.1	204.01	207.4	.2086	3.006	.1045	1221	1409	1706

Common lead correction: $^{206}Pb/^{204}Pb$: 15.7; $^{207}Pb/^{204}Pb$: 15.4; $^{208}Pb/^{204}Pb$: 35.2 .

rounding granite is the so-called Vånevik granite, a red, coarse-grained, homogeneous granite with slightly bluish quartz.

The dyke porphyry is greyish red with abundant, c. 10–15 mm large, K-feldspar phenocrysts in a relatively fine-grained matrix consisting mainly of feldspar, quartz, mica and mafic minerals. The rock contains abundant zircon, which is generally about 100 μm in grain size. However, some coarser grains, apparently broken during the milling, have been observed. The crystals which have remained intact exhibit simple prismatic-pyramidal crystal faces, and the length/breadth ratio varies between 2 and 6 with the median at about 3.5. A strong oscillatory zoning is present but neither cores nor inclusions of any significance have been observed.

The analyses form the usual pattern: the abraded fraction A is almost concordant within experimental error and the degree of discordance increases with decreasing density and increasing uranium content (Table 1). As demonstrated by the MSWD of 0.21, all scatter can be explained in terms of analytical uncertainty. The upper intercept age is 1780±3 Ma, and probably represents the time of emplacement of the rock (Fig. 2). The lower intercept, 252±26 Ma, most likely has no geological meaning.

Greyish red porphyry of a composite dyke, OSSV:02c

This sample was collected in a composite mafic-felsic dyke in a road-cut 4 km WSW of Alsterbro, map-sheet 5G Oskarshamn SV (7h), coordinates 631090/150285. The vertical dyke strikes N 80° E and only the southeastern contact towards the surrounding granite is exposed. A plagioclase-porphyritic, mafic rock separates the granite from the felsic, central part of the dyke. This mafic margin has a chilled contact towards the surrounding granite, while the contact between the two dyke components is sharp but not chilled. Inside the felsic dyke porphyry three additional mafic dykes occur.

The felsic dyke porphyry is greyish red. The very fine-grained matrix contains phenocrysts of feldspar up to 15 mm across and of smaller bluish quartz grains up to

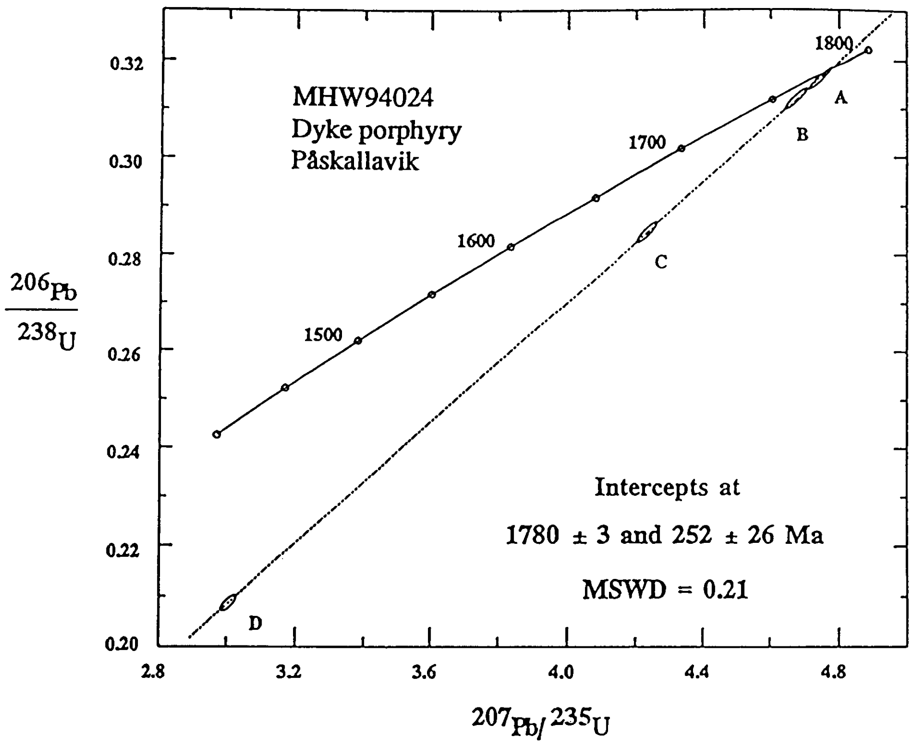

Fig. 2. U-Pb concordia diagram for zircons from sample MHW 94024, reddish grey dyke porphyry, Påskallavik porphyry.

5 mm. Some of the K-feldpar phenocrysts have a margin of sericitized plagioclase and a thin outer rim of K-feldpar. There also occur megacrysts which are clusters of plagioclase with intergrowths of small quartz grains. Also the matrix shows graphic intergrowths between quartz and feldspar. The content of mica and epidote is rather high and among the minor minerals titanite, apatite, zircon, and opaques can be mentioned.

The zircons are translucent to opaque, beige to brownish prisms with a length/ breadth ratio of c. 4. The inner parts of the crystals are zoned and criss-crossed by inclusions. After magnetic separation of six size fractions, zircons with few inclusions were picked for analysis (cf. Weihed & Schöberg 1991). The contents of uranium and radiogenic lead are normal but a slightly increased content of initial lead indicates contributions from inclusions (Table 2). The trend involving decreasing discordance with increasing crystal size is also probably disturbed by varying crystal quality. However, the discordance for the fraction >210 mm is less than 5 %. This fraction

TABLE 2. U-Pb zircon data from sample OSSV:02c, greyish red porphyry of a composite dyke.

	Fraction (μm)	Weight (mg)	U (ppm)	Pb_{rad} (ppm)	Pb_{init} (ppm)	$^{206}Pb/^{204}Pb$ [a]	^{206}Pb (at.%)	^{207}Pb (at.%)	^{208}Pb [b] (at.%)	$^{206}Pb/^{238}U$ [bc]	$^{207}Pb/^{235}U$ [bc]	$^{207}Pb/^{206}Pb$ age (Ma)
Alsterbro porphyry												
1	<45	0.30	312	92	2.2	2300	81.1	8.81	10.1	0.27835±45	4.170±20	1777
2	45-74	0.87	352	101	5.3	1100	80.8	8.81	10.3	0.26962±54	4.054±46	1783
3	74-106	1.36	338	96	6.0	950	81.5	8.83	9.7	0.26973±40	4.031±12	1772
4	106-150	1.61	321	99	8.3	750	81.4	8.83	9.8	0.29344±44	4.390±12	1774
5	150-210	1.14	222	64	1.8	2100	81.8	8.86	9.3	0.27559±41	4.116±09	1771
6	>210	0.63	163	54	2.8	1100	80.0	8.72	11.3	0.30761±58	4.624±21	1783
7	>210 ab	0.25	332	105	5.0	1200	81.9	8.97	9.2	0.30389±49	4.590±25	1792

[a] As measured .
[b] Corrected for common lead, blank and discrimination.
[c] Errors are given as least significant digits at the 95% confidence level.
Data reduction and age calculation according to Ludwig (1991), using the decay constants recommended by the IUGS Subcommission on Geochronology (Steiger and Jäger 1977) and correction terms below.

Corrections:								
	Discrimination	U	0.10% / AMU	Pb	0.18% / AMU			
	Blank	U	0.1 ng	Pb	0.05 ng			
	Initial lead	$^{206}Pb/^{204}Pb$	15.6	$^{207}Pb/^{204}Pb$	15.3	$^{208}Pb/^{204}Pb$	35.2	(Stacey & Kramers 1975 growth curve) .

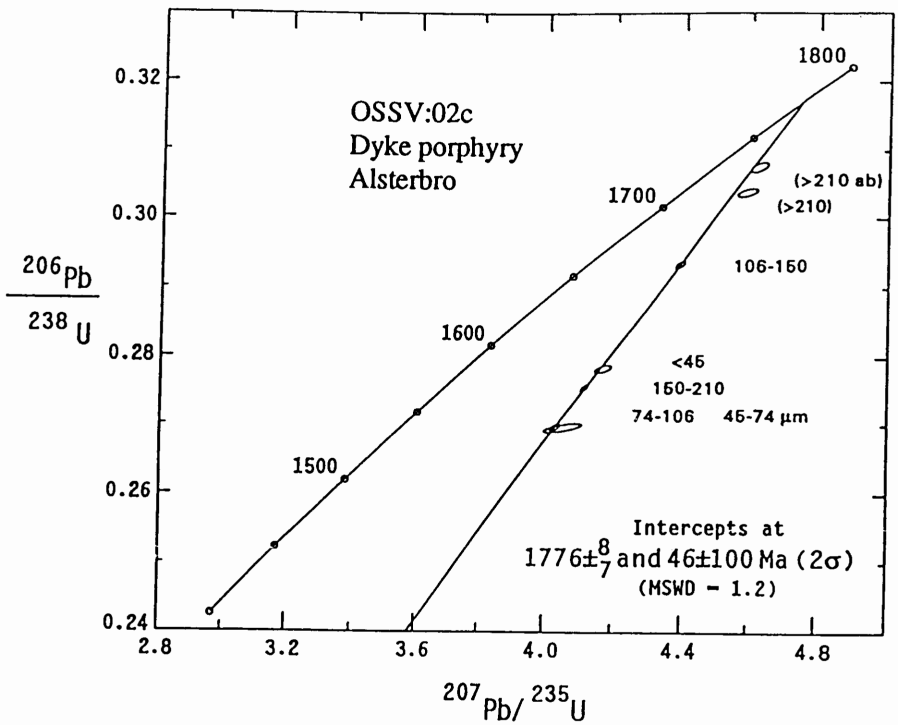

Fig. 3. U-Pb concordia diagram for zircons from sample OSSV:02c, greyish red porphyry of a composite dyke.

differs somewhat from the isochron received from regression calculations based on other fractions (Ludwig 1991). These give an upper intercept at 1776+8/-7 Ma and a lower intercept at 46±100 and MSWD=1.2 (Fig. 3). With fraction >210 mm included, roughly the same age is obtained. Here the upper intercept is at 1781+12/-10, the lower intercept at 102±136 and MSWD increases to 1.7.

In order to check whether the fraction >210 mm contains older material, the grains were abraded (Krogh 1982). The position of the fraction in the diagram then becomes more discordant, which is probably explained by inferior initial material. It also differs from the original isochron. The upper intercept remains at about the same value, 1785±13, but MSWD increases to 3.1. The conclusion is that, in spite of a primary morphology and the absence of visible cores, a certain amount of older zircon material is present in the larger crystals. However, the upper intercept age of 1776+8/-7 most probably represents the intrusion age.

DISCUSSION

The obtained ages of 1780±3 and 1776+8/-7 Ma on the two dyke porphyries indicate a close relationship to the Småland granites, which in this part of the TIB seem to have ages of c. 1800 Ma. An age determination of a granite at Ramnebo NW of Oskarshamn gave for instance 1802±4 Ma (Mansfeld 1991) and at Äspö north of Oskarshamn a granite was dated to 1804±3 Ma (Wikman & Kornfält 1995). In addition, a c. 1780 Ma age is valid for the tholeiitic basaltic magmatism connected to the intrusion of the dyke porphyries, as seen in the composite dykes (cf. Nilsson 1992).

The conclusion can also be drawn that the Vånevik granite, which is cut by the dated Påskallavik dyke porphyry, must belong to the Småland granites and not to the anorogenic granites in the region. All field and age investigations made so far of dyke porphyries in southeastern Småland thus indicate a relation to the late- to postorogenic phase of the Svecokarelian evolution rather than to a younger, anorogenic period of igneous activity.

ACKNOWLEDGEMENTS

The radiometric analysis of the Påskallavik porphyry has been performed at the Geological Survey of Finland by Dr. Matti Vaasjoki. The text concerning the analytical data of this sample is based on a report by him to the Geological Survey of Sweden. The other analysis has been performed at the Laboratory for Isotope Geology in Stockholm by Hans Schöberg. The text concerning the analytical data of this sample is based on a report by him to M. Nilsson.

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Radiometric dating of the Palaeoproterozoic Pite conglomerate in northern Sweden

By

Per-Olof Persson and Thomas Lundqvist

INTRODUCTION

The Palaeoproterozoic Pite conglomerate occurs c. 3 km ESE of the town of Piteå on the Degerberget hill, and in some minor nearby occurrences (Hällskär etc.), in the coast region of northern Sweden (cf. Fig. 1). It was briefly mentioned by Svenonius (1892), and its stratigraphic position was discussed by Grip (1939), who also provided the first description of the conglomerate. Aspects on the stratigraphic position of the conglomerate were also given by Ödman (1953 and 1957). The most accurate description of the conglomerate available at present was published by Åhman (1957), and the following brief summary is based on this work.

The Pite conglomerate contains only few intercalations of arkosic character, and very rare phyllite. The pebbles are generally of centimetre or decimetre size. They are

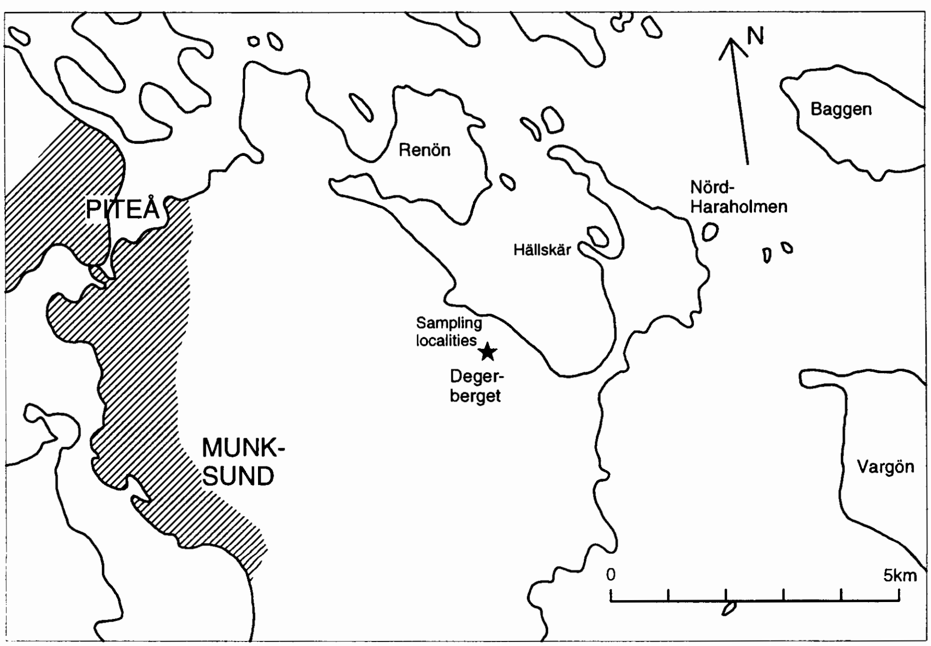

Fig. 1. Map of the Piteå area showing the position of Degerberget and the sampling localities.

dominated by quartzite and vein or pegmatite quartz. In addition there are pebbles of felsic and mafic metavolcanites similar to those of the Vallen–Alhamn area (Åhman 1953). Other pebbles consist of epidote (probably epidotized limestone). Very few pebbles are of crystalline limestone and a grey, medium-grained granodiorite-tonalite (cf. photo on cover of this volume).

The matrix of the conglomerate is to a large extent greenish due to the presence of epidote, probably formed from an original cement of calcite. Grossularite is also found in the matrix. Tourmaline has been noted.

The conglomerate is strongly deformed. Bedding structures show medium to high dips, and a pronounced stretching of the pebbles in the lineation direction or in the schistosity plane is evident.

The stratigraphic relation between the Pite conglomerate and the metasedimentary rocks (schists and migmatites) in the west is not known (cf. Ödman 1957 and Lundqvist *et al.* 1996). No exposed depositional contact between the Pite conglomerate and older plutonic (Archaean or Proterozoic) rocks has been observed. All contacts with plutonic or dyke rocks demonstrate that the conglomerate is older. Such intrusions include dykes of feldspar (tonalite) porphyry and even-grained and porphyritic diorites. "Late-Karelian" (Lina) granite, aplite and pegmatite have also intruded the conglomerate. According to Åhman (1957) the early orogenic Haparanda "granite" (tonalite) is also intrusive into the conglomerate. Åhman was inclined to accept the interpretation of Grip (1939) that the Pite conglomerate should be parallelized with the Vargfors conglomerates of Västerbotten County, more precisely with the Dömanberg conglomerate of Kautsky (1957). The granitoid pebbles of the Pite and Vargfors conglomerates were considered by Åhman to be of the same generation of granitoids (Jörn granitoid). Ödman (1957 and 1972) concluded that the Pite conglomerate was deposited during the time interval between the (early orogenic) Jörn–Arvidsjaur "granites" and the Revsund granite, i.e. the conglomerate should be parallelized with the Elvaberg series of Kautsky (1957), to which the Vargfors conglomerates belong.

DESCRIPTION OF THE SAMPLES AND THEIR LOCATION

In order to constrain the age of the Pite conglomerate two samples for radiometric dating by the U-Pb method on zircon were taken on Degerberget (cf. Fig. 1). One sample is of a granodiorite pebble in the conglomerate, the other of a tonalite porphyry dyke which cuts the conglomerate.

The sample of a c. 200 cm^3 large granodiorite pebble (TL 93:02b) was taken c. 30 m NNE of the triangulation point 80.6 m a.s.l. at the top of the Degerberget hill. Coordinates in the Swedish National Grid are 725600-177135, map-sheet 24L Luleå SV. The triangulation point is marked by a triangle in the upper part of the map, Fig. 3, of Åhman (1957). The granodiorite is grey, medium-grained, isotropic to weakly lineated. The plagioclase crystals show a hypidioblastic to xenoblastic texture, and contain c. 20–25% of the anorthite component. Other important minerals are quartz, microcline, and common hornblende with Fe/Mg = 1.3. In subordinate amounts occur epidote and sericite (from plagioclase) and titanite. Accessories are apatite, zircon and carbonate.

Sample TL 93:04 was taken of a dyke of tonalite c. 200 m W(SW) of the triangulation point on Degerberget. Coordinates in the Swedish National Grid are 725600-177125, map-sheet 24L Luleå SV. The colour of the rock is grey, and the structure is schistose to lineated. The texture is blastoporphyritic, with millimetre-size phenocrysts of plagioclase (An_{25}), in part glomeroporphyritically aggregated. Quartz forms less well developed phenocrysts. The matrix is dominated by plagioclase, quartz, biotite, and common hornblende. Titanite occurs in subordinate amounts. Accessories are apatite, sericite and epidote (from plagioclase) and zircon. Table 1 shows the chemical composition, including REEs, of the tonalite porphyry.

TABLE 1. Chemical composition of the tonalite porphyry dyke on Degerberget (sample TL 93:04).

SiO_2 (wt%)	65.8	Ba (ppm)	724	La (ppm)	18.8
TiO_2	0.49	Ga	25.7	Ce	40.5
Al_2O_3	15.9	Hf	3.98	Pr	4.16
Fe_2O_3*	4.60	Nb	13.4	Nd	17.4
MnO	0.08	Ni	33.3	Sm	3.21
MgO	2.16	Rb	35.8	Eu	0.094
CaO	4.54	Sc	5.36	Gd	2.68
Na_2O	4.99	Sr	696	Tb	0.355
K_2O	1.33	Ta	0.966	Dy	2.15
P_2O_5	0.17	Th	3.44	Ho	0.415
LOI	0.7	U	2.07	Er	1.40
Sum	100.8	Y	9.16	Tm	0.201
		Zr	160	Yb	1.75
				Lu	0.237

ZIRCON DESCRIPTIONS AND ISOTOPIC DATA

Only few zircons from the granodiorite pebble TL 93:02b could be extracted, due to the small sample size (<<1 kg), and no sieving into different size fractions was made. All crystals, with or without microfractures, were included in the analysis. Many of the zircons are pronouncedly elongated, with an L/B ratio of ≥5, but short-prismatic crystals also occur. Most zircons have well developed pyramid faces and sharp tips,

TABLE 2. U-Pb isotopic data for zircons from a granodiorite pebble (TL 93:02b) and a tonalite porphyry dyke (TL 93:04) in the Pite conglomerate.

Size fraction (µm) or shape	Weight (mg)	U (ppm)	Pb tot. (ppm)	Pb com. (ppm)	$^{206}Pb/^{204}Pb$ [a]	^{206}Pb - ^{207}Pb - ^{208}Pb Radiog. (Atom %) [b]	$^{206}Pb/^{238}U$ [b]	$^{207}Pb/^{235}U$ [b]	$^{207}Pb/^{206}Pb$ age (Ma)
TL 93:02b	**Granodiorite pebble in Pite conglomerate**								
elongated	0.053	401.3	131.9	0.88	5343	81.8 - 9.3 - 8.9	0.3104±10	4.876±20	1863±2
large	0.132	172.1	57.9	0.20	8393	82.8 - 9.4 - 7.7	0.3228±6	5.074±20	1864±2
short	0.112	272.5	84.3	0.51	6349	82.5 - 9.3 - 8.2	0.2949±6	4.611±18	1855±5
abr. 1	0.019	249.0	82.8	1.01	1959	82.0 - 9.4 - 8.6	0.3132±13	4.947±38	1873±12
abr. 2	0.005	229.4	77.1	0.14	1673	84.4 - 9.6 - 5.9	0.3295±30	5.177±51	1864±6
TL 93:04	**Tonalite porphyry dyke in Pite conglomerate**								
< 74 elongated	0.044	688.6	229.9	0.52	15974	83.7 - 9.6 - 6.7	0.3242±10	5.105±20	1868±2
< 74 wide	0.053	693.0	224.0	1.92	5855	84.6 - 9.7 - 5.7	0.3154±6	4.964±20	1866±2
74-106	0.063	673.8	228.8	0.32	24872	83.8 - 9.6 - 6.7	0.3303±7	5.202±21	1868±2
74-106 abr.	0.035	771.6	261.4	0.97	11050	83.6 - 9.5 - 6.8	0.3287±7	5.153±21	1862±2

a) corrected for mass fractionation (0.1% per a.m.u).
b) corrected for mass fractionation, blank and common Pb.

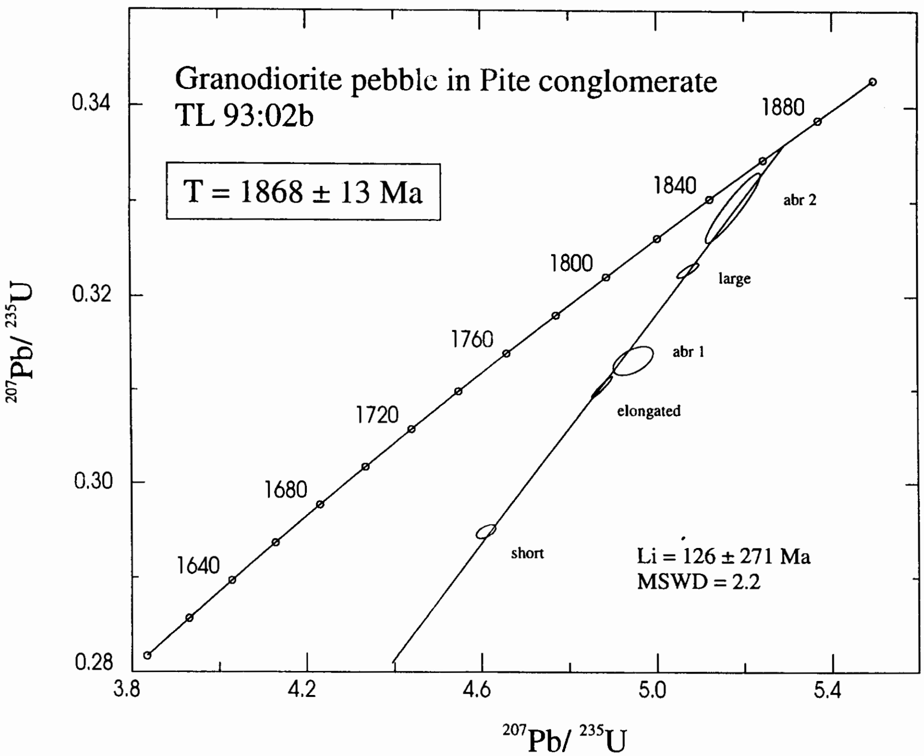

Fig. 2. U-Pb concordia diagram for sample TL 93:02b of a granodiorite pebble in the Pite conglomerate.

but some, especially the short-prismatic, have rounded terminations. A minor part of the zircon population is made up of much bigger crystals, with a width exceeding 150 µm. These crystals are shorter and more rounded. According to their morphology they seem to belong to a different generation than the most common small, elongated crystals.

Five small, elongated, and five large crystals were studied in a high-refractive index liquid. One of the small crystals had a brownish core and a thin, colourless mantle. A second crystal had a colourless "core" and a very thin mantle. A third crystal had a light mantle which showed a diffuse boundary to a "core". All other crystals (including the large ones) seemed to be homogeneous.

The zircons were subdivided into five populations, which were analysed (see Table 2): 1) *"elongated"*. Strongly elongated, L/B ratio = 5–10. 2) *"large"*. Most are short-prismatic and more or less rounded. Some are more elongated but also show more rounded terminations. 3) *"short"*. Morphology somewhat variable. Most are

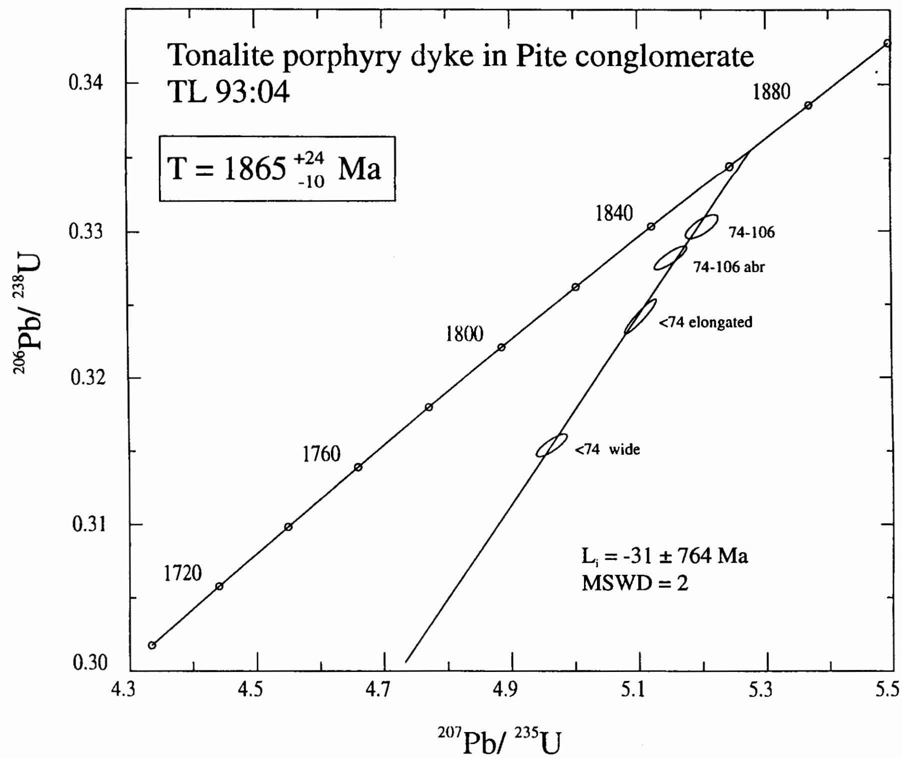

Fig. 3. U-Pb concordia diagram for sample TL 93:04 of a tonalite porphyry dyke cutting the Pite conglomerate.

short-prismatic and generally rounded. 4) *"abr 1"*. Crystals selected for abrasion were relatively big and broad. They were strongly abraded. 5) *"abr 2"*. Eight crystals of good quality, some, however, with microfractures, short to average in length (L/B ratio = 1–4). Strongly abraded.

The analytical results indicate that the selected zircons form a homogeneous group with regard to age, although fraction *"abr 1"* might contain older material, since the data point plots slightly to the right of the discordia. Within error the ellipse, however, lies on the line. The upper intercept age is 1868±13 Ma (Fig. 2), which we interpret as the crystallization age of the granodiorite from which the pebble derives.

Most zircons from the tonalite porphyry dyke (TL 93:04) are brown, but light and colourless crystals also occur. The L/B ratio varies from ≥5 to c. 2. The pyramids are weakly to strongly rounded. Most zircons are small, the majority falling in the size fraction <74 μm. Ten of the larger grains were studied in a high-refractive index liquid. All show internal structures. Half of the crystals have a euhedral zoning. Two to four crystals contain what can be inherited cores, which are, however, more or less euhedral. The cores are homogeneous and lighter than the brown mantles. In some cases the identification of cores is doubtful: euhedral zoning with similar material in the centre as in the mantle, but with a clear boundary between the two. Two grains have a narrow outer zone which is possibly a later generation than the core. All crystals studied in high-refractive index liquid (possibly excepting one of the last mentioned grains) are rather dark. Those chosen for analysis are somewhat lighter, especially those which were abraded. Most analysed crystals are brown but some are colourless. No separation according to colour was done as the colourless grains were too few. Most crystals contain a variable number of microfissures and are metamict. The best quality is found in the fraction <74 µm.

The analytical results (Table 2) give no support to the idea that the zircons should belong to several generations. If, in spite of this, more than one generation should occur, the age differences are probably small. The age calculated from the four analysed fractions is 1865+24/-10 Ma (see Fig. 3).

CONCLUSIONS

The obtained ages for the pebble and the crosscutting dyke are identical within the limits of analytical error. Even when taking the errors into account it is evident that granodiorite formation, exhumation, erosion, sedimentation, burial and dyke intrusion took place within a short time interval. The age of the Pite conglomerate is thus well constrained by the present two U-Pb datings. Sedimentation occurred c. 1865–1870 Ma ago, and the conglomerate therefore belongs to what has been called the Upper Svecofennian assemblages, which postdate the early orogenic, c. 1870–1890 Ma granitoids of the Svecokarelian orogenic belt (cf. Geological Surveys of Finland, Norway and Sweden 1987). The present investigation thus confirms the view of Grip (1939) and Åhman (1957) that the Pite conglomerate occupies the same general stratigraphic position as, e.g., the Vargfors conglomerates of Västerbotten County (cf. also Lundqvist *et al.* 1996). An ignimbrite intercalated in the latter conglomerates has recently yielded a U-Pb zircon age of 1874.9±3.7 Ma (Billström & Weihed 1996), confirming similar ages of both conglomerate associations.

An Upper Svecofennian stratigraphic position for the Pite conglomerate also implies a younger age than that of the Haparanda granitoids (tonalites – quartz diorites) of the region. These granitoids, according to U-Pb radiometric datings, have ages between 1892±14 Ma and 1867±11 Ma (Öhlander *et al.* 1987; Wikström *et al.* 1996; Wikström & Persson, this volume, pp. 73–80). This does not appear to be in harmony with the observation reported by Åhman (1957) that a Haparanda granitoid cuts the conglomerate. Until the cross-cutting granitoid is radiometrically dated the reason for this contradiction remains unclear. However, as available data suggest that the

Haparanda suite intruded during a relatively long time span, the youngest plutonic rocks of the suite may in fact postdate the conglomerate. Also, the 1865 Ma dyke of tonalite porphyry at Degerberget can be considered to be a late, hypabyssal member of this suite.

ACKNOWLEDGEMENTS

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U-Pb zircon ages of two volcanic rocks from the Växjö region, Småland, south central Sweden

By

Per-Olof Persson and Hugo Wikman

INTRODUCTION

The southern part of the Transscandinavian Igneous Belt (TIB) is to a great extent built up of Småland–Värmland granites and associated volcanic rocks, mainly porphyries (Fig. 1). The so far obtained ages of the Småland porphyries are restricted to a narrow interval at c.1800 Ma. Previously, older volcanic rocks were believed to occupy parts of the region south of Växjö down to Blekinge. Also in the northern part of the map-sheet Växjö NO older volcanic rocks were believed to occur (cf. Persson & Wikman 1986). Recent age determinations of volcanic rocks from the Växjö region, 1800±8 Ma (Mansfeld 1995, 1996) and 1791+50/-41 Ma (Wikman 1993), have shown that also these, "older" volcanic rocks are closely related to the granitoids of the TIB. However, the latter determination is somewhat uncertain due to inhomogeneity of the zircon fractions.

In order to constrain the ages of the volcanic rocks in the Växjö region two samples have been dated in connection with the regional mapping. One sample comes from the large area of volcanic rocks north of Växjö and the other from the area of volcanic rocks around Urshult and lake Åsnen c. 30 km south of Växjö. As can be seen from the provisional bedrock map SGU Ba 44 (Kornfält & Bergström 1991) the latter area is to the north bordered by Småland granitoids. Somewhat further to the south volcanic rocks occur around lake Mien.

Still further southwards, in Blekinge, the so-called Västanå group forms a large, isolated area of metasedimentary and metavolcanic rocks. This rock suite has been investigated by Andersson (1975) and Kornfält & Bergström (1983). A U-Pb zircon dating of a rhyolite from the Västanå group gave an enigmatic age of c. 1705 Ma (Johansson & Larsen 1989).

The dating of sample MHW 94474 has been performed at the Unit for Isotope Geology, Geological Survey of Finland, under the supervision of Dr. Matti Vaasjoki, and the text concerning the analytical data is based on his report to the Geological Survey of Sweden. Sample LIG 89609 has been analysed at the Laboratory for Isotope Geology in Stockholm by Dr. Per-Olof Persson (cf. editor's preface regarding analytical procedures).

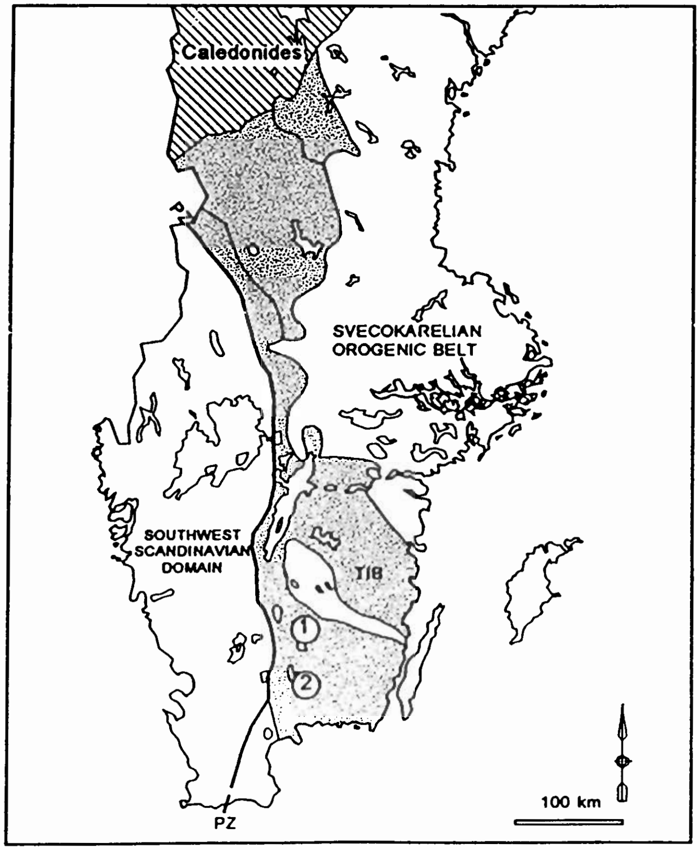

Fig. 1. Simplified map of southern Sweden showing the major Precambrian units. Stippled area represents the Transscandinavian Igneous Belt (TIB). Location of the investigated samples 1, MHW 94474 and 2, LIG 89069 are indicated.

SAMPLE DESCRIPTION AND ISOTOPIC RESULTS

Dark, brownish grey porphyry (hälleflinta), MHW 94474

Sample MHW 94474 is a dense, porphyritic, dark brownish grey, rather homogeneous volcanic rock (hälleflinta) of rhyolitic composition. The sampling site is a small road cut c. 300 m south of Fridhem, map-sheet 5E Växjö NO (5i), coordinates 632715/144035. The porphyritic texture is not pronounced and the phenocrysts, which are quite small, are dominated by feldspar, whereas quartz is more unusual. The matrix of the porphyry contains quartz and feldspar, together with mica, opaque minerals, epidote and accessory minerals like apatite and fluorite.

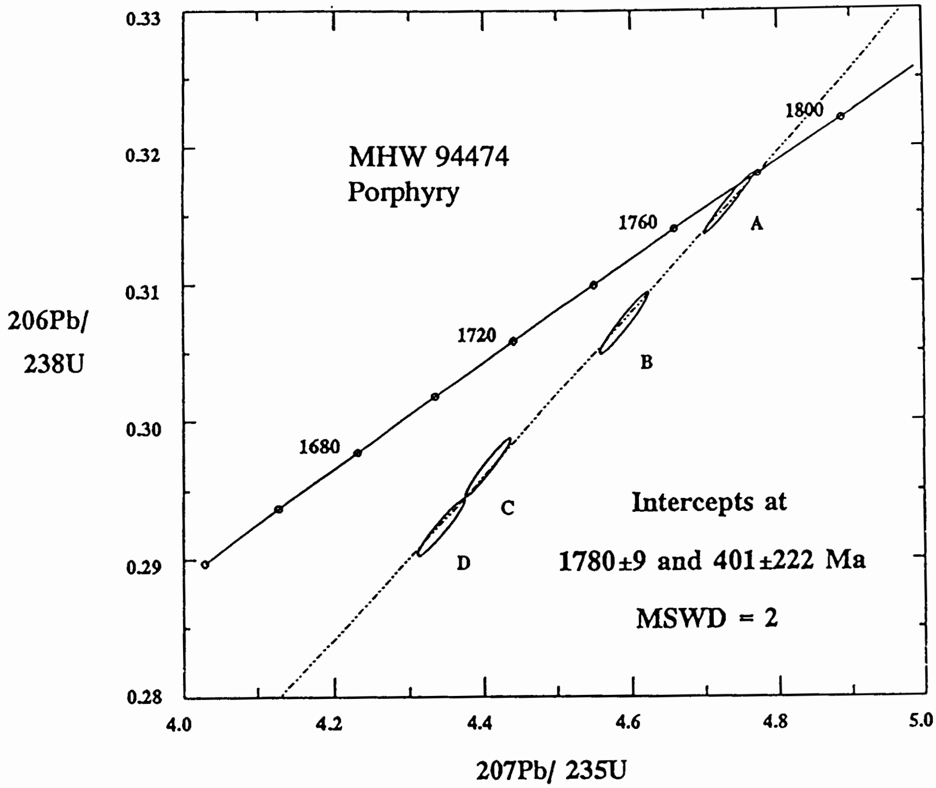

Fig. 2. U-Pb concordia diagram for zircons from sample MHW 94474, dark, brownish grey porphyry (hälleflinta).

TABLE 1. U-Pb zircon data from sample MHW 94474, dark, brownish grey porphyry (hälleflinta).

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected for blank	207/235	207/206	Apparent age in Ma 6/8	7/5	7/6
A	+4.5/ABR PALE BR.	180.1	69.92	7185	.3158	4.734	.1087	1769	1773	1778
B	+4.5 PALE BR.	176.2	72.04	590	.3071	4.591	.1084	1726	1747	1774
C	4.3-4.5 PALE BR.	327.4	129.53	798	.2966	4.405	.1077	1674	1713	1761
D	+4.3 RED	258.8	98.43	615	.2923	4.342	.1077	1653	1701	1761

Common lead correction: $^{206}Pb/^{204}Pb$: 15.7; $^{207}Pb/^{204}Pb$: 15.4; $^{208}Pb/^{204}Pb$: 35.2.

The zircons separated from the sample are very fine-grained (70 µm). In air they are mainly light brown and translucent, but about 20 % of the crystals are strongly reddish. About 50 % of the zircons are euhedral with simple prismatic-pyramidal morphology and a L/B ratio of about 3. The rest are sub- to anhedral and either very stubby or even rounded. There seems to be no correlation between crystal morphology and colour. Under oil immersion the euhedral crystals exhibit prominent oscillatory zoning and contain rod-like (fluid?) inclusions, while the anhedral zircons have no obvious internal structure.

The red zircons were hand-picked from fractions A, B, and C and combined with fraction D in order to check the possibility of two different zircon generations. From the analytical results it is evident that the two colour varieties are coeval, as all four fractions fall on the same linear trend. The analyses exhibit the usual pattern: the abraded fraction A is almost concordant, while in the other fractions the degree of discordance increases with an increasing uranium content. The red zircons are the most discordant, which may indicate that the colour difference is an effect of increased radiation damage. The U-Pb zircon data are shown in Table 1.

The linear trend defined by the analyses intersects the concordia curve at 1780±9 and 401±22 Ma (Fig. 2). The MSWD of 2 may indicate a slight heterogeneity of the zircons. The upper intercept age can be interpreted as the emplacement age of the Fridhem porphyry. It should, however, be noted that as the fraction A is almost concordant, the age may actually be more precise than indicated by the statistical error estimate.

Light grey volcanic rock, LIG 89069

Sample LIG 89069 was collected at Vemboö north of Urshult, map-sheet 4E Tingsryd SO (4h), coordinates 627330/143675. Macroscopically this volcanic rock differs considerably from the sample described above. The rock is a light grey, fine-grained, rather massive rhyolite with a faint porphyritic texture, sometimes hardly visible in hand specimen. The phenocrysts, which are relatively small, are dominated by K-feldspar together with rounded and somewhat granulated grains of quartz. The matrix is generally fine-grained, but a slight variation in grain-size might indicate some sort of fragment structure. The matrix is dominated by quartz and feldspar together with c. 5–10 vol.% of biotite and muscovite. Minor minerals are epidote, titanite, apatite, zircon and opaques.

The rock contains plenty of zircons. Most of these are light brown but some are rally less than 3. Magmatic zonation is common but cores or overgrowths have not been detected. The analysed crystals are transparent and have only few cracks. The zircons of the abraded fractions are virtually devoid of cracks and inclusions.

The results of the isotopic analyses are shown in Table 2 and Fig. 3. As can be seen from the concordia diagram the data points are slightly discordant and yield an upper intercept age of 1766+15/-10 Ma that is interpreted as the crystallization age of the volcanic rock.

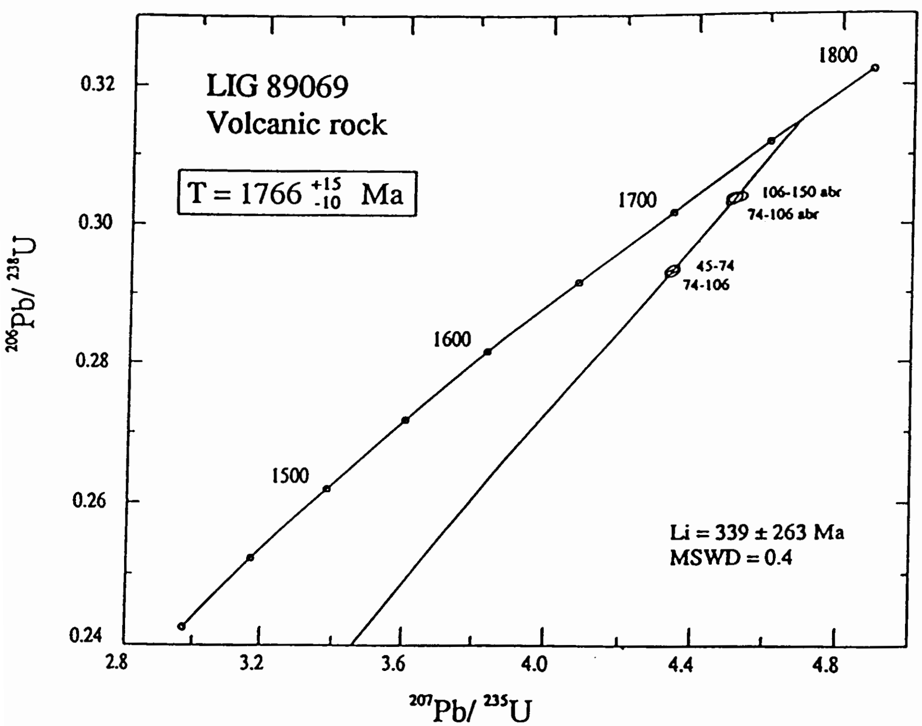

Fig. 3. U-Pb concordia diagram for zircons from sample LIG 89069, light grey volcanic rock.

TABLE 2. U-Pb zircon data from sample LIG 89069, light grey volcanic rock.

Size fraction (µm)	Weight (mg)	U (ppm)	Pb tot. (ppm)	Pb com. (ppm)	$^{206}Pb/^{204}Pb$ [a]	^{206}Pb - ^{207}Pb - ^{208}Pb Radiog. (Atom %) [b]	$^{206}Pb/^{238}U$ [b]	$^{207}Pb/^{235}U$ [b]	$^{207}Pb/^{206}Pb$ age (Ma)
45-74	0.110	252.9	81.5	0.26	10893	78.6 - 8.4 - 13.0	0.2935±6	4.333±17	1750±4
74-106	0.134	217.1	70.0	0.27	9744	78.6 - 8.4 - 13.0	0.2931±6	4.335±17	1754±3
74-106 abr	0.079	220.6	73.5	0.11	12817	78.5 - 8.4 - 13.1	0.3036±7	4.503±18	1759±5
106-150 abr	0.105	179.3	59.6	0.01	20436	78.7 - 8.5 - 12.8	0.3039±6	4.511±24	1760±9

a: Corrected for mass fractionation (0.10% per a.m.u.) .
b: Corrected for mass fractionation, blank and common Pb.

DISCUSSION

The obtained ages demonstrate that the volcanic rocks within the two sampled areas are related to the evolution of the Transscandinavian Igneous Belt. However, compared to other datings of the TIB volcanic rocks within Småland, they are about 20–30 Ma younger. The relatively young age of the Urshult volcanic rock may indicate a younging of the Småland volcanic rocks southwards although the number of age determinations is too few to allow such a model to be firmly established. A connection to the c. 70 Ma younger Västanå group is more problematic. This is due to the lack of modern regional mapping in southernmost Småland and the mentioned, contradicting results of field observations and age determinations of the Västanå volcanic rocks and the Tving granite.

Regarding the volcanic area to the north of Växjö it is obvious that the Småland volcanic rocks in this region extend to the northern part of the map-sheet Växjö NO where they border on older, mainly mafic supracrustals in the Fröderyd area (Mansfeld 1995). The extension of the volcanic area towards the Protogine zone in the west is, however, insufficiently investigated and is still an open question.

ACKNOWLEDGEMENT

The radiometric analysis of sample MHW 94474 has been performed at the Geological Survey of Finland by Dr. Matti Vaasjoki. The text concerning the analytical data of this sample is based on his report to the Geological Survey of Sweden.

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The U-Pb zircon age of the Sala–Vänge granite at Sala, south central Sweden

By

Magnus Ripa and Per-Olof Persson

INTRODUCTION

The area between the town of Sala and the village of Vänge, 10–60 kilometres west of Uppsala (Fig. 1), is dominated by red to grey, medium- to coarse-grained and predominantly undeformed granite. This granite intruded the surrounding country rocks which consist of metatonalites to -granodiorites included in the early orogenic (Svecokarelian; cf. Wahlgren *et al.* 1996) granitoids, and was itself intruded by dolerite

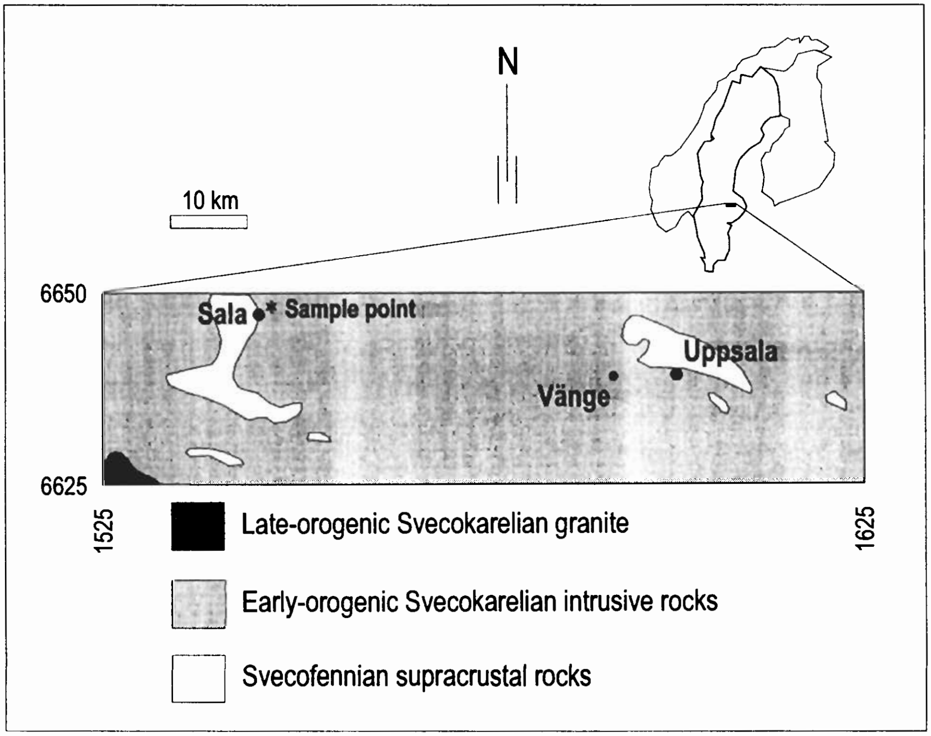

Fig. 1. Simplified geological map of the Sala–Uppsala region. Sample location is shown. Numbers at corners of the geological map denote coordinates on the Swedish national grid.

dykes. The granite has been classified as early orogenic by earlier workers (e.g. Welin *et al.* 1980; L. Persson pers. comm.) or simply as "granite" (Erdmann 1868), but from its general appearance it could also be included in the younger suites of Svecokarelian intrusive rocks.

An attempt to date a sample of the granite from Vänge was made by Welin *et al.* (1980). However, only one zircon fraction could be retrieved and the age was estimated at 1886 Ma. An estimate of the maximum age is provided by a similar granite which intruded a grey, lineated metagranodiorite northwest of Sala (referred to as the "Sala granite" by Magnusson *et al.* 1963). This metagranodiorite has yielded a U-Pb zircon age of 1890±3 Ma (Persson 1993).

Since neither the general appearance nor the field relations of the granite are conclusive regarding which generation it belongs to, the age is critical for both ongoing survey mapping on map-sheet 11G Västerås NO (see Ripa 1995, 1996) and an ongoing research project at the Geological Survey of Sweden concerning the geochemistry of felsic intrusive rocks in the Svecokarelian orogen. Thus, a radiometric dating of this granite was considered necessary.

SAMPLING

The granite was sampled at a blasted, forest road-cut east of Sala (Fig. 1; map-sheet 11G Västerås NO, coordinates 664660/154698 on the national grid).

PETROGRAPHY

The sampled granite is reddish grey, even-grained to slightly K-feldspar-phyric, medium-grained, and isotropic. A thin (c. 0.1 metre wide) chlorite-biotite-rich shear zone (orientation: 275/85N) is present in the sampled outcrop, but outside this zone the granite is undeformed. The rock is dominated by K-feldspar, plagioclase and quartz, and is a granite *sensu stricto*. Accessory minerals are biotite, sericite, chlorite, prehnite, epidote, allanite and muscovite. Of these, all but biotite are secondary. Plagioclase is variably sericitized and saussuritized. Muscovite and epidote crystallized on the alteration phases. Quartz shows undulose extinction and subgrain formation.

ZIRCON DESCRIPTION AND ANALYTICAL RESULTS

The sample contained few zircons and most of these grains were of poor quality, i.e., they were metamict and cracked. Only a limited number of grains were of acceptable quality for analysis. The zircons are colourless to pale brown. Most of them are short and prismatic with length/width ratios between 1 and 3, although more elongated crystals also exist. Several crystals have slightly rounded edges and many grains display crystal faces with high indices especially on the pyramids. However, high-index prism faces also occur. About 5–10 % of the zircons have cores or overgrowths. The cores are generally rounded but euhedral cores are also present. The analysed grains were, however, devoid of visible internal heterogeneities. All analysed zircons were strongly abraded. Due to the small size of the analysed fractions they were spiked with a mixed ^{205}Pb–^{235}U tracer (see section on analytical procedures earlier in this volume).

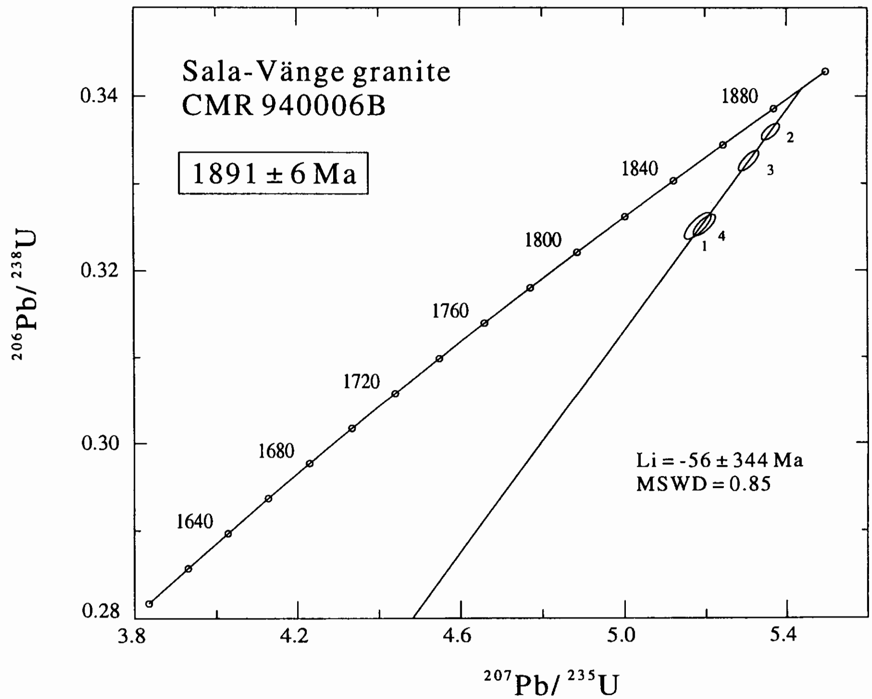

Fig. 2. Concordia diagram for zircons from the Sala–Vänge granite.

Analysed fractions:

1. 5 crystals. Medium-sized, pale brown, good quality, and virtually crack-free.

2. 22 crystals. Most are small, colourless, transparent and have high-index faces.

3. 5 crystals. Medium-sized but somewhat larger than fraction 1. They are more fractured than fractions 1 and 2.

TABLE 1. U-Pb analyses of zircons from the Sala–Vänge granite.

Analysis fraction	Weight (μg)	No. of crystals	U (ppm)	Pb tot. (ppm)	Common Pb (ppm)	$\frac{^{206}Pb}{^{204}Pb}$ [a]	^{206}Pb - ^{207}Pb - ^{208}Pb Radiog. (Atom %) [b]	$^{206}Pb/^{238}U$ [b]	$^{207}Pb/^{235}U$ [b]	$^{207}Pb/^{206}Pb$ age (Ma)
1	7	5	198.8	68.7	0.32	3019	81.3 - 9.4 - 9.3	0.3251±13	5.183±27	1889±6
2	8	22	190.3	68.6	0.71	2573	81.0 - 9.4 - 9.6	0.3360±8	5.362±18	1891±4
3	10	5	283.1	99.9	0.23	6220	81.3 - 9.4 - 9.3	0.3326±10	5.308±20	1891±4
4	7	7	203.4	71.4	0.62	2438	80.4 - 9.3 - 10.3	0.3252±10	5.199±22	1894±5

a: Corrected for mass fractionation (0.10% per a.m.u.).
b: Corrected for mass fractionation, blank and common Pb.

4. 7 crystals. Medium-sized and colourless to pale brown. Some crystals have small, black inclusions but are otherwise of good quality.

The analytical results are shown in Table 1 and Fig. 2. As can be seen from the concordia diagram (Fig. 2) the data points are weakly discordant (0.8 to 5 %). The upper intercept age is 1891±6 Ma and the lower intercept is close to zero. The linear fit is good. The obtained age is interpreted as the crystallization age of the granite.

CONCLUSIONS

The radiometric age of the Sala-Vänge granite (1891±6 Ma) is the oldest reported so far for granitoids in south central Sweden. It is, however, practically identical to the age of 1890±3 Ma obtained by Persson (1993) for an early-orogenic, Svecokarelian metagranodiorite. Other ages of early-orogenic, Svecokarelian granitoids in the region range from 1873 to 1850 Ma (Åberg & Strömberg 1984; Åberg *et al.* 1983a; Åberg *et al.* 1983b). We conclude that the Sala–Vänge granite should be grouped together with the early-orogenic, Svecokarelian granitoids.

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U-Pb zircon ages of three granitoids from the Växjö region, south central Sweden

By

Hugo Wikman

INTRODUCTION

The Transscandinavian Igneous Belt (TIB) is a N–S trending belt dominated by granites and porphyries, separating the Southwest Scandinavian Domain (Gorbatschev 1980) in the west from the Svecokarelian Orogenic Belt in the east (Fig. 1). The polymetamorphic gneisses in southwestern Sweden can be divided into a Western Gneiss (WG) Complex and an Eastern Gneiss (EG) Complex (Welin 1994). The oldest rocks in the southern part of the EG Complex have ages of about 1690 Ma (Welin 1994). The southernmost part of this gneiss complex, which is characterized by very strong and repeated metamorphism, is also called the Southwest Swedish Granulite Region (SGR; Johansson *et al.* 1991).

The southern part of the TIB is to a great extent built up of Småland–Värmland granites and associated volcanic rocks, mainly porphyries. These rocks were previously considered postorogenic in relation to the Svecokarelian orogeny and U-Pb datings have given ages of c. 1810–1650 Ma. Larson & Berglund (1992) proposed a threefold division of the magmatic rocks in the TIB with age intervals at 1810–1760, 1710–1690 and 1670–1650 Ma, respectively. According to this division the oldest TIB1 rocks are found in the east and the youngest, TIB 3 rocks, in the west. Recently a fourth, older generation at c. 1850 Ma has been investigated in the Askersund area (Persson & Wikström 1993; Wikström 1996).

The denotation postorogenic implies that these rocks should crosscut the regional, older Svecokarelian structures. However, it has been demonstrated that the oldest TIB granitoids in some areas are conformably folded and deformed together with the older bedrock (Wikström 1987, 1989, 1991, and 1996). This means that all the rocks are not postorogenic in the general meaning of the term. Both age data and structure observations indicate instead a long and complex history for the TIB-rocks and the onset of the TIB magmatism is clearly related to the late Svecokarelian development. The intrusives have probably been formed continuously from the later phases of the orogenic activity extending into a postorogenic stage.

During the regional mapping of the bedrock within the Växjö region it has been demonstrated that magmatic rocks belonging to the TIB extend westwards at least into the major tectonic lineament, usually called the Protogine zone. This zone is traditionally considered to border the TIB to the west but its origin and character have been subjects of controversy. South of lake Vättern the zone is characterized by usu-

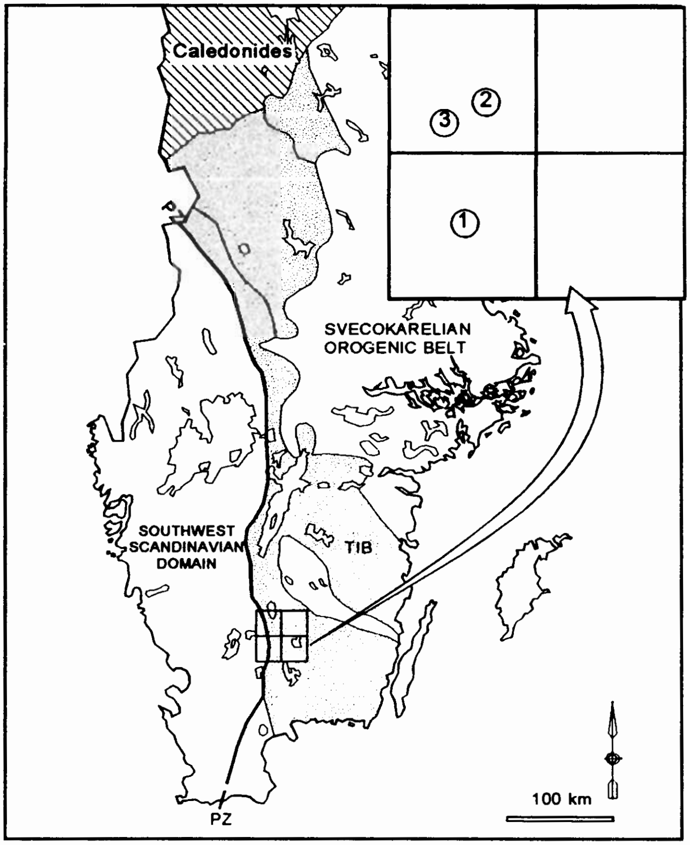

Fig. 1. Simplified map of southern Sweden showing the major Precambrian units. Stippled area represents the Transscandinavian Igneous Belt (TIB). Location of the four map-sheets Växjö (NV, SV, NO and SO) and the investigated samples 1, MHW 94060, 2, MHW 94606 and 3, MHW 94613, are indicated.

ally steep, N–S trending, often narrow, ductile deformation zones alternating with less deformed bedrock. In the Växjö region it is not only a tectonic lineament, but it also marks a change in lithology, structure and metamorphism from the EG Complex in the west to the TIB in the east. The zone is about 20 km wide in this region and most of the rocks found within the zone have suffered from deformation of varying degrees. Therefore it is usually very difficult to know, especially in the field, whether you are dealing with TIB-rocks or intrusives belonging to the EG Complex.

Further to the north along this major deformation zone detailed structural mapping, north of lake Vänern, has revealed that ductile deformation extends c. 40 km to the east of the traditional Protogine zone. This young deformation is considered a result of the Sveconorwegian orogeny and thus a new term Sveconorwegian Frontal Deformation Zone (SFDZ) has been proposed (Wahlgren *et al.* 1994). However, south of lake Vättern SFDZ follows the traditional Protogine zone and is here a genetically constrained designation for the young, ductile deformation. Besides, south of lake Vättern the Protogine zone also marks the front of the older, Gothian metamorphic processes that started the creation of the overall, characteristic gneissosity in the bedrock of SW Sweden (Larson 1996). Since the origin and significance of the zone is complex and still controversial, the genetically neutral, old term Protogine zone is used in this paper.

In order to facilitate the mapping of the obscured rocks within the Protogine zone and its surroundings, three U-Pb zircon age datings of granitoid rocks have been performed. One of the samples is from the map-sheet Växjö SV and the two others from Växjö NV. All three samples have been dated at the Unit for Isotope Geology, Geological Survey of Finland by Dr. Matti Vaasjoki and the text concerning the analytical data is based on his reports. For analytical procedure the reader is referred to the editor's preface and references given there.

SAMPLE DESCRIPTION AND ISOTOPIC RESULTS

Reddish grey granodiorite, MHW 94060

This sample was collected in a road-cut 400 m E of Ekholmen, map-sheet 5E Växjö SV (2c), coordinates 631375/141235. The rock is reddish grey, medium-grained, slightly porphyritic and shows a winding foliation. Quartz, K-feldspar and sericitized plagioclase make up c. 80 vol.% of the mineral content, whereas biotite, epidote and amphibole usually dominate the rest. Interesting is the relatively high amount of titanite, up to about 2 %. The composition of the rock varies from granitic to granodioritic, mostly depending on the varying content of megacrysts of K-feldspar.

The sample contains relatively fine-grained zircons with an average grain size of c. 100 μm. Their morphology ranges from short-prismatic to subhedral with low index pyramidal faces, and the crystals are light brown in colour. They are transparent and an oscillatory zoning can be detected under oil immersion. The length/breadth ratios range from 1.5 to 3, with the median ratio at 2.

The analytical results (Table 1) demonstrate that the discordance pattern is normal, i.e. the discordance increases with an increasing uranium content and a decreasing density. As usual, the abraded fraction (A) is the most concordant one. The analyses form a well defined linear array (MSWD = 0.23) which intersects the concordia curve at 1681±2 and 346±12 Ma (Fig. 2).

TABLE 1. U-Pb zircon data from sample MHW 94060, reddish grey granodiorite.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected for blank	207/235	206/207	Apparent age in Ma 6/8	7/5	7/6
A	+4.5/abr	291.8	94.87	3060	.2943	4.178	.1030	1662	1669	1678
B	+4.5	336.6	102.50	1647	.2747	3.834	.1012	1564	1599	1647
C	4.3-4.5	656.9	154.56	2187	.2168	2.955	.0989	1264	1396	1603

Common lead correction 6/4: 15.7; 7/4: 15.4; 8/4: 35.2.

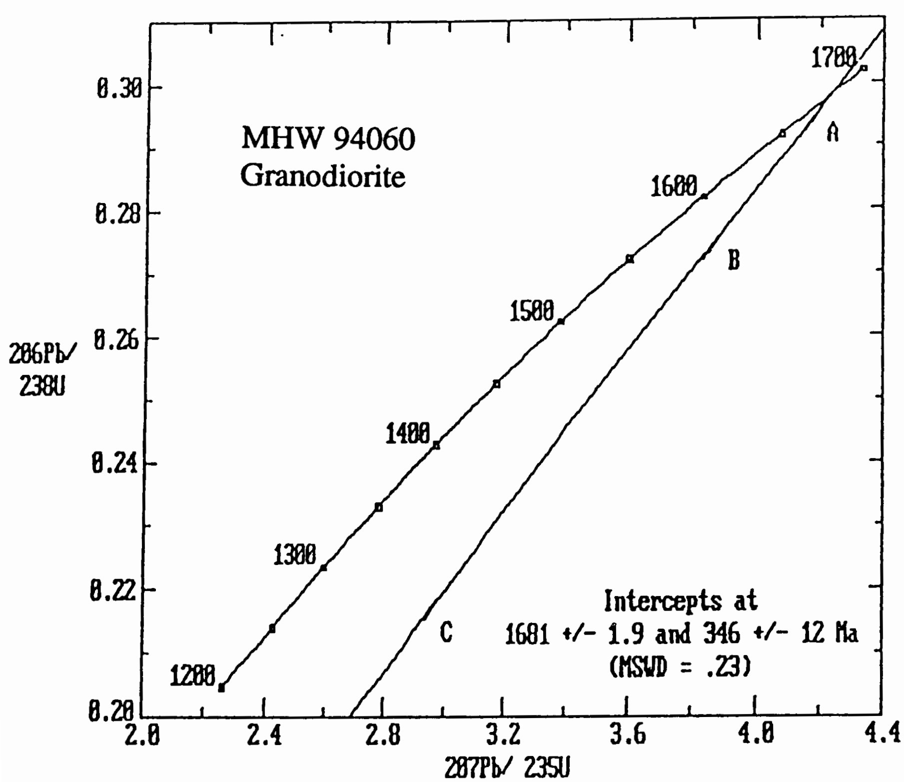

Fig. 2. U-Pb concordia diagram for zircons from sample MHW 94060, reddish grey granodiorite.

Reddish grey quartz monzonite MHW 94606

Sample MHW 94606 represents a reddish grey to grey, medium-grained homogeneous granitoid with a rather pronounced foliation striking approximately N–S. The sampling site, a road-cut c. 750 m NE of Hässleberg, coordinates 633290/141840, map-sheet 5E Växjö NV (6d), is situated relatively near the eastern boundary of the Protogine zone.

The mineral content in vol.% is dominated by plagioclase c. 40, K-feldspar 25 and quartz 15. Biotite 8, amphibole 5, epidote 3, together with apatite, titanite, zircon and opaques make up the rest. The relatively low content of quartz means that the rock is quartz monzonitic, a fact which is also reflected by the SiO_2 content (64.6 wt. %) in the chemical analysis.

The quartz monzonite contains abundant, very pale brown and transparent zircons. The crystals are euhedral, with a simple prismatic-pyramidal morphology. The L/B ratio varies from 1.5 to 4 with a median at 2.5. The zircons are generally weakly zoned and some crystals are corroded. Almost all zircons contain transparent rod-like (fluid) inclusions.

The analytical results (Table 2) demonstrate the usual pattern: the abraded fraction (A) is the least discordant, and the degree of discordance increases as the uranium contents increase and the fractions become lighter. The variation in the degree of discordance is very large (Fig. 3). If all the analyses are included in the age calculation, the upper intercept age is 1681±20 Ma with MSWD=11. If, on the other hand, the most discordant fraction (D) is excluded (Fig. 4), the MSWD drops radically to 0.3, and the upper intercept age estimate becomes 1676±4 Ma.

Irrespective of the way of calculation, the present results clearly indicate that the granite, represented by sample MHW 94606 from Hässleberg, belongs to a relatively well established, c. 1680 Ma group of granitic rocks within the Protogine zone.

TABLE 2. U-Pb zircon data from sample MHW 94606, reddish grey quartz monzonite.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected for blank	207/235	206/207	Apparent age in Ma 6/8	7/5	7/6
A	+4.5/abr	292.9	87.89	1054	.2625	3.685	.1018	1502	1568	1657
B	+4.5	349.9	97.77	1019	.2436	3.394	.1010	1405	1503	1644
C	4.3-4.5	634.5	150.10	809	.1968	2.682	.0988	1158	1323	1602
D	4.2-4.3	1458.2	326.06	372	.1552	2.016	.0942	930	1120	1512

Common lead correction: $^{206}Pb/^{204}Pb$: 15.7; $^{207}Pb/^{204}Pb$: 15.4; $^{208}Pb/^{204}Pb$: 35.2 .

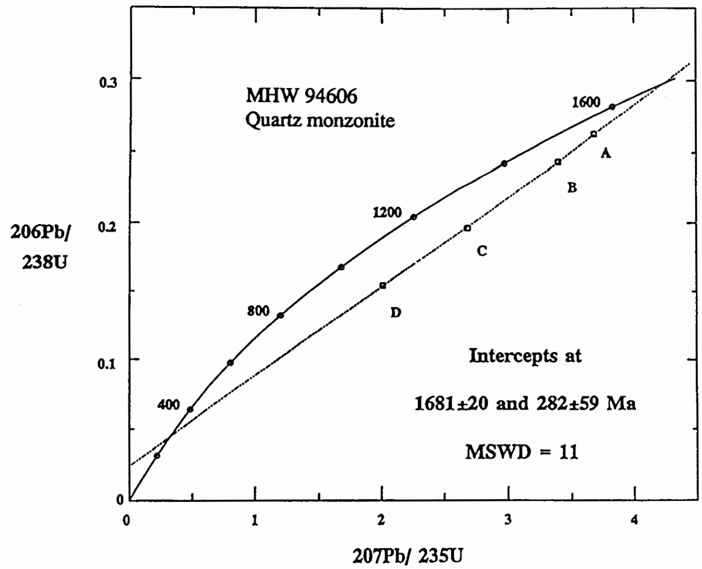

Fig. 3. U-Pb concordia diagram for zircons of all fractions from sample MHW 94606, reddish grey quartz monzonite.

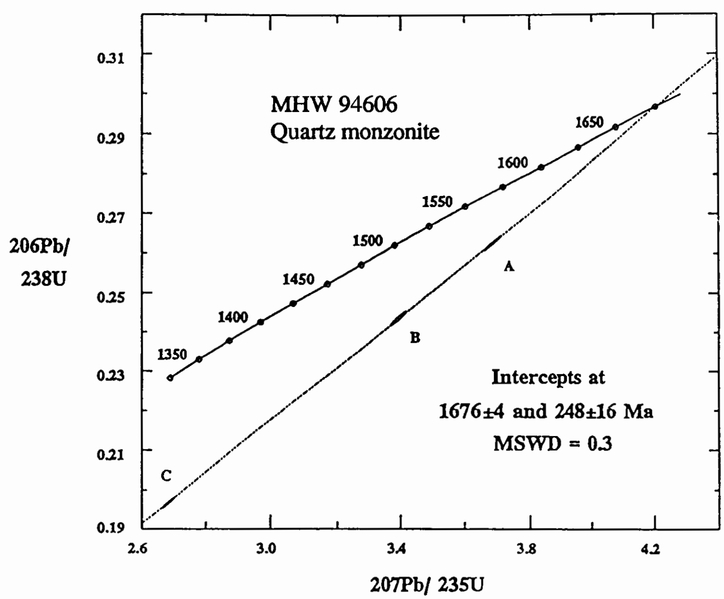

Fig. 4. U-Pb concordia diagram for zircons of all fractions, except the most discordant one, from sample MHW 94606, reddish grey quartz monzonite.

Dark grey quartz monzodiorite MHW 94613

MHW 94613 represents a strongly foliated, dark grey, finely medium-grained quartz monzodioritic rock from the map-sheet 5E Växjö NV (5b). The sample was collected in a road-cut c. 600 m WSW of Åkerås, coordinates 632865/140540. The locality is situated in the southwestern part of the map area some 20 km to the west of the true TIB. The foliation follows the Protogine zone deformation in NNW–SSE and there is a slight migmatization of the bedrock in the surroundings. However, not far from this locality an older, ductile foliation in approximately E–W is still discernible in the granitoids.

The mineral content is dominated by plagioclase 36 (vol.%) together with K-feldspar 17, biotite 15, amphibole 13 and quartz 12, respectively. Epidote, titanite, apatite, zircon and opaques make up the rest. Also in this sample the high content of 3 vol.% for titanite is noteworthy. The SiO_2 content in the chemical anlysis of this quartz monzodioritic rock is 61.7 wt.%.

The rock contains relatively fine-grained zircons with an average size of c. 100 µm. Their morphology ranges from short-prismatic to anhedral with no pyramidal faces, and the crystals are light brown in colour. The zircons are transparent and a weak zoning can be detected under oil immersion. The length/breadth ratios range from 1.5 to 3, with the median at 2.

The analytical results (Table 3) show that the discordance pattern is normal, i.e. the discordance increases with an increasing uranium content and a decreasing density. As usual, the abraded fraction (A) is the most concordant one. The analyses form a fairly well defined linear array (MSWD=1.6) which intersects the concordia curve at 1677±7 and 279±63 Ma (Fig. 5).

TABLE 3. U-Pb zircon data from sample MHW 94613, dark grey quartz monzodiorite.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected for blank	207/235	206/207	Apparent age in Ma 6/8	7/5	7/6
A	+4.5/abr	191.1	65.77	5379	.2872	4.067	.1027	1627	1647	1674
B	+4.5	191.5	65.32	3810	.2851	4.026	.1024	1616	1639	1668
C	4.3-4.5	306.3	99.86	3110	.2716	3.820	.1020	1548	1596	1661
D	4.2-4.3	977.5	278.41	1316	.2287	3.160	.1002	1327	1447	1628

Common lead correction: 6/4:15.7; 7/4:15.4; 8/4:35.2 .

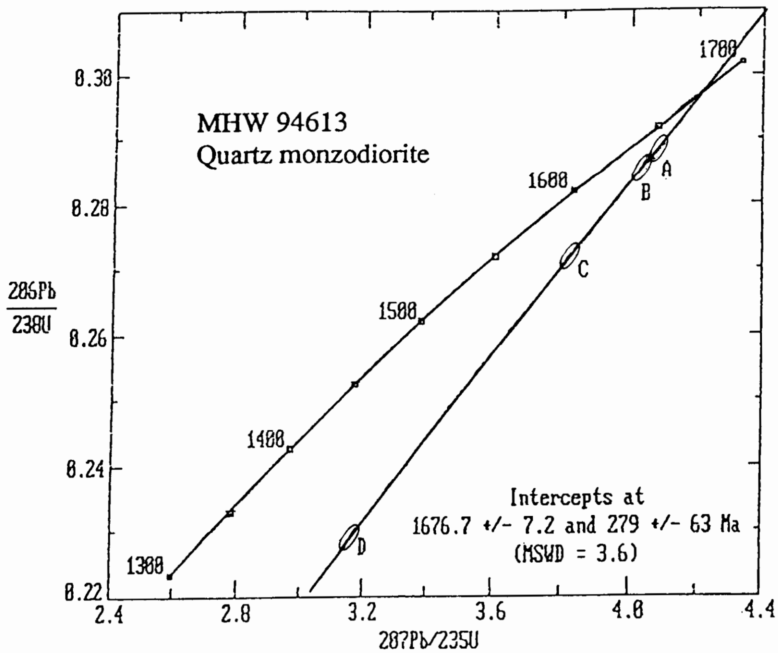

Fig. 5. U-Pb concordia diagram for zircons from sample MHW 94613, dark grey quartz monzodiorite.

DISCUSSION

The obtained ages of the three granitoids are of the same magnitude and seem to establish a magmatic period in this area at c. 1680 Ma. The existence of such an event is furthermore reinforced by the preliminary results from a geochemical-geochronological investigation of a small gabbro massif located at lake Rymmen between the sampling sites of MHW 94606 and 94613 (Claeson & Larson 1996).

The ages of the dated granitoids differ markedly from the about 100 Ma older TIB granitoids to the east of the Protogine zone within the Växjö region (Johansson *et al.* 1993). They also differ somewhat from the datings of two foliated granites in the extreme eastern part of the Protogine zone with ages of c. 1713 Ma (Johansson 1990) and 1704 Ma (Wikman 1993), respectively. The first mentioned of these rocks is a porphyritic, foliated granite south of Alvesta on the map-sheet Växjö SV. This granite was originally believed to belong to the EG Complex (Johansson 1990, Johansson *et al.* 1993), but further regional mapping has demonstrated that it is a foliated TIB granite of the so-called Filipstad type.

The obtained ages indicate a subdivision of the TIB granitoids in the Växjö region at least into two groups. The oldest rocks, with ages of about 1770–1800 Ma, are found to the east of the Protogine zone. The granites of the second group may possibly be divided in two subgroups but the age difference between them is very small. Group 2a, with ages from 1710 to 1700 Ma, is located in the eastern part of the Protogine zone, whereas group 2b comprises more deformed and sometimes slightly migmatized rocks about 1680 Ma old found within the zone. An interesting question in this context is whether the deformation of the bedrock in the Protogine zone has affected the granites of group 2 or not. A resetting of the ages might be expected to be the result of such processes. Further regional mapping combined with geochronological, geochemical and tectonic investigations will improve the understanding of the regional geology within this part of Småland and the extension of the TIB-rocks in a westward direction.

ACKNOWLEDGEMENT

The radiometric analyses have been performed at the Geological Survey of Finland by Dr Matti Vaasjoki. The text concerning the analytical data is based on a report by him to the Geological Survey of Sweden.

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Two Haparanda type granodiorites with contrasting ages in the southeastern part of Norrbotten County, northern Sweden

By

Anders Wikström and Per-Olof Persson

INTRODUCTION

Calc-alkaline intrusives of so-called Haparanda type (Ödman 1957) are important constituents of the bedrock of southeastern Norrbotten County. Two U-Pb zircon age determinations of this rock type have so far been reported. Öhlander *et al.* (1987) obtained an age of 1892±14 on a granodiorite west of Luleå (Fig. 1). Wikström *et al.* (1996) dated a fragment in the Bälinge magmatic breccia (formerly interpreted as a conglomerate) 10 km southwest of Luleå and obtained an age of 1879±4 Ma. The Archaean–Proterozoic palaeoboundary is located in the present study area and Haparanda suite intrusives have been sampled for Sm-Nd isotopic investigation (Öhlander *et al.* 1993; Mellqvist 1996) in order to constrain the position of the boundary. The current paper presents U-Pb zircon datings of two granodiorite samples collected on each side of this boundary.

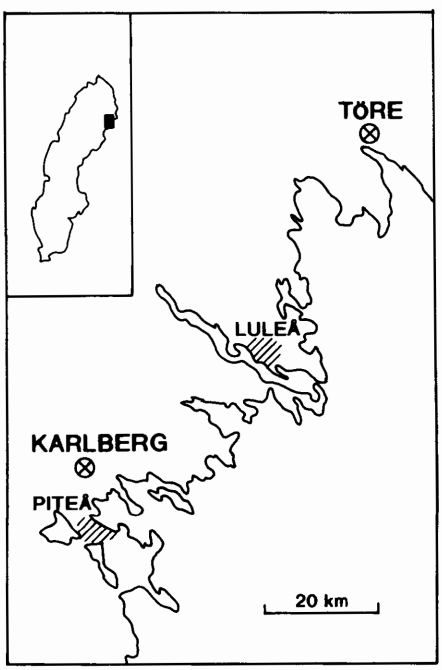

Fig. 1. Orientation map showing the position of the sampling localities.

Sample descriptions

The first sample was collected at Töre (National coordinates: 732920/181190, topographic map-sheet 25M Kalix NV), well to the north of the Archaean–Proterozoic palaeoboundary. It was taken in connection with road constructions along the E4 highway and the outcrop is now inaccessible due to soil covering. (A macroscopically identical rock is present in an outcrop at the water tower of Töre, about 300 metres to the north of the sampling locality.) A bedrock map of the area has recently been published (Wikström 1995).

The area is characterized by low amphibolite facies metamorphism (andalusite and staurolite present in adjacent metapelitic enclaves in the granodiorite) and the intensity of deformation is low (Fig. 2). Measurements of foliation and lineation are difficult to perform in these intrusives in the area, except in marginal areas of the plutons and in distinct shear zones.

The second sample has been collected in a quarry for aggregates situated near Karlberg (National coordinates: 726455/176040, topographic map-sheet 24L Luleå SV) northwest of the town of Piteå. Bedrock mapping of the Luleå map-sheets is now underway at the SGU, although the systematic investigation has so far not reached this sampling locality. As can be seen from Fig. 2, this sample is considerably more deformed and gneissic compared with the Töre sample. It can be inferred from reconnaissance work that the metamorphism in the area is characterized by medium- to

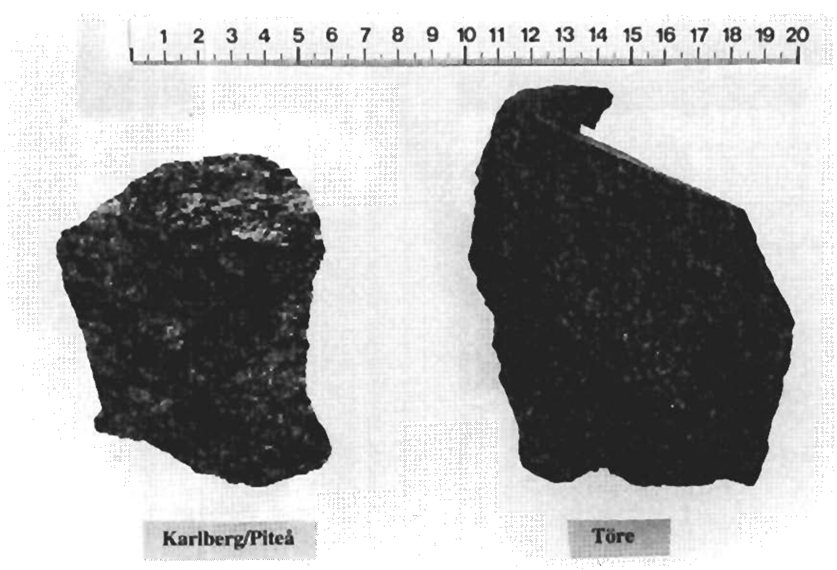

Fig. 2. Analysed samples.

high grade amphibolite facies and partly involves migmatite formation. The degree of deformation is also considerably higher compared with the Töre region. Within the quarry, younger crosscutting dykes of isotropic granites and pegmatites can be found. Mafic enclaves, elongated in the foliation direction, can be observed within the older granodiorite. The κ-value is very low, 20×10^{-5} SI units.

Modal and chemical analyses of the investigated samples are presented in Tables 1 and 2 respectively, and the REE patterns in Fig. 5.

TABLE 1. Modal composition of investigated samples.

	Quartz	K-feldspar	Plag.	Biotite	Muscovite	Chlorite	Epidote	Hornblende
Töre	21	23	28	13	1	2	5	6

Accessories: titanite, calcite, opaque minerals.

	Quartz	K-feldspar	Plag.	Biotite	Hornblende	Titanite
Karlberg	18	26	37	13	4	1

Accessories: epidote, calcite, allanite; chlorite and sericite as alteration minerals.

TABLE 2. Chemical composition of investigated samples. SiO_2–Sum : wt.%, Ba-Lu : ppm.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5	Sum
Töre	66.5	0.549	15.0	5.01	2.31	0.0824	3.47	3.95	3.18	0.179	100.2
Karlb.	66.7	0.677	15.2	5.41	0.942	0.0747	3.03	3.88	3.99	0.189	100.1

	Ba	Be	Co	Cr	Cu	Ga	Hf	Mo	Nb	Ni	Rb	Sc	Sn	Sr	Ta	Th	U
Töre	916	3.23	7.76	63.9	17.6	20.1	2.88	1.29	6.93	20.4	101	9.37	1.36	535	.515	6.39	3.14
Karlb.	690	3.25	<6	28.9	45.5	6.37	10.5	3.06	17.4	13.6	154	8.23	2.87	161	1.39	14.8	7.31

	V	W	Y	Zn	Zr	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
Töre	90.6	5.28	6.75	87.3	140	25.3	48.3	5.68	20.2	3.84	1.48	3.48	.453	2.43	.497	1.09	.215
Karlb.	38.1	1.19	43.0	108	393	39.0	81.0	9.70	38.0	7.09	1.10	7.99	1.33	7.37	1.58	4.47	.600

	Yb	Lu
Töre	1.30	.213
Karlb.	4.87	0.640

Analysed zircons

In the Töre sample, the zircons are pink, strongly metamict and rich in inclusions. A few are clear and free from fractures and inclusions. Most crystals are euhedral with sharp edges or with slightly rounded pyramids, but some are strongly rounded and some display numerous high index faces. Short prismatic crystals predominate with a length/breadth ratio between 2 and 3, although a few longer grains have also been found. Several of the clear grains have cores/overgrowths visible in alcohol. As a rule, the core dominates the crystal. Occasionally a thin overgrowth is visible on a euhedral core. All analysed zircons were strongly abraded.

74–106 μm. A first selection was made of 8 grains (6 medium sized and 2 small) which were colourless, free from fractures (although some with inclusions). They were short prismatic and some had many high-index crystal faces.

74–106 μm. A second selection was made of 8 grains with similar properties as above but with somewhat more abundant fractures and inclusions.

<106 μm. 12 crystals were selected. They were of poorer quality than the previous fractions but showed no visible cores or inclusions.

>106 μm. 3 crystals which were clear, colourless and short prismatic and showed numerous crystal faces were analysed from this fraction. One grain had possibly a thin overgrowth. A few dark inclusions were observed.

The Karlberg/Piteå sample contained plenty of zircon crystals, which were pale brown to brown and transparent and exhibited a simple prismatic-pyramidal morphology. The grain size varied from 50 to 150 μm. A minor (<5%) amount of turbid, dark brown crystals were removed by hand picking before the analysis. Inspection under oil immersion revealed a strong oscillatory zoning and the presence of unidentified, transparent rodlike inclusions. As the yield of the heavy fraction was minimal, this was not analysed.

RESULTS AND DISCUSSION

The analytical result of the Töre sample shows that the zircons constitute a heterogeneous population. Two fractions plot close to the concordia with an upper intercept of 1883±6 Ma (Fig. 3) which is close to the hitherto obtained ages for Haparanda-type intrusives. We interpret this age as the crystallization age of the rock. Since the two-point regression line has a strongly negative lower intercept of -580 Ma we prefer to draw the line through zero with an arbitrary uncertainty of ±400 Ma. The two other fractions plot to the right of the regression line and obviously contain inherited material though not optically discernible. The fraction >106 μm has a $^{207}Pb/^{206}Pb$ age of 2.3 Ga (Table 3). The multi-faceted appearance is characteristic of metamorphic zircons, suggesting that analysed crystals consist of xenocrysts which became recrystallized 1.88 Ga ago, possibly encompassing addition of new material (cf. zircon description above). Archaean rocks outcrop in the sampling area, implying that the inherited zircons are of Archaean age. The existence of inherited Archaean zircons

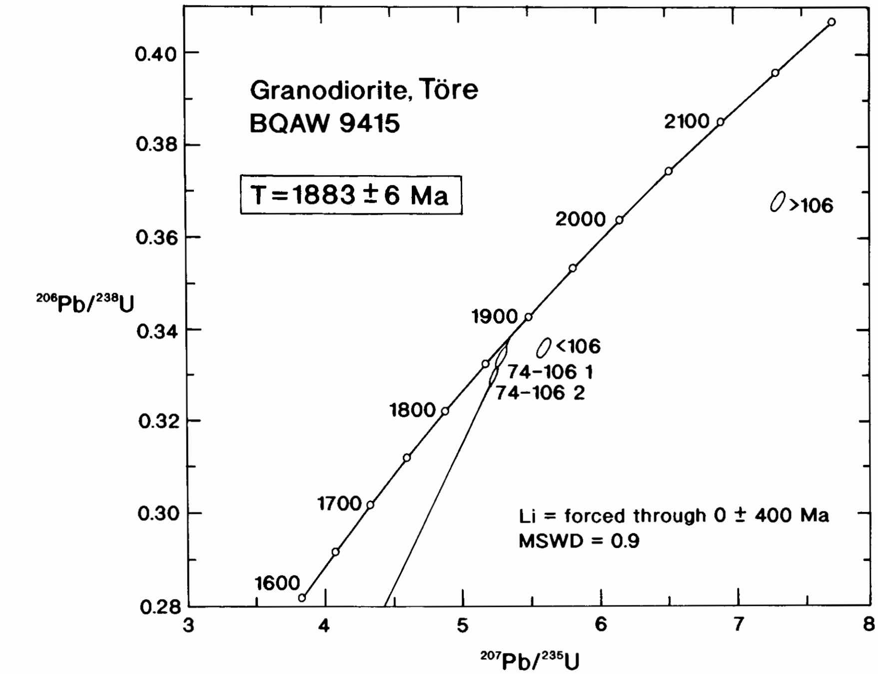

Fig. 3. U-Pb concordia diagram for zircons from the Töre sample.

TABLE 3. U-Pb zircon data of the Töre sample (BQAW 9415).

Fraction µm	Weight µg	U ppm	Pb(tot) ppm	Pb(com.) ppm	$^{206}Pb/^{204}Pb$ a)	^{206}Pb-^{207}Pb-^{208}Pb Radiog.(at.%)b)	$^{206}Pb/^{238}U$ b)	$^{207}Pb/^{235}U$ b)	$^{207}Pb/^{206}Pb$ age (Ma)
74-106 (1)	18	129.3	46.7	0.27	4142	80.0-9.2-10.8	0.3340 ±20	5.300±34	1882±5
74-106 (2)	18	178.1	62.3	0.07	4473	80.9-9.3-9.8	0.3301±16	5.247±28	1884±4
<106	14	180.5	67.1	1.52	1532	79.6-9.6-10.7	0.3360±16	5.606±38	1971±8
>106	16	142.4	57.8	0.14	3573	78.1-11.3-10.6	0.3678±19	7.328±-48	2282±6

a) corrected for mass fractionationa (0.1% per a.m.u.).
b) corrected for mass fractionation, blank and common Pb.

also agrees with Nd isotopic results from the sampling area, yielding strongly negative ε_{Nd} values (Mellqvist 1996).

The Karlberg/Piteå sample yields a slightly discordant linear array with an upper intercept age of 1867±11 Ma (Table 4 and Fig. 4). It is younger than Haparanda type granitoids further to the north but similar in age (1868 ±13 Ma) to a pebble in the Pite conglomerate some 15 km to the south (Persson & Lundqvist, this volume, pp. 41–49).

TABLE 4. U-Pb zircon data for the Karlberg/Piteå sample (BQAW 9453, analysed at the Geol. Survey of Finland).

Sample	Fraction	Uconc ppm	Pb(tot) ppm	$^{206}Pb/^{204}Pb$ meas.	$^{206}Pb/^{238}U$ Corrected for blank	$^{207}Pb/^{235}U$ Corrected for blank	$^{206}Pb/^{207}Pb$ Corrected for blank	Apparent age in Ma 6/8	7/5	7/6
A	4.3-4.5(abr)	587.3	192.41	9427	.3234	5.068	.1137	1806	1830	1859
B	4.3-4.5	649.2	208.69	3709	.3132	4.884	.1131	1756	1799	1849
C	4.2-4.3	799.9	244.06	3499	.2980	4.608	.1121	1681	1750	1834
D	4.0-4.2	956.1	277.19	4504	.2844	4.377	.1116	1613	1707	1825

Common lead correction: $^{206}Pb/^{204}Pb$: 15.7; $^{207}Pb/^{204}Pb$: 15.4; $^{208}Pb/^{204}Pb$: 35.2.

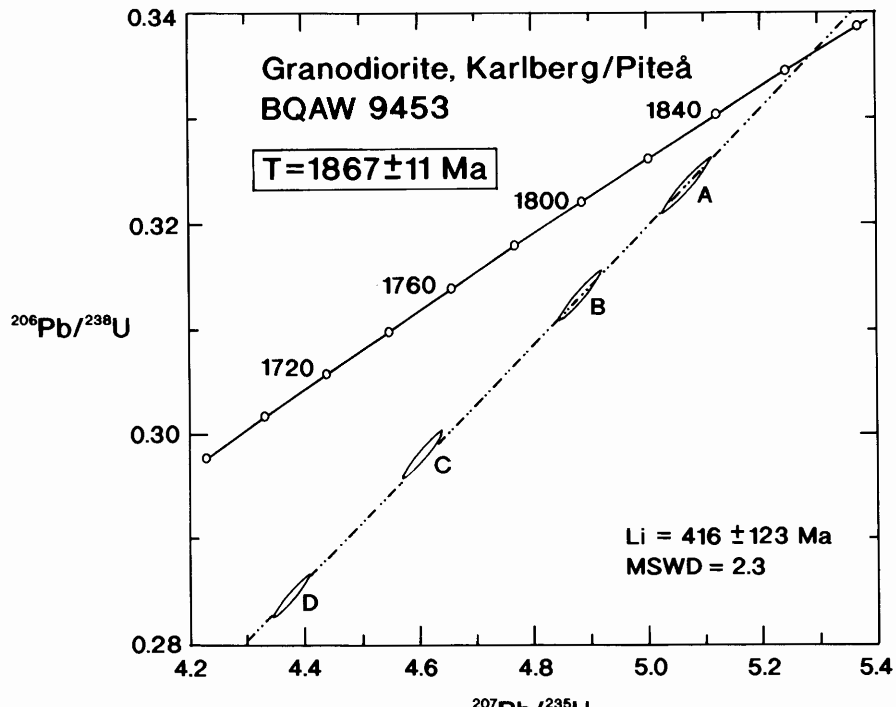

Fig. 4. U-Pb concordia diagram for zircons from the Karlberg/Piteå sample.

It is unlikely that the amphibolite facies metamorphism in the area has affected the Pb isotopic system, as the zircons have a magmatic appearance and the points are located close to the concordia.

The spread in the obtained ages for samples from southeastern Norrbotten is within the range so far established for the early Svecokarelian granitoids in Northern Sweden. They range from 1859+/-3 Ma (Weihed & Vaasjoki 1993) to 1954+/-6 Ma (Wasström 1993). Lundqvist *et al.* (in manuscript 1996) have summarised the pub-

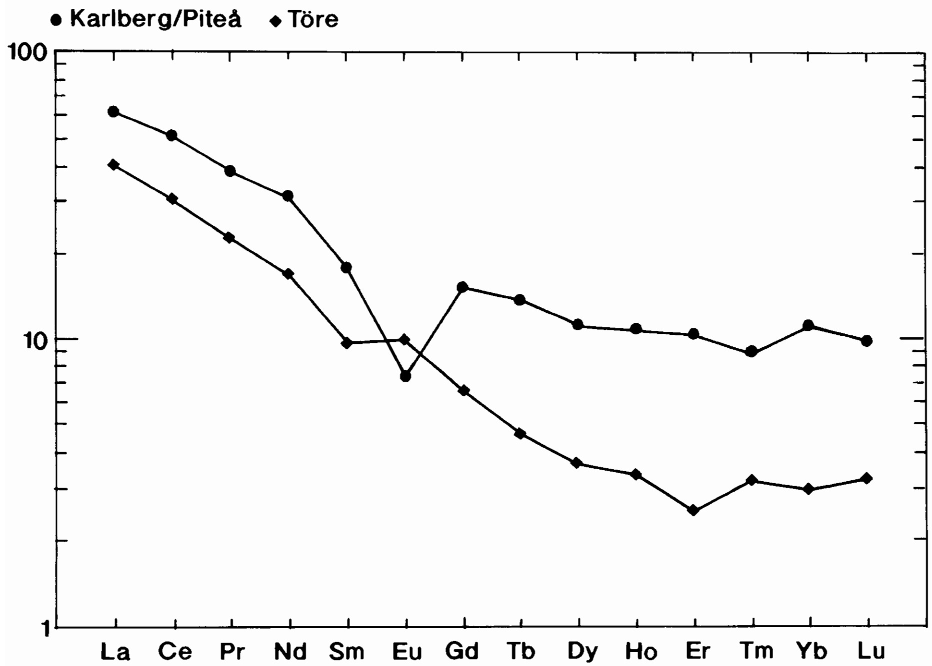

Fig. 5. Chondrite normalized REE patterns for the granodiorites at Töre (diamonds) and Karlberg/Piteå (circles).

lished dating results of the early orogenic granitoids in the Bothnian Basin of north-central Sweden and also suggested that the spread in ages is linked with a prolonged interplay between magmatism and sedimentation in the early stages of the orogenic process.

ACKNOWLEDGEMENTS

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Benno Kathol is thanked for his help in producing Fig. 5. The radiometric analyses of the sample Karlberg/Piteå have been performed at the Geological Survey of Finland and the text concerning this sample is based on a written report to the SGU by Dr. Matti Vaasjoki.

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U-Pb zircon and monazite dating of a Lina type leucogranite in northern Sweden and its relationship to the Bothnian shear zone

Anders Wikström and Per-Olof Persson

INTRODUCTION

On the bedrock map of Norrbotten County by Ödman (1957), an area surrounding the name Raggdynan between Töre and Kalix (Fig. 1) is marked as younger granite of the Lina-type (medium-grained, red, migmatite-associated and with rare biotite; Ödman 1957, p. 141)). Approximately two thirds of the exposed bedrock within the lineaments of the Bothnian shear zone in the area of Fig. 1 are also composed of this type of rock, mainly as mobilisate in a migmatite association. The rest consists of various paleosomes, mainly metasediments and gneissic granodiorites and tonalites of the Haparanda suite. Areas with different paleosomes are separated from each other by the unexposed, north-south trending topographic lineaments which also can be seen on the aeromagnetic map (Wikström 1995). No visible macroscopic difference in the younger granite has been observed when comparing the blocks with different paleosomes. The lineaments are part of a larger structure known as the Baltic–Bothnian megashear (Berthelsen & Marker 1986), or the Bothnian shear zone (Wikström 1995), as its continuation southwards into the Baltic has not been documented. The name Pajala shear zone (Kärki *et al.* 1993) for this structure has also appeared in the

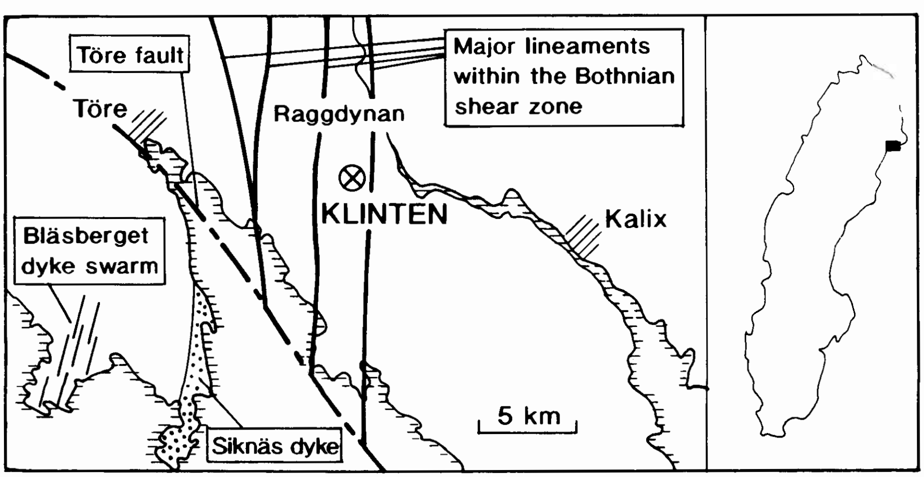

Fig. 1. Orientation map of the sampling locality with some names mentioned in the text.

literature. In a previous study (Wikström *et al.* 1996a), magmatism regarded to be associated with this structure on the Kalix SV map-sheet was found to be around 1.88 Ga old. Of particular interest was the fact that the Bläsberget dyke swarm, which cross-cuts the regionally folded wall-rock migmatite structures, had this old age and that the migmatites are consequently still older in this area. In order to investigate how far north these migmatites can be traced a sample of the Lina type granite was collected within the shear zone northeast of the Bläsberget locality. The sample locality is *Klinten* (National Coordinates: 732880/182130, map-sheet Kalix NV; Fig. 1).

Modal and chemical compositions of the investigated sample are presented in Tables 1 and 2.

TABLE 1. Modal composition of the investigated leucogranite.

Quartz	K-feldspar	Plag.	Biotite	Muscovite	Chlorite	Epidote
25	43	25	4	2	1	1

Accessory minerals: calcite, apatite, zircon, prehnite, allanite, opaques

TABLE 2. Chemical analysis of the investigated leucogranite. SiO_2–LOI : wt.%, Ba–Lu : ppm.

SiO_2	TiO_2	Al_2O_3	Fe_2O_3(tot)	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5	Sum	LOI
74.2	.207	13.9	1.77	.675	.0199	1.12	3.32	5.00	.0597	100.1	.5

Ba	Be	Co	Cr	Cu	Ga	Hf	Mo	Nb	Ni	Rb	Sc	Sn	Sr	Ta	Th	U	V	W
508	2.43	7.02	48.8	6.62	20.0	3.51	<.68	6.28	15.2	182	2.42	.671	112	.640	20.9	2.28	17.2	.226

Y	Zn	Zr	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
10.0	21.3	156	57.7	112	12.4	39.2	5.95	1.14	4.95	.627	3.00	.522	1.23	.149	1.44	.644

SAMPLE DESCRIPTION

The collected sample *Klinten* consists of a red, fine medium-grained, seemingly isotropic, microcline leucogranite with a modal composition according to Table 1 and chemical composition according to Table 2. At the sampling site the granite contains sedimentary gneisses as fragments, which constitute approximately 30% of the surface and lack any visible regular orientation.

For the U-Pb isotopic analyses two zircon and two monazite fractions were prepared. The sample contained relatively few zircons, which constituted a rather heterogeneous population. A small number of grains were large and wide (length/breadth ratios from 1 to 2) and colourless to light brown. The majority of the grains were of normal size but with varying colour and shape. The colour ranged from colourless to dark brown or reddish brown. Some crystals were elongated and euhedral with slightly rounded edges and were turbid and contained inclusions. Other grains were short, euhedral and generally colourless, whereas others were rounded and short. Nearly all grains were metamict. As the rock sample contained relatively few zircons, these were not sieved into different size fractions.

A *first zircon selection (zircon 1 or zr 1)* comprised nine crystals (six medium sized and three small). Two were elongated and the others short. They were all clear and colourless but had some cracks and inclusions. Before analysis they were strongly abraded.

The *second zircon selection (zircon 2 or zr 2)* was made up of seven medium sized, clear and colourless crystals; four elongated and three short ones. They were of somewhat poorer quality compared with the first selection. Also these grains were strongly abraded.

The sample contains more monazite than zircon. The monazite grains which were analysed were greenish yellow and clear. The size fraction 74–106 μm was used for the analysis and the crystals were gently abraded.

Monazite fraction 1 (monazite 1 or mo 1) was made up of five euhedral to slightly rounded crystals, some with dark inclusions.

Monazite fraction 2 (monazite 2 or mo 2) was made up of six crystals with the same shape and colour as the first, but slightly more rounded and somewhat more turbid.

ANALYTICAL RESULTS AND DISCUSSION OF THE ISOTOPIC DATA

A presentation of the analytical data is given in Table 3 and Fig. 2. The monazite analyses yield one concordant data point and one which is slightly reversely discordant. The zircons show an age heterogeneity, which is what might be expected considering the presence of metasedimentary fragments in the granite and the wide range in morphology of the crystals. One of the zircon fractions falls on the monazite regression line (might be accidental), whereas the other obviously contains inherited material and indicates an older age. Since the granite has not been subjected to subsequent high-grade metamorphism, the monazite age is interpreted as the crystallization age of the granite. The three-point discordia calculated on the monazite fractions and on zircon fraction *zr 2* gives an upper intercept age of 1783±3 Ma. With regard to the field evidence of a rather close association between the formation of the granite and the local migmatization event, it is reasonable to assume that the obtained age also dates the migmatization.

TABLE 3. U-Pb isotopic data for Lina type leucogranite (BQAW 94:14).

Mineral and analysis fraction	Weight (µg)	U (ppm)	Pb tot. (ppm)	Pb com. (ppm)	$^{206}Pb^{a}/^{204}Pb$	^{206}Pb - ^{207}Pb - ^{208}Pb Radiog. (Atom %)[b]	$^{206}Pb/^{238}U^{b}$	$^{207}Pb/^{235}U^{b}$	$^{207}Pb/^{206}Pb$ age (Ma)
Zircon 1	13	803	266.4	0.20	12013	78.6 - 8.7 - 12.6	0.3027±28	4.638±44	1818±4
Zircon 2	14	737	263.0	5.97	1963	77.4 - 8.4 - 14.1	0.3140±7	4.716±19	1782±6
Monazite 1	12	1873	4582	3.11	8648	11.4 - 1.2 - 87.4	0.3214±5	4.831±10	1783±2
Monazite 2	12	2820	6017	1.31	22711	12.9 - 1.4 - 85.7	0.3185±4	4.790±9	1784±3

a) corrected for mass fractionation (0.1% per a.m.u).
b) corrected for mass fractionation, blank and common Pb.

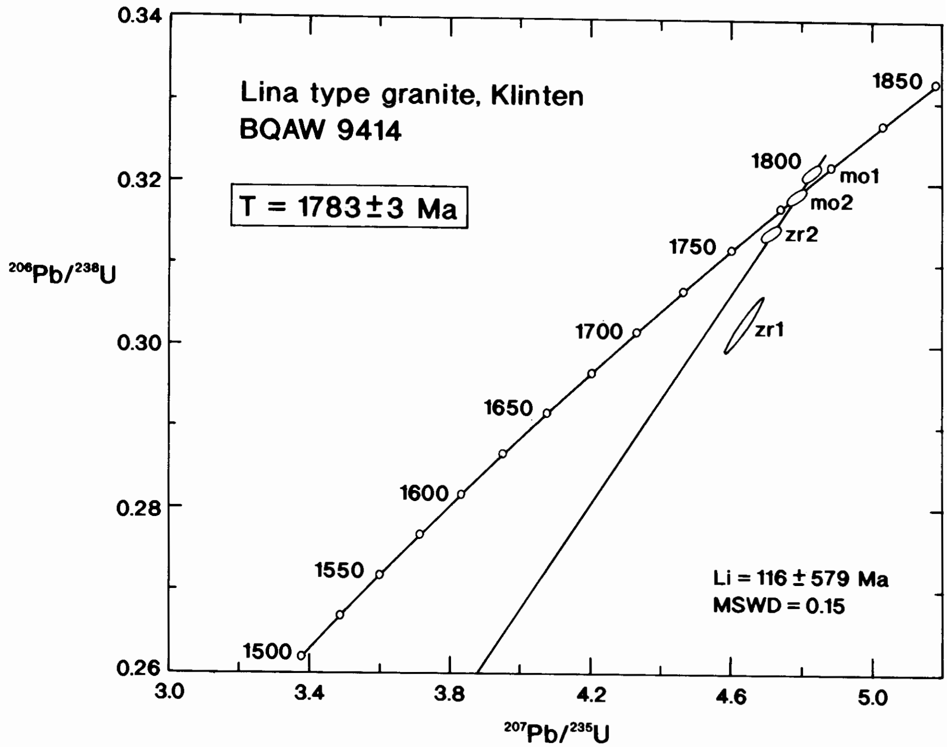

Fig. 2. U-Pb concordia diagram for zircons and monazites from the Klinten sample.

GENERAL DISCUSSION

The investigation shows that the migmatites in the area clearly belong to a younger generation than the migmatites further to the south. The obtained age is also in accordance with ages of other similar granites in the County of Norrbotten (e.g. Öhlander *et al.* 1987 and Öhlander & Skiöld 1994).

Of particular importance is also that considerable movements have taken place in the shear zone much later than was indicated by the previous investigation further to the south. The reason for this conclusion is that the north-south trending lineaments separate blocks with different types of paleosomes in the migmatites. A natural question is therefore how to explain the difference between these results and those previously received.

There are several factors, apart from the dating results of the Bläsberget dykes, which support the existence of an older migmatite formation in the coastal areas. The

Degerberg granite, which also has an age of around 1880 Ma (Wikström *et al.* 1996a), generally has a cross-cutting contact towards the country rocks, although it is sometimes locally, in marginal zones, involved in migmatite-forming processes (Romer & Öhlander 1991).

Another argument for an older age in the coastal areas can be found in the work by Perdahl (1995), who found that the mafic lavas to the east of Luleå are geochemically similar to mafic lavas in a marine environment close to the Archaean basement in Finland. This also implies that the surrounding metasediments would be quite old in the area. Also since Archaean rocks are present to the south and west of Luleå (Lundqvist *et al.* 1996; Wikström *et al.* 1996b), a somewhat older development could be anticipated in the coastal region.

Returning to the Bothnian shear zone, a major topographic and magnetic lineament, the Töre fault (Fig. 1) is found along Töreviken in a northwest–southeast direction, truncating the Siknäs dyke in the north. Neither has the Bläsberget dyke swarm been found to the north of this line, which could thus be the dividing line between an older block in the south and a younger in the north. The dyke activity would then be restricted to the older block. As to the dynamic development of the shear zone, the obtained results in the north and south are more difficult to interpret. One possible explanation, although little attractive from field evidence, could be that the parallel trend of the Bläsberget dyke swarm and the shear zone is accidental and that the mafic dykes within the shear zone, which clearly have intruded during the shear movements (Wikström 1993, Fig. 5C), do not have the same age as the Bläsberget dyke swarm.

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