Research Papers

SGU series C 828

Forskningsrapporter

Radiometric dating results 2

Division of Bedrock Geology

Geological Survey of Sweden

Edited by Thomas Lundqvist

SGU

Sveriges Geologiska Undersökning

Geological Survey of Sweden

UPPSALA 1996

Research Papers

SGU series C 828

Forskningsrapporter

Radiometric dating results 2

Division of Bedrock Geology

Geological Survey of Sweden

Edited by Thomas Lundqvist

UPPSALA 1996

ISBN 91-7158-556-7
ISSN 1103-3371

Address:

Thomas Lundqvist
Geological Survey of Sweden
Box 670
S-751 28 UPPSALA

Cover: Multi-faceted zircon crystal from the
Nuortenjuone gneiss (p. 57 ff.). Length of crystal 0.25 mm.
Scanning Electron Microscope photo by Per-Olof Persson.

Layout: Agneta Ek, SGU
Print: Gotab, Stockholm 1996

CONTENTS

EDITOR'S PREFACE

This paper is the second 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.

It is a great pleasure for me to acknowledge the good cooperation we have had with the isotope laboratories involved in the present work: The Institute of Precambrian Geology and Geochronology in St. Petersburg, Russia (head Prof. Lev K. Levsky), 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 following papers information is given on what laboratory has been responsible for the isotopic analyses.

For the analytical procedure of the **Unit for Isotope Geology, Geological Survey of Finland,** the reader is referred to the following two publications:

SUOMINEN, V., 1991: The chronostratigraphy of southwestern Finland with special reference to Postjotnian and Subjotnian diabases. – Geological Survey of Finland Bulletin 356, 105 pp.

and

VAASJOKI, M., RÄMÖ, O.T. & SAKKO, M., 1991: New U-Pb ages from the Wiborg rapakivi area: constraints on the temporal evolution of the rapakivi granite-anorthosite-diabase dyke association of southeastern Finland. – Precambrian Research 51, 227– 243.

The analytical procedure of the **Laboratory for Isotope Geology in Stockholm** is, according to Dr. Per-Olof Persson, 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, 3.1 N HCl was added after which the solution was aliquoted. One aliquot was spiked with a ^{208}Pb tracer. The sample aliquots were loaded onto anion exchange columns with 50 ml resin volume for extraction of Pb and U, using HCl ion exchange technique. 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 ratios and the error propagation were made using the PBDAT program of Ludwig (1991a) and the decay constants recommended by Steiger and 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 and Kramers (1975). The mass fractionation for Pb is 0.1% per a.m.u. The mass fractionation for U was monitored and corrected for by means of the $^{233-235}U$ ratio of the spike. All analytical errors are given as 2σ.

The analytical procedure for titanite is similar to that of zircon with the exception of the ion exchange chemistry, where HBr- and HNO_3-steps are added.

The analytical procedure applied by the **Institute of Precambrian Geology and Geochronology in St. Petersburg** is summarized in the paper by Kornfält (p. 15).

REFERENCES

KROGH, T.E., 1973: A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determination. – Geochimica et Cosmochimica Acta 37, 485–494.

KROGH, T.E., 1982: Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique. – Geochimica et Cosmochimica Acta 46, 637–649.

LUDWIG, K.R., 1991a: PBDAT. A computer program for processing Pb-U-Th isotope data. Version 1.20. – Unites States Geological Survey, Open File Report 88–542.

LUDWIG, K.R., 1991b: ISOPLOT. A plotting and regression program for radiogenic-isotope data. Version 2.53. – Unites States Geological Survey, Open File Report 91.

STACEY, J.S. & KRAMERS, J.D., 1975: Approximation of terrestrial lead isotope evolution by a two-stage model. – Earth and Planetary Science Letters 26, 207–221.

STEIGER, R.H. & JÄGER, E., 1977. Convention on the use of decay constants in geo- and cosmochronology. – Earth and Planetary Science Letters 36, 359–362.

Acknowledgements: The authors want to thank the following co-workers at the Geological Survey of Sweden for their valuable help: Agneta Ek (editorial work), Barbro Landerborg (drawing of maps and diagrams) and Kerstin Finn (typing).

Uppsala, December 1995

Thomas Lundqvist

U-Pb zircon ages of granitoids in the Kårböle region, central Sweden

By
Hans Delin

INTRODUCTION

During the regional bedrock mapping of the northern Hälsingland area, central Sweden, a number of different granitoid bodies were defined (Delin 1989, Delin & Aaro 1991). Both their relative and absolute ages were in several cases unknown, and therefore five granitoids were sampled for U-Pb zircon dating. The results from one of these datings, concerning the Ljusdal granodiorite, has been reported in the previous volume of this publication (Delin 1993). Radiometric ages of the four other granitoids have been published in the short description of the geological map-sheets 16F Kårböle (Delin & Aaro 1991), and the results from these works will be more thoroughly dealt with here.

In the western parts of the Kårböle map-sheets the porphyritic Rätan granitoid intrusion is the predominant rock type. At the margin of this intrusion two different, similarly porphyritic granitoid bodies were recognized in the course of mapping. In older small-scale maps these granitoids were interpreted as a marginal facies of the Rätan intrusion, though somewhat different in composition (Lundegårdh 1967, Lundqvist 1968, Lundegårdh et al. 1984). In recent works (Delin & Aaro 1992) these granitoids were observed to differ from the Rätan type granitoid, both petrographically and structurally. As they also showed markedly different geophysical properties (magnetic and radiometric), the two granitoid bodies finally became regarded as belonging to a generation of intrusions, apart from that of the normal Rätan granitoid. In order to verify these thoughts, U-Pb zircon analyses were carried out on three samples of the rock types above, including one from the true Rätan granitoid.

In the southwestern corner of the map-sheet Kårböle SV a felsic, undeformed granite was recognized during the recent mapping. It is located between the post-orogenic Rätan granitoid intrusion to the northeast and an older, early-orogenic intrusion (so-called Rullbo granite) to the southwest. Some general field relationships and the aeromagnetic structural pattern indicated that the felsic granite was possibly cross-cutting the margin of the Rätan granitoid, and could thus be considered to be younger than the latter. If true, these facts would have suggested that the felsic granite in fact belongs to the Dala Granite Group further west. To solve this local geological problem, a U-Pb zircon dating of the critical rock was carried out.

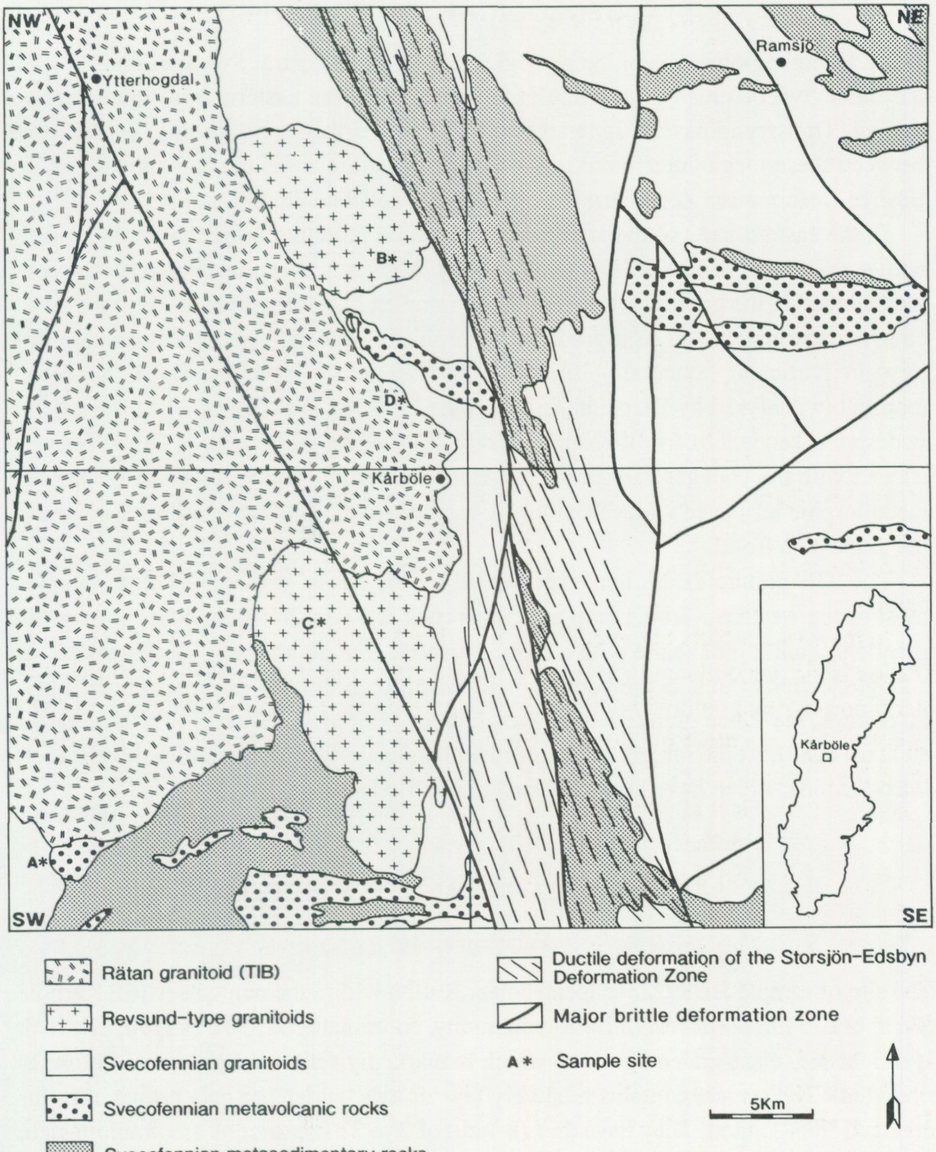


Fig. 1. Geological map of the map-sheet 16F Kårböle, simplified from Delin & Aaro (1992). A, B, C and D refer to dating samples HD 89223, LK 88127, BW 89014 and LK 89341, respectively.

GEOLOGICAL SETTING

The Kårböle region is one of the geological key areas in central Sweden (Fig. 1). Here the older Svecofennian rock complex connects with the eastern front of the cross-cutting Transscandinavian Igneous Belt (TIB). Furthermore, in the border area between these mega-units, there is a major deformation zone, the so-called Storsjön-Edsbyn Deformation Zone, striking roughly in a north-south direction.

In the eastern parts of the area the large Ljusdal granitoid intrusion predominates, with a zircon age of 1843±2 Ma (Delin 1993). A great deal of metasupracrustal rocks are included in the granitoid, and the whole complex has been affected by strong, penetrative deformation and high-grade metamorphism. The multi-phase deformation history, in particular concerning the Storsjön-Edsbyn Deformation Zone, has been thoroughly analysed by Bergman & Sjöström (1994). In the map-sheet Kårböle SV a widespread sequence of well preserved, supracrustal rocks of the Loos Group forms a contact with the younger TIB granitoids. Here the deformation is rather weak, and the metamorphic influence varies from low to medium grade (including a hornfelsic aureole at the TIB front).

The TIB granitoids are here represented by the Rätan granitoid, which occupies most of the western Kårböle map area. This rock is a very homogeneous, porphyritic granite to quartz monzonite with a high magnetite content, and it is clearly visible as a single, coherent unit in the aeromagnetic map. According to earlier radiometric U-Pb datings, the Rätan granite has an age of about 1700 Ma (Wilson et al. 1985, Patchett et al. 1987). At the margin of this intrusion there are two more granitoid bodies (cf. Introduction), which have been analysed in this study.

SAMPLES LOCATION AND DESCRIPTION

Felsic granite

The site of sample HD89223 is located near Rullbo within the map-sheet 16F Kårböle SV, about 15 km northwest of Loos community, coordinates 685380/145190. The rock is a light red, even-grained granite, which is markedly felsic and shows no deformation at all. The sample contains relatively few zircons, which are pale brown, translucent and fine-grained. They have an L/B ratio of 2 to 3. The zircons are uranium-rich, which is reflected by the fact that no significant fraction with a density higher than 4.3 could be separated.

Revsund-type granodiorite 1

Sample LK88127 was taken at Björnberget within the map-sheet 16F Kårböle NV, about 11 km north of Kårböle village, coordinates 688640/147090. This granodiorite is a light grey, porphyritic rock, with microcline phenocrysts in a relatively biotite-rich groundmass. It is slightly deformed, which is mostly indicated by mineral lineation, and the deformation is probably due to magmatic flow. The zircons of the sample are euhedral tetragonal prisms, terminating in simple pyramidal faces. Their L/B ratio varies from 1.5 to 4 with a median at about 2.5. Internal zonation, which is typical of magmatic zircons, has been observed in most grains. Older cores have not been detected.

Revsund-type granodiorite 2

Sample BW89014 was taken at Borrberget within the map-sheet 16F Kårböle SV, about 10 km southwest of Kårböle village, coordinates 686680/146690. The rock type is similar to that in the previous sample, i.e. a light grey, porphyritic granodiorite with microcline phenocrysts. However, here the phenocrysts are more heterogeneously distributed and there is no sign of deformation. In contrast to those from sample LK88127, the zircons are apparently heterogeneous.

Rätan granite

Sample LK89341 represents the eastern margin of the Rätan intrusion, and the sample site is located at Öjeforsen within the map-sheet 16F Kårböle NV, a few kilometers northwest of Kårböle village, coordinates 687870/147140. This rock is a greyish red, porphyritic granite to quartz-monzonite with numerous homogeneously distributed microcline phenocrysts. The zircons are developed as quite coarse (>150 μm), stubby pale brown crystals with typically magmatic, simple crystal faces and growth zoning.

AGE DETERMINATIONS

The U-Pb dating of zircons was carried out at the Unit for Isotope Geology, Geological Survey of Finland, under the supervision of Dr. Matti Vaasjoki. The results are displayed in Table 1 and Figs. 2–5.

Felsic granite

In sample HD89223, the four analysed zircon fractions form a relatively good linear trend with an MSWD of 15.8 (Fig. 2), suggesting some internal heterogeneity in the zircons. The data are, due to metamictization caused by the high uranium content, relatively discordant, the abraded fraction having a concordancy degree of 79.4%. Considering this, both the upper and lower intercept ages are fairly well defined at 1858±15 and 358±33 Ma, respectively. The age of the upper intercept may be regarded as the true age of emplacement, but the high MSWD suggests that the rock may

TABLE 1. U-Pb analyses, U/Pb ratios and apparent radiometric ages for zircons from the Kårböle map sheet area.

Sample	Fraction	Concentrations		Lead ratios, 206=100				Atomic ratios			Apparent ages (Ma)		
		^{238}U	$Pb_{(tot)}$	$^{206}Pb/^{204}Pb$	^{204}Pb	^{207}Pb	^{208}Pb	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	T (6/8)	T (7/5)	T (7/6)
Sample LK88127, Revsund-type granodiorite 1													
A	+4.5	308.3	96.22	11825	.0085	10.99	9.83	.2978	4.465	.1087	1680	1724	1778
B	4.3-4.5/+70µm	668.3	202.36	4451	.0224	11.18	8.71	.2905	4.355	.1087	1643	1703	1778
C	4.2-4.3	963.0	277.18	2867	.0349	11.27	8.97	.2748	4.088	.1079	1564	1652	1764
C	4.0-4.2	1297.4	331.29	2907	.0344	11.10	8.77	.2445	3.582	.1062	1410	1545	1734
Sample BW 89014, Revsund-type granodiorite 2													
A	4.3-4.5/abr 3h	749.8	208.65	3302	.0303	11.28	6.68	.2710	4.061	.1087	1545	1646	1777
B	4.3-4.5	803.0	224.86	5133	.0194	11.09	6.47	.2741	4.091	.1082	1561	1652	1770
C	4.2-4.3	1180.7	300.47	4236	.0236	10.93	6.24	.2498	3.654	.1061	1437	1561	1733
D	4.0-4.2	1765.2	402.40	3247	.0308	10.90	6.17	.2237	3.232	.1048	1301	1464	1710
E	4.3-4.5/abr 6h	733.4	219.60	5730	.0175	11.06	6.18	.2940	4.386	.1082	1661	1709	1769
Sample HD89223, felsic granite													
A	+4.2	870.7	217.14	3639	.0275	11.26	9.43	.2375	3.563	.1088	1373	1541	1779
B	4.0-4.2	1672.9	327.63	2166	.0462	11.03	10.48	.1846	2.646	.1040	1092	1313	1696
C	3.8-4.0	2773.6	523.42	1718	.0582	11.01	11.78	.1757	2.472	.1021	1043	1263	1662
D	+4.2/abr	753.7	220.74	2942	.0340	11.55	9.79	.2771	4.236	.1109	1576	1681	1814
Sample LK89341, Rätan granite													
A	+4.5/+70µm	233.5	78.15	890	.1123	11.92	20.17	.2869	4.105	.1038	1625	1655	1692
B	+4.5/abr	230.2	82.55	570	.1755	12.84	24.13	.2933	4.215	.1042	1657	1676	1700
C	4.2-4.3/+70µm	630.0	167.33	796	.1256	11.95	19.50	.2283	3.217	.1022	1325	1461	1664
D	4.3-4.5/+70µm	389.1	125.92	435	.2297	13.53	22.04	.2649	3.786	.1036	1515	1589	1690

Corrections in µg/g; corrected for blank. Atomic ratios for common lead. 6/4=15.7; 7/4=15.4; 8/4=35.2.

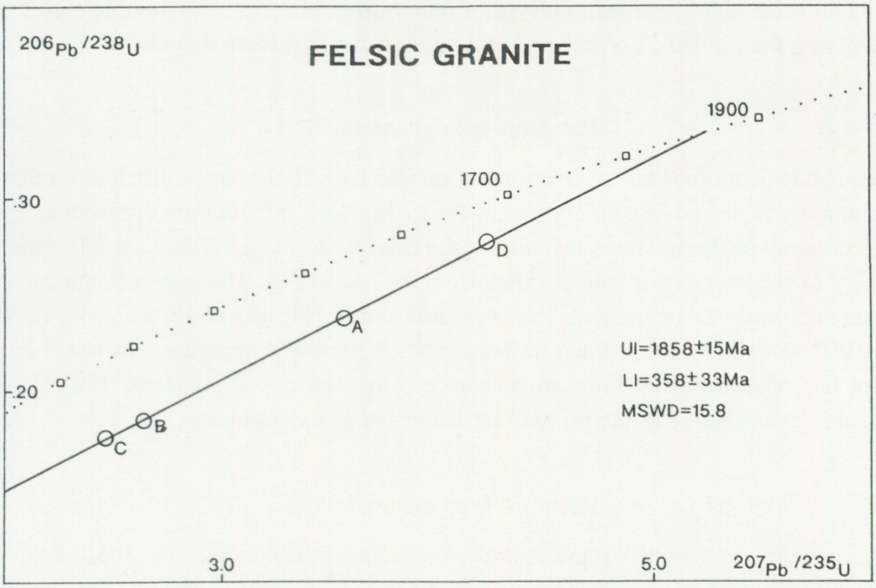


Fig. 2. Concordia diagram for analysed zircon fractions from the felsic granite, sample HD 89223.

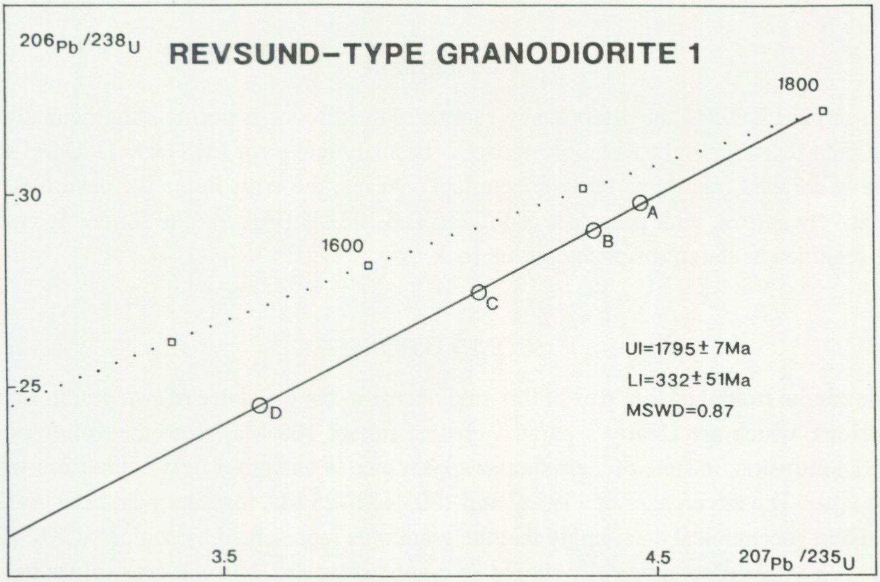


Fig. 3. Concordia diagram for analysed zircon fractions from the Revsund-type granodiorite 1, sample LK 88127.

contain some older, sediment-derived or remobilized material. Only whole rock work involving the Sm/Nd-, Rb/Sr- and U/Pb-systems could resolve this matter.

Revsund-type granodiorite 1

The results from four zircon fractions of sample LK88127 show a distribution that is commonly observed in primary magmatic rocks. Both the uranium contents and the discordancy of the fractions increase as the density decreases (Table 1). The concordancy of the analysed fractions varies from 91.3 to 71.4%. The age estimate derived from the upper intercept with the concordia curve (Fig. 3) is 1795±7 Ma. As the MSWD value for the fit is 0.87, no sample heterogeneity is apparent. The lower intercept has probably no geological relevance. Thus the upper intercept, 1795±7 Ma, should be considered as the primary intrusion age of the granitoid.

Revsund-type granodiorite 2

Though sample BW89014 represents a rock similar to the previous one, the zircons are apparently heterogeneous. The linear fit has a very high MSWD of 72.7 (Fig. 4). Thus the error estimates become very high, with the upper intercept at 1803 +31/-25 and the lower at 373 +159/-153. These results do not markedly differ from the more precise results from sample LK88127, so the upper intercept certainly represents the intrusion age of the granitoid.

Rätan granite

In sample LK89341 the discordancy pattern of the zircons is normal, but the analytical data reveal a slight variation in excess of analytical error (MSWD=11.1). As the heavy abraded fraction is fairly concordant , 96.7%, the error limits are nevertheless relatively narrow, with intercepts at 1702±6 and 202±58 (Fig. 5). The former age may be regarded as the intrusion age of the rock.

CONCLUSIONS

The results from the main part of this study confirm the existence of two granitoid intrusions, which are clearly separated in time (about 100 Ma) from the voluminous Rätan intrusion, in spite of their similar appearance to and close field connection with the latter. The zircon ages of 1795±7 and 1803 +31/-25 Ma, together with petrographical and geochemical data, imply that the granitoids represented by samples LK88127 and BW89014 chronologically should be compared to the Revsund granitoid suite. If so, these are the most southerly occurrences of Revsund-type granitoids at present. They also fit within the age range of older TIB granitoids, according to (Larson &

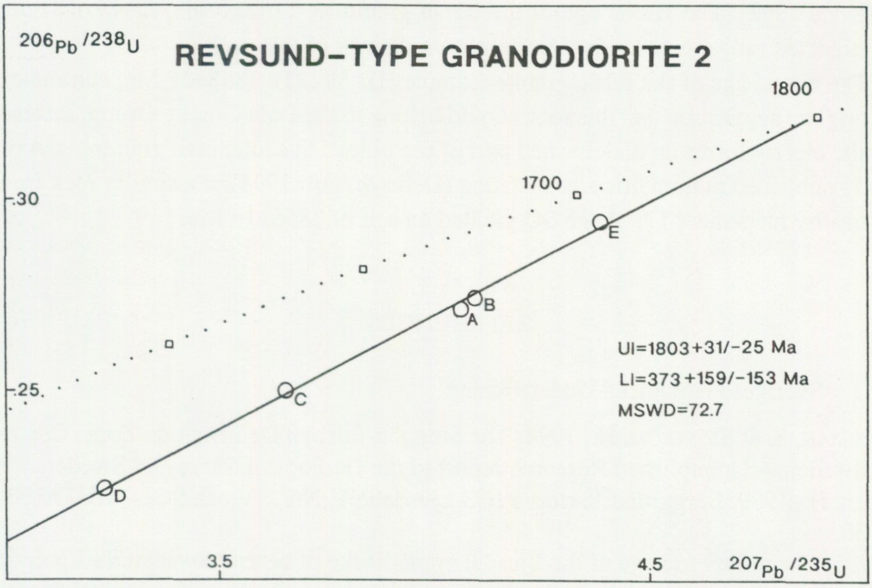


Fig. 4. Concordia diagram for analysed zircon fractions from the Revsund-type granodiorite 2, sample BW 89014.

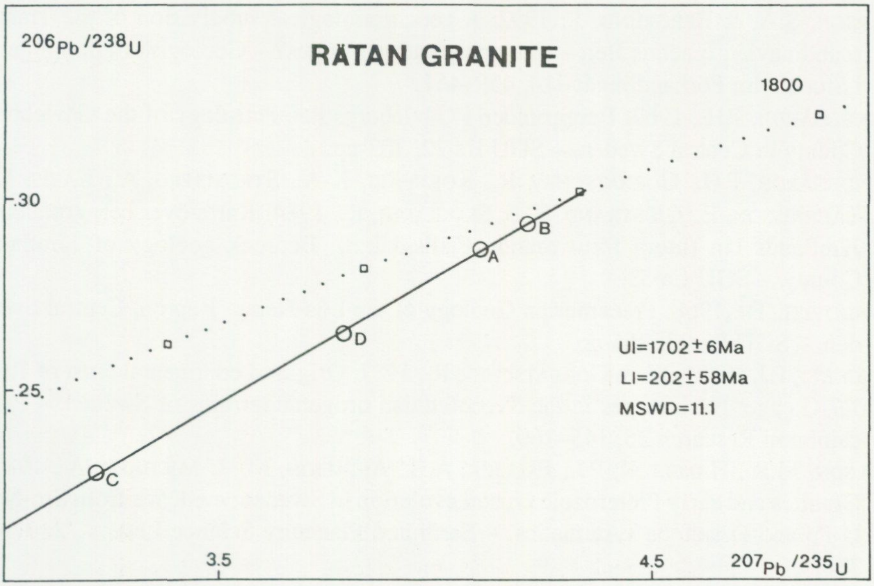


Fig. 5. Concordia diagram for analysed zircon fractions from the Rätan granite, sample LK 89341.

Berglund 1992). The zircon age of the Rätan granitoid, 1702±6 Ma, fits well within the expected range, considering earlier zircon datings of this rock.

The zircon age of the felsic granite (sample HD 89223), 1858±15 Ma, contradicts the original suggestion that this rock should belong to the Dala Granite Group. Instead, it quite clearly forms an undeformed part of the oldest, Svecofennian granitoids. A recently published radiometric zircon dating (Delin & Aaro 1994) of a similar rock from the nearby map-sheet 17F Ånge SO yielded an age of 1856±19 Ma.

REFERENCES

SGU = Sveriges Geologiska Undersökning

BERGMAN, S. & SJÖSTRÖM, H., 1994: The Storsjön-Edsbyn Deformation Zone, Central Sweden. – Unpublished Research report to the Geological Survey of Sweden.

DELIN, H., 1989: Berggrundskartorna 16G Ljusdal NV, NO, SV och SO. – SGU Ai 33–36.

– 1993: The radimetric age of the Ljusdal granodiorite of central Sweden. *In* Lunqvist (ed.): Radiometric dating results, Division of Bedrock Geology, Geological Survey of Sweden. – SGU C 823, 13–16.

DELIN, H. & AARO, S., 1992: Berggrundskartorna 16F Kårböle NV, NO, SV och SO. – SGU Ai 56–59.

– 1994: Berggrundskartorna 17F Ånge SV och SO. – SGU Ai 82–83.

LARSON, S.Å. & BERGLUND, J., 1992: A geochronological subdivision of the Transscandinavian Igneous Belt – three magmatic episodes? – Geologiska Föreningens i Stockholm Förhandlingar 114, 459–461.

LUNDEGÅRDH, P.H., 1967: Berggrunden i Gävleborgs län. Petrology of the Gävleborg County in Central Sweden. – SGU Ba 22, 303 pp.

LUNDEGÅRDH, P.H., GORBATSCHEV, R., KORNFÄLT, K-A., STRÖMBERG, A., KARIS, L., ZACHRISSON, E., SJÖSTRAND, T. & SKOGLUND, R., 1984: Karta över berggrunden i Jämtlands län (utom förutvarande Fjällsjö k:n). Bedrock geology of Jämtland County. – SGU Ca 53.

LUNDQVIST, TH.,1968: Precambrian Geology of the Los-Hamra Region, Central Sweden. – SGU Ba 23, 255 pp.

PATCHETT, P.J., TODT, W. & GORBATSCHEV, R., 1987: Origin of continental crust of 1.9–1.7 Ga age: Nd isotopes in the Svecofennian orogenic terrains of Sweden. – Precambrian Research 35, 145–160.

WILSON, M.R., HAMILTON, P.J., FALLICK, A.E., AFTALION, M. & MICHARD, A., 1985: Granites and early Proterozoic crustal evolution in Sweden: evidence from Sm-Nd, U-Pb and O isotope systematics. – Earth and Planetary Science Letters 72, 376–388.

Hans Delin, Sveriges geologiska undersökning, Box 670, S-751 28 Uppsala, Sweden.

U-Pb zircon ages of six granite samples from Blekinge County, southeastern Sweden

By
Karl-Axel Kornfält

BACKGROUND

As has been demonstrated in an earlier paper (Kornfält *in* Lundqvist 1993), no substantial age difference exists between the rocks north of the Småland–Blekinge zone (Småland granitoids), and the rocks south of it (Tving granitoids). They have both yielded ages of c. 1770 Ma, which means that the Tving granite can be looked upon as a variety of Småland granite. The Småland–Värmland intrusions belong to the Transscandinavian Granite-Porphyry Belt or the Transscandinavian Igneous Belt (TIB).

The existence of porphyritic Småland granites in the southern parts of Blekinge County, indicated by the U-Pb zircon dating of an alleged Filipstad granite at Torstäva (op. cit.), rises the question if there are more granitoid rocks in southeastern Blekinge which could be grouped among the Småland granites. In the region there also occur foliated fine-grained granites of unknown age. They could either belong to the Småland granites or to the c. 1400 Ma old Karlshamn granite suite. There are also foliated porphyritic granites resembling the Karlshamn granite as well as the porphyritic variety of Småland granite (the Filipstad granite). It was thus important for the interpretation of the regional geology to get more rocks dated in this region.

SAMPLES LOCATION AND DESCRIPTION

Foliated Karlshamn granite (sample KK 90:3)

Sample KK 90:3, from a road cutting 2.3 km NNE of Ramdala church (map-sheet 3F Karlskrona NO; coordinates in the National Grid: 623018/149878), is a greyish red, foliated Karlshamn granite. This granite is porhyritic with 1–2 cm large and rather sparsely occurring megacrysts of potash feldspar, thus differing from the common, isotropic Karlshamn granite which as a rule has larger and more densely spaced megacrysts of potash feldspar.

Two generations of zircon occur. The first generation is represented by very rare, clear transparent, light-yellow crystals with prismatic shape and unzoned structure. The grains sporadically contain small gaseous and mineral inclusions. Some crystals have fine rims (Figs. 1a, b). The zircons of the second generation are by far the most

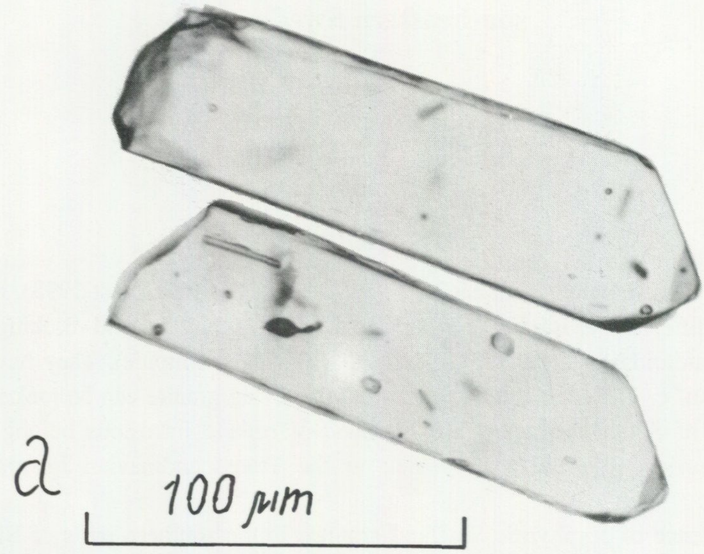


Fig. 1a. Zircon crystal of the first generation. From foliated Karlshamn granite (sample KK 90:3).

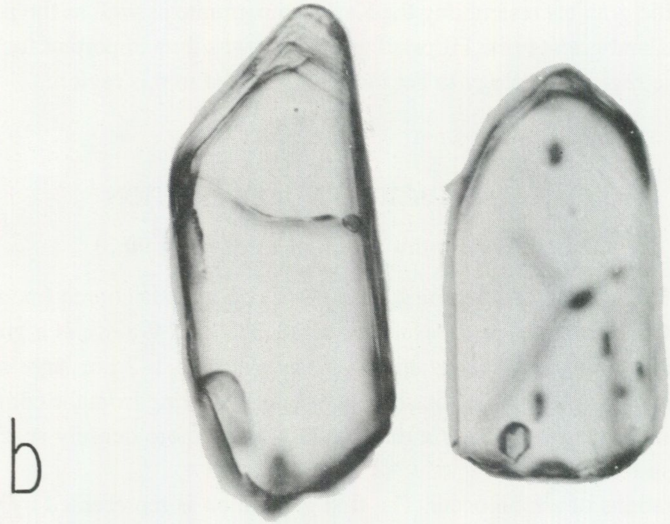
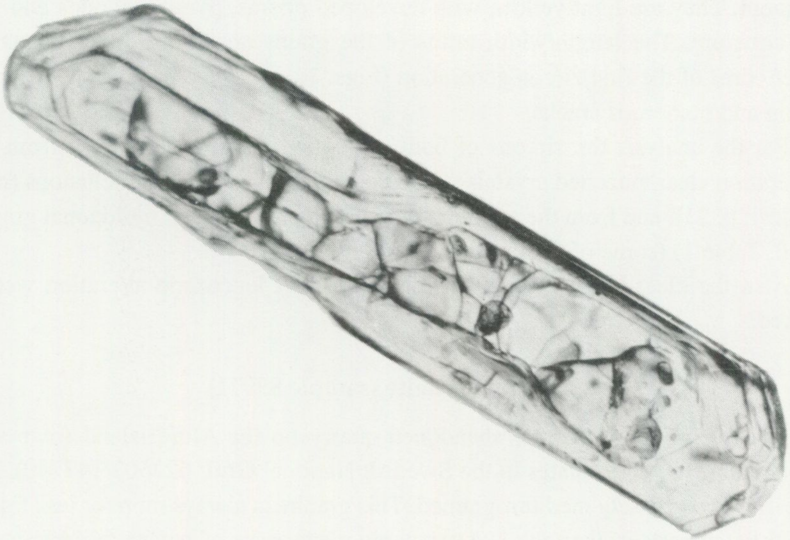
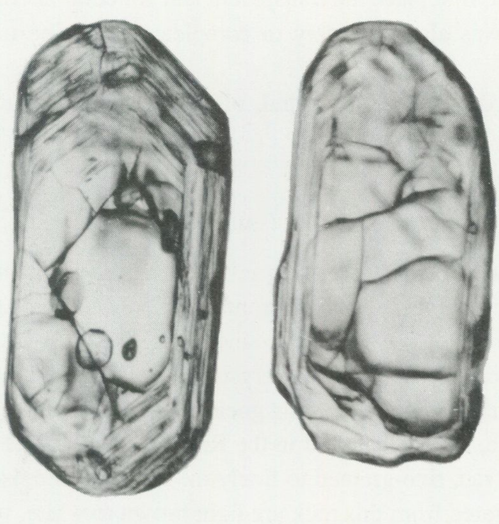


Fig. 1b. Zircon crystal of the first generation with fine second-generation mantles. From foliated Karlshamn granite (sample KK 90:3).



c



d

Figs. 1c and d. Multizonal zircon of the second generation with unzoned core of the first generation. From foliated Karlshamn granite (sample KK 90:3).

frequent. They are light yellow, with developed prisms, pyramidal ends and multizonal structure. The length/width ratios of the grains are 1–6. Some zircons contain inner cores of the first zircon generation (Figs. 1c, d). The cores have traces of dissolution and numerous cracks.

For the analysis the zircons of both generations were handpicked: from the first generation clear, unzoned crystals without mantles and with rare inclusions (nos. 1–3, Table 1, p. 21), and from the second generation the translucent multizonal grains (nos. 4–10, Table 1) (some of them may be with cores – no. 10).

Also the clear brown grains of titanite without leucoxene alteration were handpicked.

Almö granite (sample 89071)

Sample 89071, from a little, abandoned quarry on the Almö island (map sheet 3F Karlskrona NO; coordinates in the Swedish National Grid: 622503/147740), is red to greyish red and finely medium-grained. This granite is always more or less foliated. In less foliated parts of the rock 3–4 mm large megacrysts of potash feldspar are found. On weathered surfaces one can see stripes of narrow, red, parallel bands of potash feldspar alternating with dark grey bands of quartz.

Some of the zircons have outer rims which could be later overgrowths. The homogeneous grains were chosen for the analysis. Most of the zircons are white to colourless and turbid. Around 10 % of them are euhedral with pyramidal shape. In the rest the pyramid and prism edges are more or less rounded. The majority of the grains are short prismatic. In the first place the transparent and euhedral zircons were chosen for the analysis, but it was also necessary to complete with some turbid grains to get enough material.

The titanites are dark brown, anhedral, often fragmented. The grains chosen for analyses are clear and unaltered.

Rödeby granite (sample KK 93:35)

Sample KK 93:35 is from a road-cutting c. 2 km northwest of the little village of Rödeby (topographic map sheet 3F Karlskrona NO, coordinates 623884/148650 in the National Grid). This granite is medium-grained, largely isotropic, reddish grey with red, as a rule not so clearly defined megacrysts of potash feldspar. The granite has in general diffuse contacts to the surrounding gneissic granite (Tving granite). A few xenoliths of the latter are, however, found in the Rödeby granite. The latter is cut by dikes of red to greyish red, fine-grained to finely medium-grained, isotropic granite.

The zircons separated from this rock are light brown to white, with length/breadth ratios 2–3. They have as a rule pyramidal shape but a few are more rounded. Most zircons are strongly metamict, but there are also clear grains with only few cracks or no cracks at all. Among the latter the grains for the analysis have been selected. A number of those zircons were studied in high-refractive immersion liquid under the microscope. Most of the grains have either no internal structures or euhedral, magmatic zoning. A few have more distinct borders towards the marginal zones which might be interpreted as overgrowths. One grain has a rounded core and a zoned outher rim. The conclusion is that the occurrence of visible signs of overgrowths or cores is too subordinate to have an influence on the dating.

"Filipstad granite" (sample KK 93:36)

Sample KK 93:36, from a road-cutting at Torp in the southeastern part of the island of Senoren (map sheet 3F Karlskrona SO, coordinates 622104/149672 in the National Grid), is a reddish grey, medium-grained, porphyritic, weakly migmatized gneissic granite similar to the Filipstad granite. (Filipstad granite is a porphyritic variety of Småland granite). In this gneissic Filipstad granite the former large megacrysts and the matrix minerals have been crushed and the grain-size is now medium-grained. The potash feldspar megacrysts are sometimes elongated and form cm-wide, red bands alternating with black bands of biotite and amphibole.

The zircons are stubby, subhedral and very light brown in colour. The average grain size is c. 100 µm. Yellow crystals occurring in the lighter fractions were removed by hand-picking as they were too few to allow dating.

Tjurkö granite (sample KK 93:37)

Sample KK 93:37, from a very large abandoned quarry in the northern part of the island of Tjurkö (map sheet 3F Karlskrona SO, coordinates 622173/148828 in the National Grid), is a medium-grained, greyish red quartz-rich, foliated granite with a low content of mafic minerals. This granite has a structure defined by elongated clusters of dark quartz grains.

The zircons of the sample are rather uniform and average about 120 µm in size. They are turbid, but nevertheless a weak zonation can be observed. Morphologically they are subhedral prismatic to anhedral, as a rule with a light brown colour. There are also some reddish crystals which were removed by handpicking.

Jämjö granite (sample KK 93:38)

Sample KK 93:38, from a large abandoned quarry 2.2 km NW of Torhamn church (map-sheet 3F Karlskrona SO, coordinates 622047/150040 in the National Grid), is a finely medium-grained, red granite with a very weak structure defined by thin streaks of mafic minerals.

The zircons are rather uniform and average about 120 µm in size. They are turbid with increasing turbidity as the fractions become lighter. Morphologically the zircons are subhedral prismatic to anhedral, and generally light brown in colour. There are also some reddish crystals which were removed by handpicking. Some molybdenite was observed in the +4.5 g/cm^3 density fraction. The 4.3–4.5 fraction was so small that no analysis was possible. Instead, analyses were made on normal and abraded samples from the 4.2–4.3 fraction.

ANALYTICAL PROCEDURE

The analysis of sample KK 90:3 was carried out at the Institute of Precambrian Geology and Geochronology in St. Petersburg, Russia, under the supervision of Professor Lev K. Levsky. Dissolution and chemical separation of Pb and U were performed according to Krogh (1973). A highly enriched ^{208}Pb/^{235}U tracer was used for spiked samples. Blank lead was less than 200 pg and U less than 50 pg. To increase concordancy, some zircon fractions (nos. 2, 5, 7) and titanite (no. 11) were abraded. Moreover the fraction of no. 8 represents the residue from the preliminary treatment of the zircon grains of 75–85 μm size by HF acid at 200°C for 4 hours. The Pb data were corrected for fractionation with 0.13 % per atomic mass unit determined by analyses of the NBS-981 standard. All Pb and U isotopic ratios were measured in the static mode on a Finnigan MAT 261 mass spectrometer equipped with a 8-cup arrangement. Repeated analyses of zircon indicated that the uncertainties associated with U-Pb ratios were ±1.5 % for fractions of nos. 1–3, 7, 8 and 0.7 % for fractions of nos. 4–6, 9–11 at the two-sigma level. The isotopic composition of the initial common lead was estimated from the two-stage model of Stacey and Kramers (1975). Lead-loss lines were regressed using the program of Ludwig (1991).

The analyses of samples KK 89071 and KK 93:35 were performed by Per-Olof Persson at the Laboratory for Isotope Geology, Swedish Museum of National History, Stockholm (see editor's preface).

The analyses of samples KK 93:36, KK 93:37 and KK 93:38 were carried out at the Unit for Isotope Geology at the Geological Survey of Finland under the supervision of Matti Vaasjoki. References to the techniques used for the two latter laboratories can be found in the editor's preface.

The descriptions of the samples and isotopic results in the present paper are based on reports written by L.K. Levsky, P.-O. Persson and M. Vaasjoki.

Table 1. U-Pb zircon and titanite data from sample KK 90:3 of foliated Karlshamn granite.

no.	Fraction	Sample weight, mg	Concentrations		Observed atomic ratios			Calculated ratios		Age (Ma)
			U ppm	Pb ppm	206 Pb / 204 Pb	206 Pb / 207 Pb	206 Pb / 208 Pb	206 Pb / 238 U	207 Pb / 235 U	207/206
1	1g, 100-150, tr.	0.27	75.1	32.4	539.7	7.95237	0.75435	0.20484	2.8478	1640.0
2	1g, 100-150, tr., a	1.45	20.0	5.87	383.2	7.37766	4.10584	0.24710	3.4117	1627.0
3	1g, 85-100, tr.	0.59	63.4	27.2	433.2	7.62683	0.86581	0.21364	2.9396	1620.0
4	2g, 100-150	1.64	619.0	107.0	956.4	9.72446	7.53180	0.15988	1.94878	1391.3
5	2g, 100-150, a	3.55	806.0	202.0	171.3	5.89471	2.21277	0.16164	1.9714	1392.4
6	2g, 85-100	1.80	650.0	132.0	241.3	6.85029	3.82544	0.15595	1.9017	1392.1
7	2g, 85-100, a	0.46	92.0	25.3	507.6	8.45298	4.55084	0.23329	2.9319	1450.0
8	2g, 75-85, R	1.10	87.7	26.0	857.3	9.44800	4.08955	0.25128	3.1107	1421.0
9	2g, 60-75	1.62	704.0	122.0	801.9	9.49866	6.26359	0.15617	1.8956	1383.2
10	2g, 85-150, r, s. tr.	0.14	227.0	50.0	849.3	9.32742	5.99544	0.20530	2.5817	1450.9
11	Titanite, a	4.55	169.0	67.0	350.4	7.67311	1.51519	0.24490	3.0674	1443.3

1g, 2g -first and second zircon generations, + 100 - sieve fraction (µm).
tr. - transparent grains, s. tr. - semi-transparent (translucent) grains, r - rounded grains.
a- abraded grains of minerals, R - HF acid residue.

Table 2. U-Pb zircon and titanite data from samples 89071 (Almö granite) and 93:35 (Rödeby granite).

Size fraction (μm)	Weight (mg)	U (ppm)	Pb tot. (ppm)	Common Pb (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)
89071	**Almö granite**								
45-74	0.28	500.8	122.1	3.56	1792	80.6 - 8.2 - 11.2	0.2218±4	3.095±7	1646
45-74 abraded	0.09	470.8	134.1	2.03	3121	80.0 - 8.2 - 11.8	0.2607±5	3.688±9	1671
74-106	0.31	410.6	101.3	3.03	1730	80.2 - 8.2 - 11.6	0.2230±3	3.133±8	1659
74-106 abraded	0.16	278.7	84.5	0.69	5282	78.9 - 8.2 - 12.9	0.2757±5	3.975±9	1707
ti <106	0.27	213.3	76.5	6.45	490	64.6 - 5.9 - 29.5	0.2458±5	3.081±12	1444
ti 106-150	0.31	213.3	75.5	5.27	586	63.3 - 5.7 - 31.0	0.2417±5	3.012±14	1433
KK 93:35	**Rödeby granite**								
<74	0.105	483.8	105.3	1.28	3894	81.3 - 8.4 - 10.3	0.2032±4	2.877±11	1673
<74 abraded	0.054	346.3	96.5	3.13	1515	80.9 - 8.5 - 10.6	0.2535±5	3.665±17	1712
74-106	0.079	358.4	87.0	1.52	2663	82.5 - 7.9 - 9.6	0.2252±6	3.234±13	1699
74-106 abraded	0.073	307.1	86.6	0.20	10416	80.8 - 8.6 - 10.6	0.2643±6	3.858±15	1729

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

Table 3. U-Pb zircon data from sample KK 93:36 of "Filipstad granite" from Senoren.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected	207/235 for blank	206/207	Apparent age in Ma 6/8	7/5	7/6
A	+4.5/abr	222.0	68.83	1875	.2835	4.111	.1052	1609	1656	1717
B	+4.5	284.6	81.05	843	.2515	3.566	.1028	1446	1542	1676
C	4.3-4.5	607.2	138.97	358	.1829	2.493	.0988	1083	1269	1602
D	4.2-4.3	1682.0	405.09	97.7	.1244	1.552	.0905	755	951	1436

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

Table 4. U-Pb zircon data from sample KK 93:37 of Tjurkö granite.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected	207/235 for blank	206/207	Apparent age in Ma 6/8	7/5	7/6
A	+4.3/abr	1101.8	173.75	1106	.1457	1.921	.0957	876	1088	1541
B	+4.3	1110.0	159.08	906	.1309	1.715	.0951	792	1014	1529
C	4.2-4.3	1720.4	194.33	676	.1023	1.272	.0902	627	833	1429
D	4.0-4.2	2168.5	218.57	298	.0814	0.984	.0877	504	695	1375

Common lead correction: 6/4:15.7; 7/4:15.4; 8/4:15.2

Table 5. U-Pb zircon data from sample KK 93:38 of Jämjö granite from Gisslevik.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected	207/235 for blank	206/207	Apparent age in Ma 6/8	7/5	7/6
A	+4.5/abr	198.2	67.03	1919	.2929	4.291	.1062	1656	1691	1736
B	+4.5	341.5	82.86	1535	.2181	3.047	.1013	1272	1419	1648
C	4.2-4.3/abr	1869.6	233.72	303	.1024	1.241	.0879	628	819	1380
D	4.2-4.3	1853.9	212.87	421	.1000	1.207	.0876	614	804	1372

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

ISOTOPIC RESULTS

Analytical results are presented in Tables 1–5 and plotted in the figures.

Foliated Karlshamn granite (sample KK 90/3)

The numbering of the different fractions in the text and in Table 1 is consistent with that of the sample points in Fig. 2.

The zircon of the first generation differs from the second one by the lower contents of U, and older age. The zircon fractions of both generations display different degrees of discordance which is due to Pb-loss. The fraction no. 8 has concordant ages. Titanite (no. 11) is characterized by nearly concordant ages.

In the concordia diagram analytical data define two regression lines. A regression line through three fractions (nos. 1, 2, 3) of the first generation yields a discordia line (MSWD = 1) with intercept ages of 1620±44 Ma and -57±264 Ma. With the exception

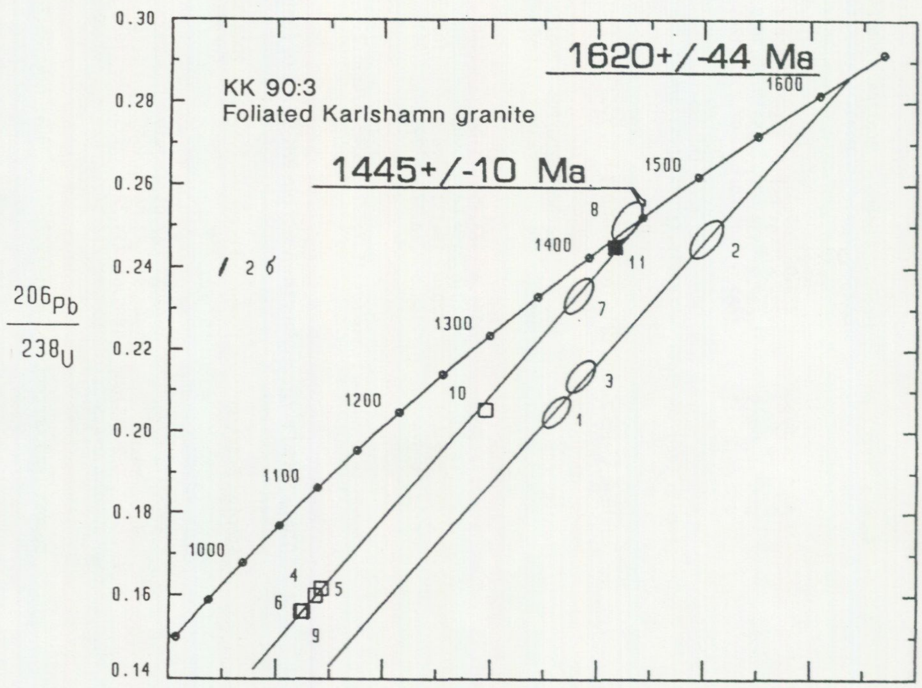


Fig. 2. U-Pb concordia diagram for zircon and titanite from the foliated Karlshamn granite (sample KK 90:3).

of fraction no. 10, eight points of second zircon generation (nos. 4, 5, 6, 7, 8, 9) and of titanite (no. 11) lie on a best-fit line (MSWD =2.5) giving intercept ages of 1445±10 Ma and 154±26 Ma.

Almö granite (sample 89071)

Four fractions of zircon were analysed (Table 2). The points do not fall on a perfect straight line but show a great scatter. They form a linear trend (MSWD = 36) on a concordia diagram (Fig. 3) which results in upper and lower intercepts at 1716+105/-59 Ma and 305±395 Ma, respectively. Some of the zircons had rims which could be later overgrowths. The grains chosen for the analysis looked homogeneous, however. There might nevertheless be a heterogeneity in the zircons, which cannot be observed optically. Another explanation of the scatter could be a complex lead-loss history, i.e. lead-loss at several, separate occasions.

Two fractions of titanites were analysed (Table 2). The points are not concordant and plot near each other. The uncertainty in the intercept age is therefore rather large,

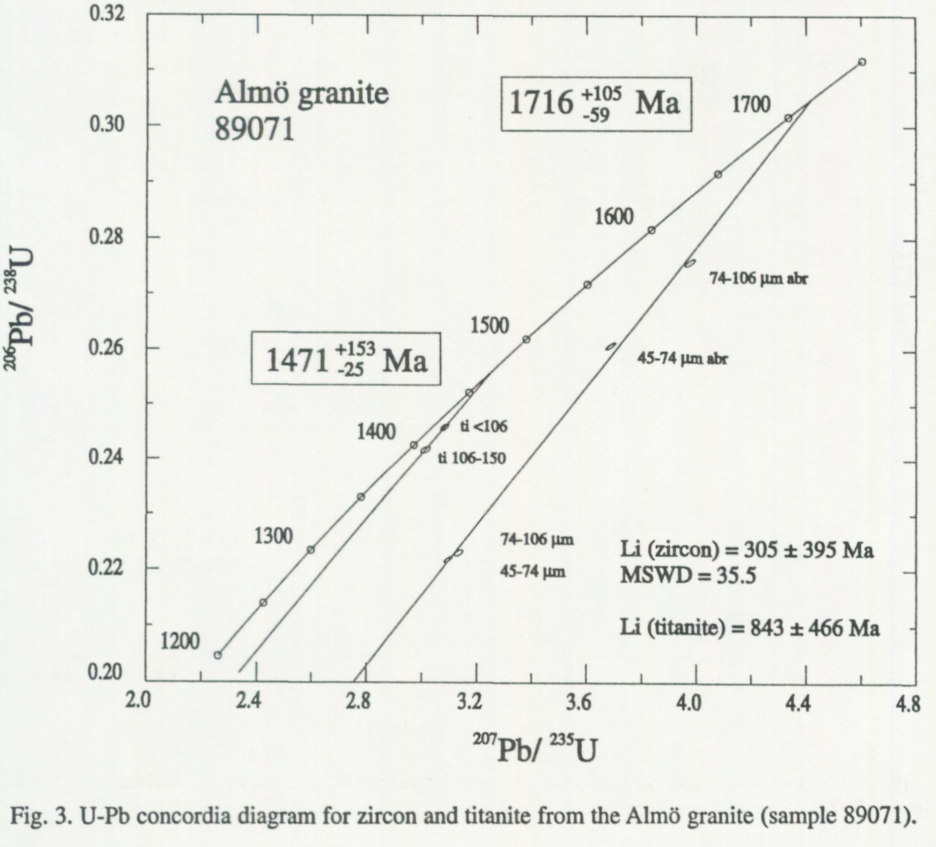


Fig. 3. U-Pb concordia diagram for zircon and titanite from the Almö granite (sample 89071).

especially upwards. The plots form a linear trend which results in upper and lower intercept ages at 1471+153/-25 Ma and 843±466 Ma, respectively. It is possible that some lead has been leached out during the washing of the titanites in warm HNO_3 and HCl. This can, however, not be the major cause of the discordancy, since the lower intercept would then have been close to zero.

Rödeby granite (sample KK 93:35)

Four fractions were analysed (Table 2). The zircons chosen for analysis were of good quality and two of the fractions were furthermore abraded. Nevertheless, the data points are relatively discordant. The points do not fall on a perfect straight line, perhaps owing to some heterogeneity within the zircons or to polyphase disturbance. Within the margins of error all points, however, do fall on the discordia. The upper and lower intercept ages are 1751+41/-33 Ma and 250±160 Ma, respectively (Fig. 4). The upper intercept age can be interpreted as the crystallization age of the rock.

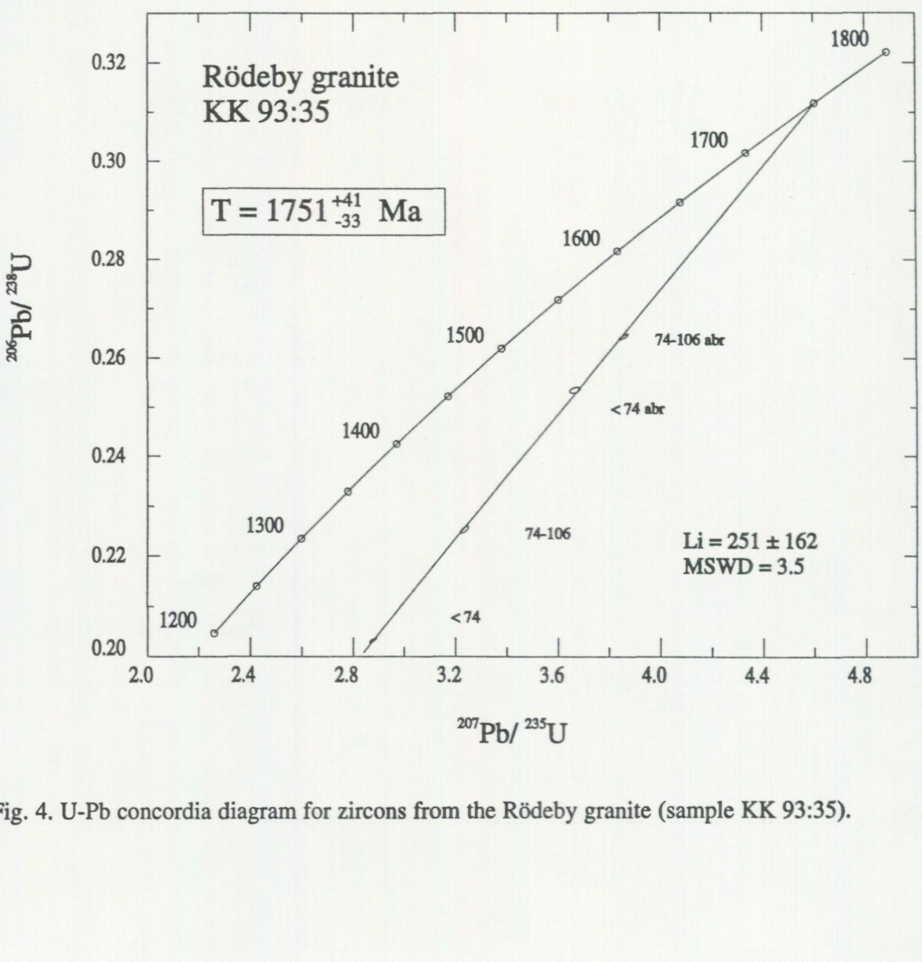


Fig. 4. U-Pb concordia diagram for zircons from the Rödeby granite (sample KK 93:35).

"Filipstad granite" (sample KK 93:36)

The results (Table 3) demonstrate the usual discordancy pattern, i.e. the discordancy increases with increasing uranium content and decreasing density. A striking feature in the data is the extremely high common lead contents of fraction D, which has one of the lowest $^{206}Pb/^{204}Pb$ ratios Matti Vaasjoki has ever measured in zircons. This particular analysis is, consequently, very dependent on the common lead correction. However, as the $^{206}Pb/^{204}Pb$ ratio of fraction A is quite high, the upper intercept age of 1724±39 Ma (Fig. 5) is independent of the common lead value used. The lower intercept age is 322±162 Ma. The high error estimate is a result of a very high MSWD value of 52, which suggests that there may be zircons from several sources in the analyzed fractions. Excluding the abnormal fraction D from the calculation does not significantly alter the result.

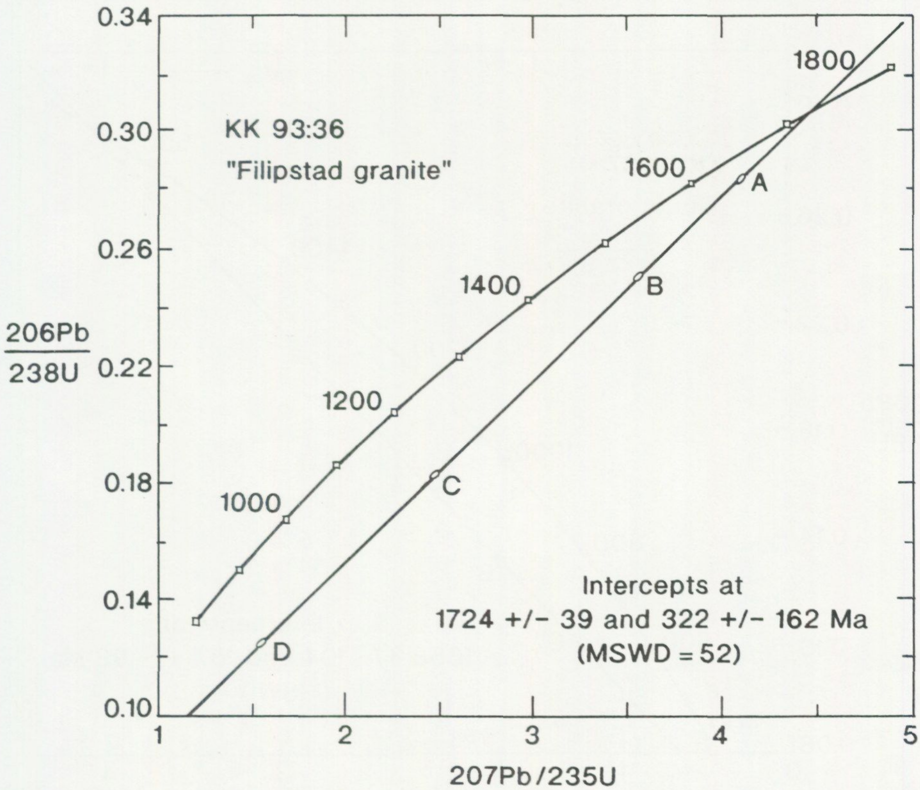


Fig. 5. U-Pb concordia diagram for zircons from the "Filipstad granite" (sample KK 93:36).

Tjurkö granite (sample KK 93:37)

The analysed zircons (Table 4) exhibit increasing discordancy with increasing uranium content and decreasing density. The uranium contents in the samples are very high, ranging from 1100 to 2200 ppm, and consequently their degree of discordancy is very high. With such discordant data it is virtually impossible to obtain an exact age result. It is not sure that the very high MSWD (=110) of this analysis reflects multiple sources for the zircons. It may as well be the result of extreme lead loss. The upper intercept age of 1658±104 Ma (Fig. 6) should consequently be regarded only as indicative. The lower intercept age is 187±93 Ma.

Jämjö granite (samle KK 93:38)

The zircons exhibit the usual trend of increasing discordancy with increasing uranium content and decreasing density. Their uranium contents are very variable, ranging from 200 to 1850 ppm, and consequently the variation in their degree of discordancy is very

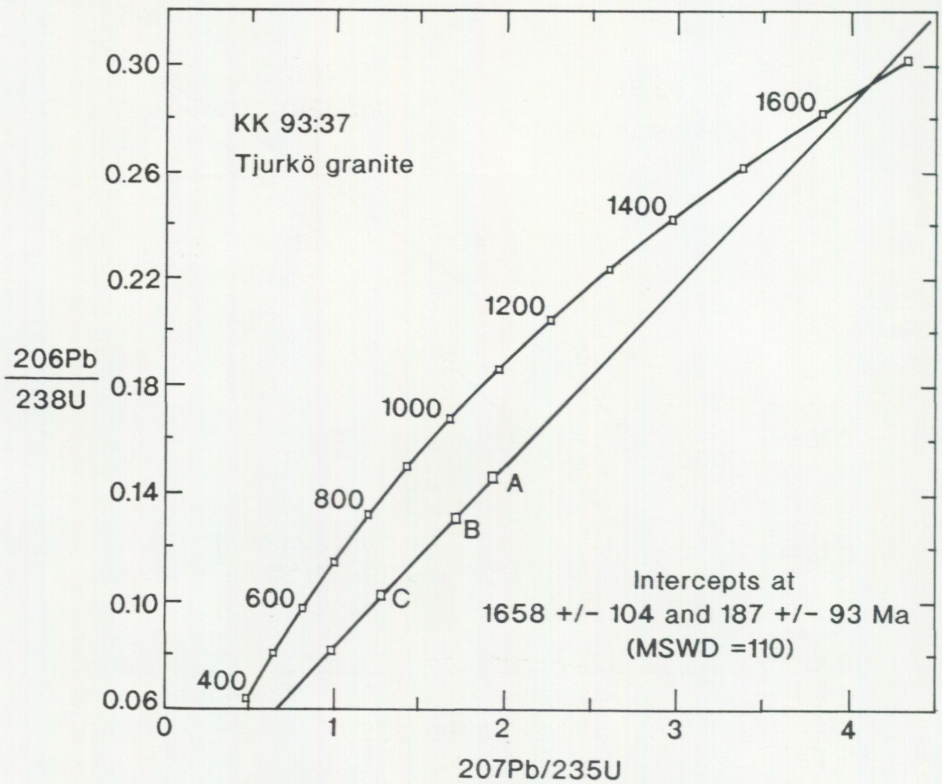


Fig. 6. U-Pb concordia diagram for zircons from the Tjurkö granite (sample KK 93:37).

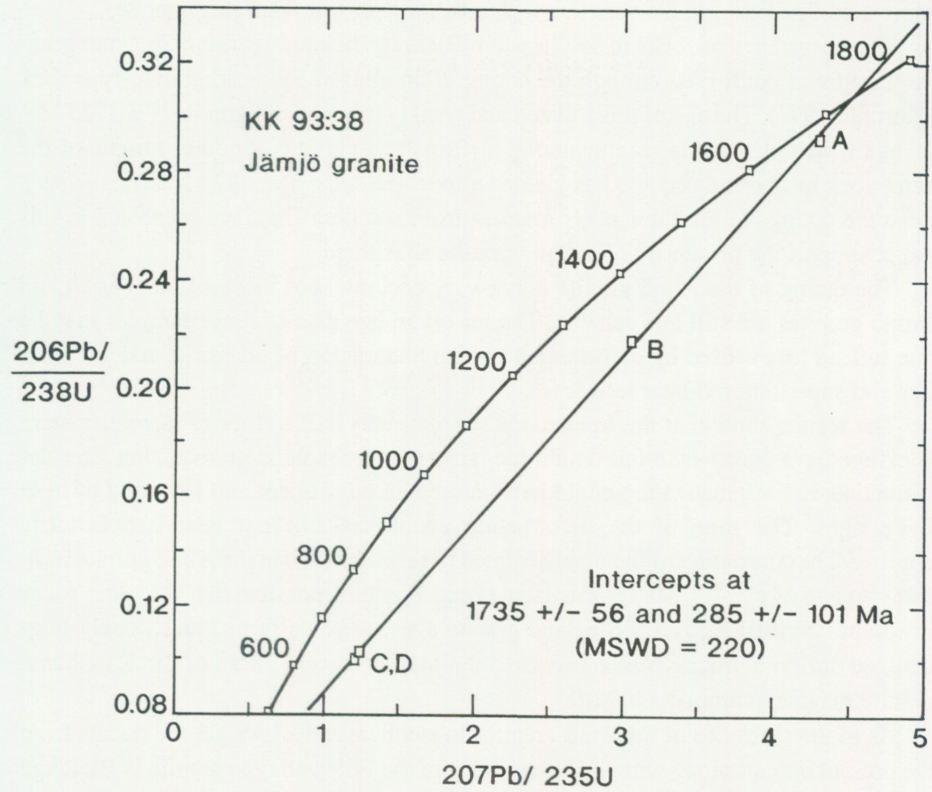


Fig. 7. U-Pb concordia diagram for zircons from the Jämjö granite (sample KK 93:3).

large (Table 5). As the 4.2–4.3 fractions are very discordant, it is virtually impossible to obtain an exact age result. Moreover, the very high MSWD (=220) in this case does not necessarily reflect multiple sources for the zircons, but may as well be the result of extreme lead loss. Thus the upper intercept age of 1735±59 Ma (Fig. 7) should be regarded only as indicative. The lower intercept age is 285±101 Ma.

DISCUSSION

The age of the Rödeby granite, c. 1751 Ma, can be interpreted as a rough estimate of the crystallization age of the rock. The granite can thus be regarded as a variety of Småland granite. The Rödeby granite is surrounded by the 1767-1769 Ma old (Kornfält 1993) Tving granite, which is the dominating rock of the region. The contacts between the two rocks are as a rule very diffuse, which excludes a tectonic contact. The Rödeby granite is thus an example of the existence of somewhat younger and more acid Småland granite varieties within the domains of the Tving granite.

The occurrence of rocks in southeastern Blekinge belonging to the Småland granite group was confirmed through the dating of an alleged Filipstad granite-type rock (Kornfält 1993). The age of this foliated and weakly migmatized granite is c. 1723 Ma, an age which places this granite among the Småland granites. Another sample of the same rock has been dated and has yielded almost the same age, 1724 Ma (this paper). Also the datings of the three other granites from southern Blekinge presented in this paper support the presence of Småland granite ages there.

The dating of the Almö granite is not very accurate, but those of the Tjurkö and Jämjö granites are still less reliable. The uncertain age data of these samples may be due to lead loss caused by deformation and migmatization of original Småland granites and superimposed later lead loss.

The results show that the foliated and in part recrystallized rocks in southeastern Blekinge have ages which fall within the range of the Småland granites, but later deformation and migmatization could have caused an adjustment and lowering of their U-Pb ages. The time of the deformation event has still not been satisfactorily approved, but the dating of the newly formed or reset titanites in the Almö granite indicates an age of c. 1471 Ma for this later event. It is thus possible that the older rocks in southeastern Blekinge (of Småland granite ages) were deformed and weakly migmatized during a process which preceded the main intrusion phase of the Karlshamn granite magma at around 1400 Ma.

As to the existence of Småland granites in southeastern Blekinge, the results from the present datings along with the older dating of the Filipstad type granite in Blekinge can verify this. Southeastern Blekinge can thus be regarded as a part of the Transscandinavian Igneous Belt (TIB) which has been affected by deformation, and in part migmatization, in the interval c. 1750–1400 Ma. The Småland-Blekinge zone thus does not constitute a major tectonic southern border for the TIB rocks but rather the approximate northern limit of penetrative deformation affecting the TIB complex.

ACKNOWLEDGEMENT

I wish to thank Per-Olof Persson for comments and improvements of the manuscript.

REFERENCES

KORNFÄLT, K.-A., 1993: U-Pb zircon ages of three granite samples, from Blekinge County, south-eastern Sweden. *In* Lundqvist, Th., (ed.), 1993: Radiometric dating results. Division of Bedrock Geology, Geological Survey of Sweden - Sveriges geologiska undersökning C 823.

KROGH, T., 1973: A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determination. Geochimica et Cosmochimica Acta 37:485-494.

LUDWIG, K. R., 1991: A Computer program for Processing Pb-U-Th Isotope Data, version 1.20. - United States Geological Survey Open-file Report 88-542.

LUNDQVIST, TH., (ed.), 1993: Radiometric dating results. Division of Bedrock Geology, Geological Survey of Sweden - Sveriges geologiska undersökning C 823.

STACEY, J. S. & KRAMERS, J. D., 1975: Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Science Letters 26: 207-221.

Karl-Axel Kornfält, Sveriges geologiska undersökning, Kiliansgatan 10, S-223 50 Lund, Sweden.

Preliminary note on the occurrence of Archaean rocks in the Vallen-Alhamn area, northern Sweden

By
Thomas Lundqvist, Matti Vaasjoki and Torbjörn Skiöld

The Precambrian bedrock of the Vallen-Alhamn area on the coast of the Bothnian Gulf between the towns of Luleå and Piteå (cf. Fig. 1, p. 49, in this volume) was investigated by Åhman (1953). A map of the area in scale 1:20,000 was also presented. An older complex, named Svecofennian, embraced felsic and mafic volcanic rocks, conglomerates, mafic intrusive rocks of various ages as well as "gneiss" and "Revsund granite". A younger complex including black slate, arkose, conglomerate, younger dike porphyry and "late Karelian granite" was ascribed to the so-called Karelian orogenic cycle, at that time considered to postdate the Svecofennian orogeny.

Since the 1950s the chronological subdivision of the Precambrian of Sweden has been radically changed as a result of the introduction of radiometric dating methods. The bedrock of the Vallen-Alhamn area is now thought to be underlain mainly by rocks related to the Palaeoproterozoic Svecofennian (or Svecokarelian) orogeny (NSG 1990). However, the presence of Archaean complexes on the Finnish coast of the Gulf of Bothnia, c. 150 km east of Vallen-Alhamn (Simonen 1980a, b), raises the question whether these complexes could extend as far west as the Swedish coast areas.

Radiometric dating of zircons by the U/Pb method was therefore, within the frame of the inter-Nordic Mid-Norden Project, carried out on five granitoid samples from the Vallen-Alhamn area: the "Svecofennian gneiss", the "Revsund granite" (in fact an augen-bearing foliated granodiorite), two tonalite clasts in the "Karelian" conglomerate on the shore at Fagervik and one tonalite to granodiorite clast in the "Karelian" conglomerate on Mittihedberget (Mitthedberget), Vallen (cf. map of Åhman 1953). The former two analyses were carried out at the Unit for Isotope Geology, Geological Survey of Finland by M. Vaasjoki and the latter three at the Laboratory for Isotope Geology, Stockholm, by T. Skiöld. The results indicate an Archaean age of 2710±3 Ma for the "Svecofennian gneiss", and an Archaean, but due to a heterogeneous zircon population imprecise age for the augen-bearing foliated granodiorite. The two conglomerate clasts from Fagervik yielded c. 2710 Ma and c. 1900 Ma, respectively. The clast from Mittihedberget, which is similar in modal composition, structure and texture to the sampled augen-bearing foliated granodiorite from Vallen, yielded 2655±4 Ma.

The results prove the presence of exposed Archaean rocks near the south-eastern end of the Luleå–Jokkmokk zone, viz the Archaean–Proterozoic palaeoboundary of Öhlander et al. (1993). Furthermore these Archaean rocks have been exposed to weathering and have become included in the conglomerate at Fagervik. The deposition of this conglomerate occurred after 1900 Ma, as tonalitic clasts of this age also occur.

C. 20 km north of Vallen-Alhamn occurs the so-called Bälinge conglomerate (Åhman and Ödman 1952; Ödman 1957), which has recently been reinterpreted as a magmatic hydraulic breccia (Wikström *et al.* 1993). A similar interpretation of the conglomerate on Mittihedberget, Vallen, may be valid (Anders Wikström, Uppsala, personal communication 1994). Therefore, the correlation of the Mittihedberget rock with the conglomerate at Fagervik is doubtful. As to their chronological position the former clearly postdates 2655 Ma, the latter, 1900 Ma.

REFERENCES

ÅHMAN, E., 1953: Vallen-Alhamnområdet i Nederluleå s:n. Summary: The Vallen–Alhamn area, parish of Nederluleå, North-Eastern Sweden. – Sveriges geologiska undersökning C 529, 21 pp.

ÅHMAN, E. & ÖDMAN, O.H., 1952: Konglomeratet på Bälingsberget i Nederluleå s:n. – Sveriges geologiska undersökning C 523, 20 pp.

NSG (Nämnden för statens gruvegendom; State Mining Property Commission), 1990: Digitalisering av geoinformation från Norrbotten (av T. Sjöstrand). – FoU-program för utökad prospektering, slutrapport 30 september 1990.

ÖDMAN, O.H., 1957: Beskrivning till berggrundskarta över urberget i Norrbottens län. Map to the scale of 1:400 000. – Sveriges geologiska undersökning Ca 41, 151 pp.

ÖHLANDER, B., SKIÖLD, T., ELMING, S.-Å., BABEL WORKING GROUP, CLAESSON, S. & NISCA, D., 1993: Delineation and character of the Archaean-Proterozoic boundary in northern Sweden. – Precambrian Research 64, pp. 67–84.

SIMONEN, A., 1980a: The Precambrian in Finland. – Geological Survey of Finland Bulletin 304, 58 pp.

SIMONEN, A., 1980b: Prequaternary rocks of Finland. Map to the scale of 1:1 000 000. – Geological Survey of Finland.

WIKSTRÖM, A., MELLQVIST, C. & BARBARIN, B., 1993: The Bälinge conglomerate in northern Sweden reinterpreted as a magmatic, hydraulic breccia. – EUG VII, Strasbourg, Abstracts 5.

Thomas Lundqvist, Sveriges geologiska undersökning, Box 670, S-751 28 Uppsala, Sweden.

Matti Vaasjoki, Geological Survey of Finland, FIN-02150 Espoo, Finland.

Torbjörn Skiöld, Laboratoriet för isotopgeologi, Naturhistoriska riksmuseet, Box 50007, S-104 05 Stockholm, Sweden.

U-Pb zircon dating of a quartz-feldspar porphyritic dyke in the Knaften area, Västerbotten County, northern Sweden.

By
Annika Wasström

INTRODUCTION

The granitoids in the Swedish part of the Bothnian Basin have traditionally been divided into a) the early-orogenic granitoids 1870–1880 Ma and down to 1840–1850 Ma (Claesson & Lundqvist 1990 and in press, Lundqvist *et al.* 1990, Welin *et al.* 1993, Weihed & Vaasjoki 1993, Delin 1993), b) late-orogenic, S-type, granites 1800–1820 Ma (Lundqvist *et al.* 1990, Claesson & Lundqvist 1995, Lindström *et al.* 1991, Romer & Smeds 1994), c) postorogenic granitoids 1770–1800 Ma (Claesson & Lundqvist 1990) and d) anorogenic rapakivi granitoids 1510–1580 Ma (Welin & Lundqvist 1984, Welin 1994). In the Skellefte Field, the early-orogenic granitoids are 1860–1890 Ma (Wilson *et al.* 1987, Weihed & Schöberg 1991, Weihed & Vaasjoki 1993).

The Knaften granitoids are texturally different from other granitoids in the region. They are often porphyritic, have a more sub-volcanic character and are unfoliated. Their contact relationships with other rock types were not well known when the granitoid was sampled and dated to 1954±6 Ma (Wasström 1993). At that time this was the oldest known granitoid in the Svecofennian of Sweden. Later, two granodiorites have been dated to c. 1930 Ma at the Unit for Isotope Geology, Geological Survey of Finland (Thomas Lundqvist, personal communication). There is also a somewhat uncertain age of a foliated granite near Sundsvall (2030±6 Ma; Welin *et al.* 1993).

The Knaften granitoids form two complex domes. In the vicinity of the domes, there are quartz-feldspar porphyritic dykes that intersect the basic-intermediate volcanic rocks. The dykes are interpreted to be associated with the domes. As they also clearly intersect the volcanic rocks (deformed pillow lavas) they can provide a minimum age for the supracrustal rocks in the Knaften area.

As a part of the bedrock mapping programme of the Geological Survey of Sweden a U-Pb zircon age determination of a quartz-feldspar porphyritic dyke was carried out. The analysis was made at the Unit for Isotope Geology at the Geological Survey of Finland (GTK) under the supervision of Matti Vaasjoki.

REGIONAL GEOLOGY

The Knaften area (Fig. 1) is situated in the northern part of the Svecofennian Bothnian Basin, about 50 km south of the Skellefte Field. The area is dominated by basic-intermediate volcanic and volcaniclastic rocks intercalated with greywackes (Wasström 1989, 1990). The supracrustal rocks were intruded by the Knaften granitoids at 1954±6 Ma (Wasström 1993). The granitoids are chemically associated with porphyritic dykes and some reworked tuffitic acid sedimentary rocks. Later, basic–ultrabasic sills were intruded between the basic–intermediate volcanic rocks and the tuffitic acid sedimentary rocks, and also into the volcaniclastic rocks. The whole complex was folded and metamorphosed at amphibolite facies conditions about 1820–1850 Ma ago (Lindström *et al.* 1991). At 1770–1800 Ma (Claesson & Lundqvist 1990, 1995) large areas in this region were intruded by postorogenic granitoid intrusions belonging to the Revsund suite. These granitoids surround most of the Knaften area, which makes correlation with other supracrustal rocks in the region difficult. Later, at 1200–1250 Ma, anorogenic dolerite dykes intruded (Lundqvist & Samuelsson 1973, Welin & Lundqvist 1979, Lundqvist *et al.* 1990).

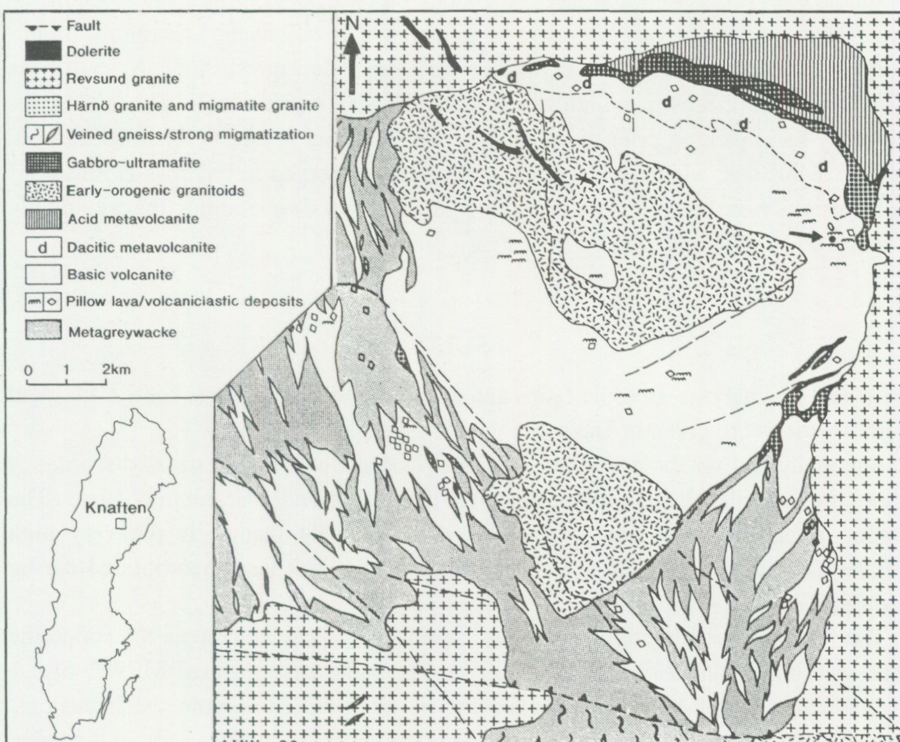


Fig. 1. Geological map of the Knaften area and location of the age determined quartz-feldspar porphyry dyke. Arrow with dot (in right part of map) indicates sample location.

SAMPLE DESCRIPTION

The quartz-feldspar porphyritic dyke (map-sheet 22I Lycksele, National Grid coordinates 715573/164220) is light grey and displays a cross-cutting contact relationship to the host basic volcanic rock, a strongly deformed pillow lava. The contacts and the shape of the dyke are very irregular. The quartz phenocrysts are 1-3 mm, euhedral to subhedral and occasionally contain resorption embayments. They form less than 10 % of the total rock volume. The feldspar phenocrysts are hard to recognize because they are altered, but seem to be less frequent than quartz. All phenocrysts are sometimes strained, polycrystalline and may occur in clusters. The grain size of the matrix is <0.2 mm. Mineralogically the porphyry contains 40–45 % quartz, 20-30 % K-feldspar, 20 % plagioclase, 5 % biotite-chlorite and 5 % muscovite. Accessory minerals are amphibole (hornblende), opaque minerals, Fe-hydroxides(?), zircon, sphene, rutile(?), calcite, apatite and epidote. The dyke is cut by some quartz-filled fractures.

The zircons separated from this rock are (according to a report written by Matti Vaasjoki, Geological Survey of Finland) pale brown and generally euhedral, but the pyramidal ends often exhibit higher order index faces. Under oil immersion, oscillatory growth zoning is obvious. The sizes of the crystals as well as the L/B ratio were impossible to determine, as many crystals were broken during crushing. A few of the crystals were dark brown, roundish and turbid under crossed nicols. These were removed by hand picking prior to the analyses. Some other crystals contained darkish, rod-like inclusions, which at least in one case were observed to be cross-twinned. As the inclusions were not visible in ordinary light, the crystals containing them could not be removed by hand picking.

RESULTS

The U and Pb analyses, isotopic ratios and apparent radiometric ages for the analysed zircon fractions are given in Table 1.

The analytical results according to Matti Vaasjoki exhibit the usual discordancy pattern, i.e. both density and discordancy are dependent on the uranium contents. The abraded fraction (A) is least discordant. A noteworthy feature is the very high $^{206}Pb/^{204}Pb$ ratios, indicating a minimal amount of initial lead incorporated during crystallisation.

The four analysed fractions define a discordia trend that intercepts the concordia curve at 1940±14 and 287±174 Ma (Fig. 2). The somewhat elevated MSWD of 3.4 may indicate a slight sample heterogeneity, possibly resulting from the inclusions. Nevertheless, the upper intercept age may be regarded as the intrusion age of the dyke.

TABLE 1. U-Pb analyses, isotopic ratios and apparent radiometric ages for analysed zircon fractions from a quartz-feldspar porphyry dyke in the Knaften area.

Analysis	Fraction	Concentration			Atomic ratios			Apparent age (Ma)		
		U ppm	$Pb_{(tot)}$ ppm	$^{206}Pb/^{204}Pb$ measured	$^{206}Pb/^{238}U$ corrected for blank	$^{207}Pb/^{235}U$	$^{206}Pb/^{207}Pb$	6/8	7/5	7/6
A	4.3-4.5 abr	503.6	179.5	41390	0.3290	5.364	0.1182	1833	1879	1930
B	4.3-4.5	508.5	178.0	59530	0.3242	5.283	0.1182	1810	1866	1929
C	4.2-4.3	821.7	282.4	41470	0.3121	5.055	0.1175	1750	1828	1918
D	4.0-4.2	1020.3	334.4	31950	0.2951	4.764	0.1171	1666	1778	1912

Atomic ratios corrected for common lead: 6/4=15.7; 7/4=15.4; 8/4=35.2. abr=abraded.

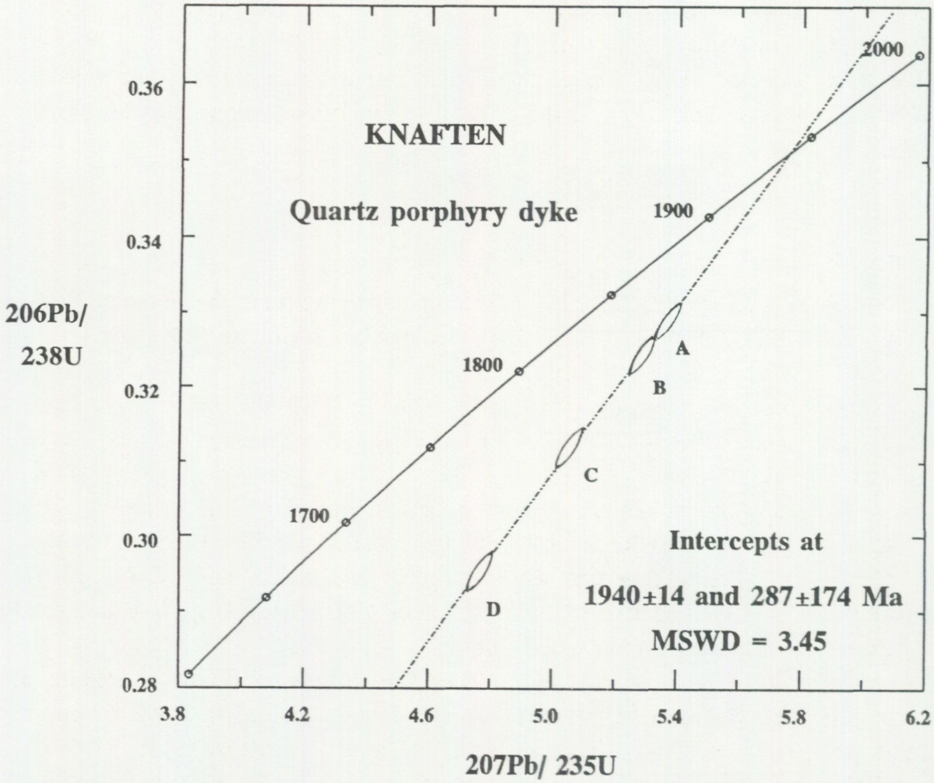


Fig. 2. Concordia diagram for analysed zircon fractions from the quartz-feldspar porphyritic dyke in the Knaften area.

DISCUSSION AND CONCLUSIONS

Despite the slightly elevated MSWD number this new age determination of 1940±14 Ma confirms the high age of the Knaften granitoids. The two age determinations, paying regard to the error limits, clearly overlap and show that the granitoid and porphyry dyke belong to the same group of intrusions. The somewhat higher age of the granitoid may also indicate that the dyke is a late phase of intrusion. A small age difference is not rare in a suite of intrusions. The new age determination also confirms that the basic-intermediate volcanic rocks are more than 1940±14 Ma old, as the porphyritic dyke intersects these rocks.

The two recently dated granitoids in the Bothnian Basin of c. 1930 (Thomas Lundqvist, personal communication) are slightly younger than the Knaften granitoid and dyke. They are more deformed and foliated, but may belong to the same early group of intrusions.

Acknowledgements: This work was totally financed by the Geological Survey of Sweden (SGU): my MSc thesis work (Wasström 1989, 1990), and an FoU project (Wasström 1994). I would like to thank SGU for the financial support and also Thomas Lundqvist, Leif Björk, Leif Kero and several other persons at SGU for their help.

REFERENCES

CLAESSON, S. & LUNDQVIST, TH., 1990: Svecofennian granites in the Bothnian Basin, Central Sweden. Abstract, 19. Nordiske Geologiske Vintermøte, Stavanger. – Geonytt 17:1, 36.

CLAESSON, S. & LUNDQVIST, TH., 1995: Origins and Ages of Proterozoic Granitoids in the Bothnian Basin, Central Sweden; Isotopic and Geochemical Constraints. – Lithos, 36, 115–140.

DELIN, H., 1993: The radiometric age of the Ljusdal granodiorite of Central Sweden. *In*: Lundqvist Th. (ed.) Radiometric dating results. Division of Bedrock Geology, Geological Survey of Sweden. – Sveriges geologiska undersökning C 823, 13–16.

LINDSTRÖM, M., LUNDQVIST, J. & LUNDQVIST, TH., 1991: Sveriges geologi från urtid till nutid. – Studentlitteratur, Lund, 398 pp.

LUNDQVIST, TH. & SAMUELSSON, L., 1973: The differentiation of a dolerite at Nordingrå, central Sweden. – Sveriges geologiska undersökning C 692, 62 pp.

LUNDQVIST, TH., GEE, D. G., KUMPULAINEN, R., KARIS, L. & KRESTEN, P., 1990: Beskrivning till berggrundskartan över Västernorrlands län. With maps to the scale of 1:200 000. – Sveriges geologiska undersökning Ba 31, 429 pp.

ROMER, R. & SMEDS, S.-A., 1994: Implications of U-Pb ages of columbite-tantalites from granitic pegmatites for the Palaeproterozoic accretion of 1.90–1.85 Ga magmatic arcs to the Baltic Shield. – Precambrian Research 67, 141–158.

WASSTRÖM, A., 1989: Evolution of a Proterozoic volcanic arc at a continental margin south of the Skellefte ore province, northern Sweden. – New Mexico Bureau of Mines & Mineral Resources Bulletin 131, Continental Magmatism IAVCEI 1989 Abstracts, p. 288.

WASSTRÖM, A., 1990: Knaftenområdet - en primitiv tidig Proterozoisk vulkanisk öbåge söder om Skelleftefältet, norra Sverige. – Unpublished Master of Science thesis at the Åbo Akademi University, Finland, 128 pp.

WASSTRÖM, A., 1993: The Knaften granitoids of Västerbotten County, northern Sweden. *In*: Lundqvist Th. (ed.) Radiometric dating results. Division of Bedrock Geology, Geological Survey of Sweden. – Sveriges geologiska undersökning C 823, 60–64.

WASSTRÖM, A., 1994: The felsic intrusive and extrusive rocks in the Knaften area. – Unpublished FoU report, 32 pp.

WEIHED, P. & SCHÖBERG, H., 1991: Age of porphyry-type deposits in the Skellefte District, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 113, 289–294.

WEIHED, P. & VAASJOKI, M., 1993: Regional implications of an age determination of a gneissose granitoid south of the Skellefte district, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 115, 189–191.

WELIN, E., 1994: The U-Pb zircon age of the Rödön rapakivi granite, central Sweden. Geologiska Föreningens i Stockholm Förhandlingar 116, 113–114.

WELIN, E. & LUNDQVIST, TH., 1979: K-Ar ages of Jotnian dolerites in Västernorrland County, central Sweden. Geologiska Föreningens i Stockholm Förhandlingar 97, 83–88.

WELIN, E. & LUNDQVIST, TH., 1984: Isotopic investigations of the Nordingrå rapakivi massif, north-central Sweden. Geologiska Föreningens i Stockholm Förhandlingar 106, 41–49.

WELIN, E., CHRISTIANSSON, K. & KÄHR, A.-M., 1993: Isotopic investigations of meta-sedimentary and igneous rocks in the Palaeoproterozoic Bothnian Basin, central Sweden. Geologiska Föreningens i Stockholm Förhandlingar 115, 285–296.

WILSON, M.R., CLAESSON, L.-Å., SEHLSTEDT, S., SMELLIE, J.A.T., AFTALION, M., HAMILTON, P.J. & FALLICK, A.E., 1987: Jörn: An early Proterozoic intrusive complex in a volcanic arc environment. Precambrian Research 36, 201–225.

Annika Wasström, Geologiska institutionen, Göteborgs Universitet, Geovetarcentrum, Guldhedsgatan 5A, S-413 81 Göteborg.
Present address: Boliden AB, Prospektering, S-932 81 Boliden, Sweden.

U-Pb zircon dating of a coarse porphyritic quartz monzonite and an even grained, grey tonalitic gneiss from the Tiveden area, south central Sweden

By
Anders Wikström

INTRODUCTION

A number of different generations of granitoids within the Transscandinavian Igneous Belt (TIB) has recently been distinguished. Apart from the three generations defined by Larson & Berglund (1992) with age intervals at 1.81–1.76, 1.71–1.69 and 1.67–1.65 Ma respectively, a fourth generation is present in the Askersund area (Persson & Wikström 1993) with ages around 1845 Ma. In the latter case the coarse, porphyritic and isotropic Askersund granite could be demonstrated to have continuous transitions into augen gneisses deformed within the Svecokarelian orogeny (Wikström 1991).

The coarse porphyritic Askersund granitoid dated by Persson & Wikström (1993) at Kerstintorp (Fig. 1) is situated in a low magnetic area within the aeromagnetic map-sheet Askersund SO (Wikström, in prep.). This is separated from a high magnetic area to the west in the central part of the Tiveden district by a major displacement, the Aspa fault (Fig. 1). If a younger TIB granitoid should be present in the Tiveden region it is likely that it should be present to the west of this fault. Larson & Berglund (1992) have also argued for a westward younging of the granitoids within the TIB. For that reason a sample was collected of the coarse porphyritic and isotropic quartz monzonite at Långmossen (national coordinates: 651710/142935, Fig. 1) characterized by high susceptibility values.

In this area another rock-suite, dominated by medium-grained, weakly deformed, grey granodioritic to tonalitic gneisses is also present (Fig. 1). In the old geological map-sheet "Töreboda" (Westergård & Johansson 1915) this unit was denoted as "Unden gneiss". As stated in that map description and also verified in the present mapping project (Wikström, in prep.), it is generally a rather heterogeneous unit. However, within the triangular area dominated by this gneiss (Fig. 1), where the "Samfallet" sample has been taken, it consists of a rather homogeneous, medium-grained, grey, weakly deformed tonalite with very few aplite veins and with local dikes and massifs of amphibolite. The contact towards the coarse porphyritic quartz monzonite in the south is partly associated with a minor shear zone. It is also linked to a heterogeneous distribution in the size of the feldspar phenocrysts within the quartz monzonite, a typical phenomenon associated with intrusive contacts of the megacrystic granitoids in the region. The main impression of the field observations is thus that the grey gneiss is somewhat older than the megacrystic granitoids, although some observations indi-

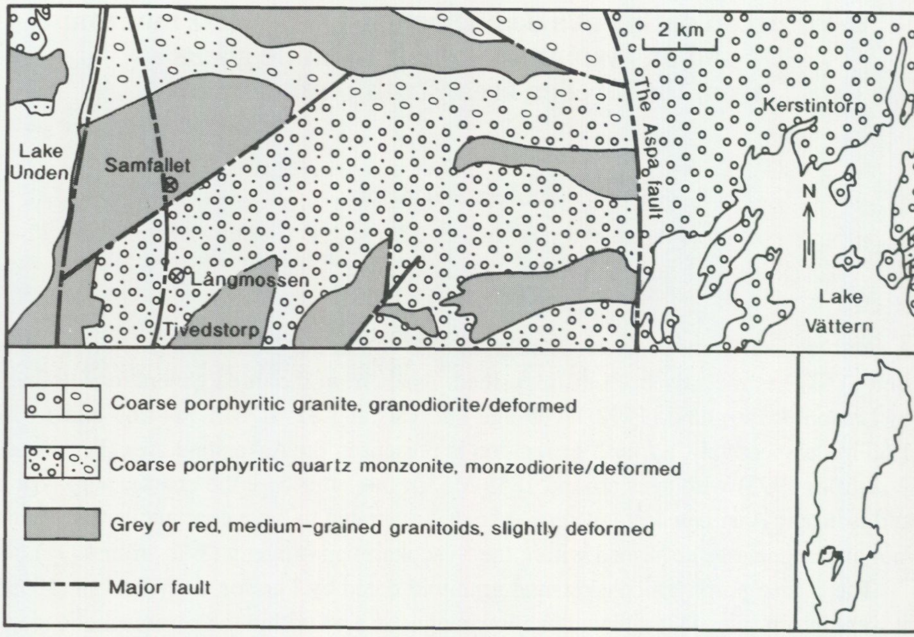


Fig. 1. Sketch map of the bedrock in the northern part of map-sheet area Askersund SO with sampling sites indicated.

cate gradual transitions between the two. This latter observation was also made by Westergård & Johansson (1915).

The Tiveden district has for many years been an excercise area for students at the Geological Dept. of Gothenburg University. In several reports, e.g. Driveklepp & Gynnemo (1989), a marked chemical difference has been demonstrated between the grey gneiss (generally referred to as "Older granitoid of Skaga kapell-type") and the megacrystic quartz monzonite. The grey gneiss has also in most of these reports been regarded as belonging to the older, early orogenic, Svecokarelian granitoids. This was also the view-point of the present author when the mapping project Askersund SO started. However, the sometimes transitional nature of the contact between the tonalite and the megacrystic granitoids, as well as the fact that no clear distinction in the tectonic history between the two, motivated a radiometric dating of the tonalite. A sample of this rock was collected at Samfallet (national coordinates: 651945/142930).

ANALYTICAL DATA

The samples have been analysed at the Unit for Isotope Geology at the Geological Survey of Finland by Dr Matti Vaasjoki and the text below is based on a report presented by him.

The sample from the coarse porphyritic quartz monzonite collected at Långmossen contains abundant, light brown zircon crystals with euhedral prismatic-pyramidal crystal faces and a length/breadth ratio of 1.5–2.5 (M 1.9). Under oil immersion, distinct oscillatory zoning is visible but neither older cores nor significant inclusions were detected.

The results (Table 1, Fig. 2) show the usual features, i.e. the degree of discordancy increases with increasing uranium contents and decreasing density. There is a slight scatter in excess of the experimental error (MSWD = 1.6), but the upper intercept age estimate is nevertheless rather precise at 1854±3 Ma.

A chemical analysis of this sample is presented in Table 3, p. 46.

The zircons from the grey, medium-grained tonalite at Samfallet are mainly euhedral, simple prismatic-pyramidal, although some crystals exhibit higher order index faces as well. The length/breadth ratio varies between 1.5 and 3 with a median at

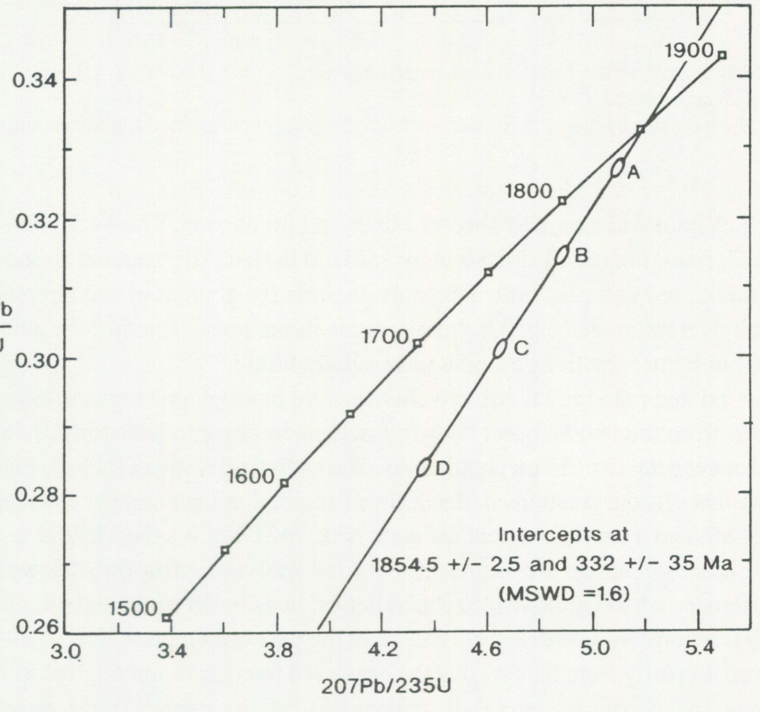


Fig. 2. U-Pb concordia diagram for zircons from the coarse porphyritic quartz monzonite sampled at Långmossen.

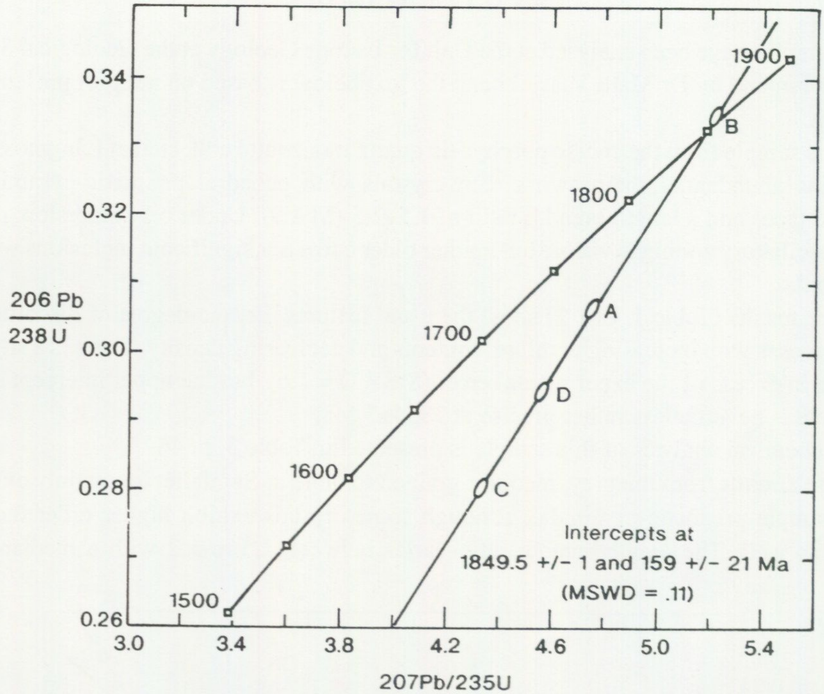


Fig. 3. U-Pb concordia diagram for zircons from the grey, even-grained tonalite sampled at Samfallet.

about 2. A faint zonation was observed under oil immersion. The +4.5 g/cm^3 fraction is notably fine-grained, all crystals being <70 µm in size. All separated zircon fractions contain both red and pale brown crystals, the relative amount of red zircons increasing with decreasing density. Also, the crystals in the heavy fraction are almost transparent, but lighter fractions become increasingly turbid.

The red and pale brown zircon varieties were hand-picked under a binocular microscope from the two heaviest density fractions in order to look for possible differences between the two zircon populations. The analytical results (Table 2, Fig. 3) demonstrate that all four fractions define a linear trend yielding an upper intercept age of 1850±1 Ma and a lower intercept estimate of 159±21 Ma. As the MSWD is very low at 0.11, it is evident that the scatter results from analytical error only. However, there is a difference between the two zircon varieties, in as much as the red zircons of both density fractions are less disconcordant than the pale brown ones. The small error estimate arises partly from the fact that the heavy red fraction B, although plotting slightly above the concordia curve, is concordant within experimental error. As the 206Pb/204Pb ratios are high, the common lead correction has no effect on the result.

Table 1. U-Pb zircon data from the coarse porphyritic quartz monzonite from Långmossen.

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	292.0	100.2	12870	.3267	5.095	.1131	1822	1835	1849
B	+4.5	302.2	99.90	4276	.3142	4.887	.1128	1761	1799	1845
C	4.3-4.5	483.1	151.34	4151	.3010	4.654	.1126	1697	1758	1841
D	4.2-4.3	1004.1	293.90	6198	.2834	4.352	.1113	1608	1703	1820

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

Table 2. U-Pb mineral data from the even-grained, grey tonalite.

Sample	Fraction	Uconc ppm	Pbconc ppm	206/204 meas.	206/238 Corrected for blank	207/235	206/207	Apparent age in Ma 66/8	7/5	7/6
A	+4.5/pale	458.5	142.73	8931	.3058	4.748	.1126	1720	1775	1842
B	+4.5/red	426.7	145.09	6954	.3347	5.221	.1131	1861	1856	1850
C	4.3-4.5/pale	621.3	176.48	6072	.2801	4.331	.1121	1592	1699	1834
D	4.3-4.5/red	700.4	208.03	5142	.2943	4.564	.1125	1662	1742	1839

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

Table 3. Chemical analysis of the quartz monzonite from Långmossen. Laboratory: Geol. Surv. of Latvia, Riga, Latvia.

SiO_2	60.2	Ba	590	Zr	140
TiO_2	1.08	Co	11.4	La	68.1
Al_2O_3	16.4	Cr	27	Ce	–
FeO	5.31	Cu	600	Pr	–
Fe_2O_3	2.13	Hf	5.1	Nd	<0.1
MnO	0.09	Ni	41	Sm	7.99
MgO	1.77	Rb	79	Eu	1.4
CaO	3.50	Sc	8.59	Gd	–
Na_2O	3.12	Sr	4200	Tb	0.62
K_2O	4.82	Ta	0.51	Dy	8
P_2O_5	0.35	Th	12.7	Ho	0.38
CO_2	0.17	U	2.4	Er	–
LOI	0.76	V	44	Tm	–
		W	2.5	Yb	1.17
Sum	99.70	Zn	<40	Lu	0.11

DISCUSSION

The obtained age of the Långmossen sample of the highly magnetic, coarse porphyritic quartz monzonite, is of the same magnitude as that of the low magnetic coarse porphyritic granodiorite at Kerstintorp (Persson & Wikström 1993). From geological observations about the structural interplay between these granitoids and Svecokarelian deformation forces in the adjacent areas covered by the Finspång and Katrineholm SV map-sheets (Wikström 1987, 1991), it is likely that these older TIB rocks also cover considerable areas in the region. This has implications for the interpretation of the structural evolution within the Svecokarelian.

The chemical and petrographical character of the TIB indicate that these rocks have intruded in a tectonic environment characterised by a transition from compressional to extensional forces (Barbarin 1990). The dating result of the quartz monzonite at Långmossen further emphasizes that the onset of TIB magmatism is related to the late Svecokarelian development in the area. It is thus likely that the TIB magmatism should be regarded as formed during a continuous development from an orogenic to a postorogenic state. The present day, mainly north–south extension of TIB, which was probably not developed around 1850 million years ago, is thus in itself not an indication that there is an abrupt change between an orogenic and a postorogenic tectonic regime as e.g. Park (1994) has suggested.

The age of the grey tonalite from Samfallet is more problematical. The situation reminds of the conditions further to the south where it has been debated if the so-called "grey Växjö" granite should be regarded as belonging to the TIB or not. For instance the grey "Tving granite", which earlier has been classified as older Svecokarelian, has recently been dated and classified as TIB (Kornfält 1994). The reverse relationship has been found in the Vetlanda map-sheet area. Although a tonalite at Eksjö, yielded a

U/Pb zircon age of 1754±10 Ma (Åberg & Persson 1986), these authors regarded the result as due to contact metamorphism and resetting caused by young TIB intrusions. Persson (1985) has further emphasized the chemical and tectonic difference between these rocks and those of a more unquestionable TIB character. However, as stated above, a similar chemical contrast between the rocks investigated here has also been demonstrated in the Tiveden area by several students from the Geological Dept. of Gothenburg University in unpublished B.Sc. theses. For practical mapping purposes, this ambiguity how to distinguish an older generation from the TIB rocks, has raised problems during the mapping campaign of map-sheet Askersund SO.

It is so far not understood how a calc-alkaline magmatism can occur contemporaneously with the somewhat more alkaline type of the coarse porphyritic granitoids and also how this magmatism is paired in different TIB-generations during the process.

REFERENCES

ÅBERG, G. & PERSSON, L., 1986: U-Pb dating of a synorogenic Svecokarelian tonalite from Eksjö in Småland, southern Sweden. – Geologiska Föreningens i Stockholm Förhandlingar 108, 35–38.

BARBARIN, B., 1990: Granitoids: main petrogenetic classifications in relation to origin and tectonic setting. – Geological Journal 25, 227–238.

DRIVEKLEPP, M. & GYNNEMO, M., 1989: Petrologisk och geokemisk undersökning av ett område kring sjön Tarmlången, Tiveden, Skaraborgs län. – Unpublished B. Sc. thesis, Geol. Dept., Gothenburg University. 83 pp.

KORNFÄLT, K.-A., 1993: U-Pb zircon ages of three granite samples from Blekinge County, south-eastern Sweden. *In* Lundqvist, Th. (ed): Radiometric dating results. – Sveriges geologiska undersökning C 823, 17–23.

LARSON, S.Å. & BERGLUND, J., 1992: A geochronological subdivision of the Transscandinavian Igneous Belt – three magmatic episodes? – Geologiska Föreningens i Stockholm Förhandlingar 114, 459–461.

PARK, R.G., 1994: Early Proterozoic tectonic overview of the northern British Isles and neighbouring terrains in Laurentia and Baltica. – Precambrian Research 68, 65–79.

PERSSON, L., 1985: Beskrivning till berggrundskartorna Vetlanda NV och NO. – Sveriges geologiska undersökning Af 150 och 151, 1–138.

PERSSON, P.-O. & WIKSTRÖM, A., 1992: A U-Pb dating of the Askersund granite and its marginal augen gneiss. – Geologiska Föreningens i Stockhom Förhandlingar 115, 321–329.

WESTERGÅRD, A.H. & JOHANSSON, H.E., 1915: Beskrivning till kartbladet Töreboda. – Sveriges geologiska undersökning Aa 139, 1–55.

WIKSTRÖM, A., 1987: Magmatic diapirism of granites in south-eastern Sweden. – Revista Brasileira de Geosciencias 17, 456–458.

WIKSTRÖM, A., 1991: Structural features of some younger granitoids in central Sweden and implications for the tectonic subdivision of granitoids. – Precambrian Research 51, 151–159.

WIKSTRÖM, A., (in prep.) Berggrundskartan Askersund SO. – Sveriges geologiska undersökning Af 195.

Anders Wikström, Sveriges geologiska undersökning, Box 670, S-751 28 Uppsala, Sweden.

An Archaean megaxenolith and a Proterozoic fragment within the Bälinge magmatic breccia, Luleå, northern Sweden

By
Anders Wikström, Claes Mellqvist
and Per-Olof Persson

INTRODUCTION

The Bälinge "conglomerate" in northern Sweden has been described by Åhman & Ödman (1952), Wikström *et al.* (1993) and Mellqvist (1994). In regional map compilations (e.g. Ödman 1957) it has been assigned as an important stratigraphic key formation as it contained "pebbles" of the older Svecokarelian granitoids. The epiclastic character of these rocks was challenged by Wikström *et al.* (1993) and Mellqvist (1994) who instead regarded the rocks in question as fluidised, magmatic breccias. In the following text the term "Bälinge magmatic breccia" will be used for this rock unit.

Two samples of rocks related to this unit have now been radiometrically U/Pb zircon dated. In Fig. 1, the sample localities as well as the extension of so far recognised Archaean rocks in the Luleå area and geographically associated fragment-bearing volcanic and plutonic rocks are displayed.

A PORPHYRITIC AND GNEISSIC GRANITOID FROM THE BÄLINGSBERGET HILL FORMING A MEGAXENOLITH WITHIN THE BÄLINGE MAGMATIC BRECCIA

Lundqvist *et al.* (1996, this volume) have found Archaean rocks in the Vallen-Alhamn area (Fig. 1) south of the town of Luleå, an area which has been previously mapped by Åhman (1953). The Archaean ages were received in rocks classified as "grey gneisses" and "Revsund granite" respectively by Åhman (1953). In the investigation of the "Bälinge conglomerate" by Åhman & Ödman (1952), a smaller (roughly 100 x 50 m) area was designed as "Revsund granite " in their map. With the results received by Lundqvist *et al.* (op.cit.) in mind, the question arose whether this rock also had an Archaean age.

The "Revsund granite" (sensu Åhman & Ödman 1952) is a porphyritic granitoid with a texture displayed by Fig. 2 and a chemical composition shown in Table 1. At the investigated locality (national coordinates: 729235/178035) contact relationships show that the rock has been intruded by younger tonalites of the Haparanda suite. This is in agreement with other observations in the vicinity where similar rocks either have intrusive or tectonic contacts towards younger rocks. Nowhere has a basement-cover relationship been observed or inferred.

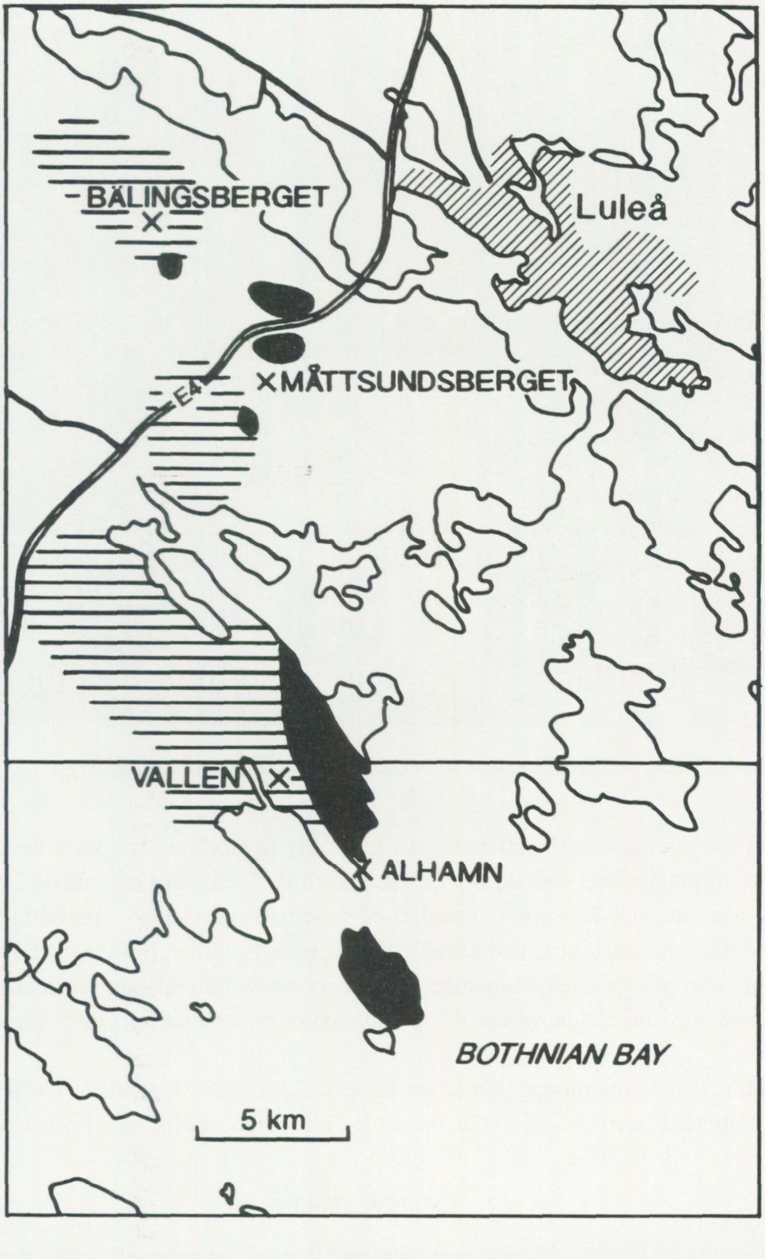


Fig. 1. Location of investigated samples and some local names mentioned in the text. The areal distribution of Archaean rocks (black) and fragment-bearing volcanic/plutonic rocks (horizontal ruling), the latter more or less invaded by younger granites, is also schematically shown. The area corresponds to map-sheets 24L Luleå NO and northern part of Luleå SO.

Fig. 2. The Archaean porphyritic granitoid in the megaxenolith from Bälingsberget.

Under the microscope the phenocrysts, generally microcline, are perthitic, locally rimmed with plagioclase and slighly quartz poikilitic. Inclusions of euhedral plagioclase are also present. The matrix consists of sericitised plagioclase, perthitic microcline, undulose quartz, biotite and hornblende. Accessory minerals are sphene, zircon, apatite and titanomagnetite or ilmenite. These accessory minerals are concentrated in accumulations of biotite in where the titanomagnetites or ilmenites are rimmed by sphene.

It should also be mentioned that an unsuccessful attempt was made to U-Pb zircon date the fragment-bearing felsic volcanite at Bälingsberget during this investigation.

ANALYTICAL DATA

As the heavy (+4.5) zircon fraction was quite small, work was carried out on the lighter fractions. The zircons are uniformly brown, their habit varying from subhedral to euhedral. Their length/breadth ratio varies from 1.5 to 3 with the median at about 2. The grain size is rather fine, 90% of the crystals being < 70 µm in size. Under oil im-

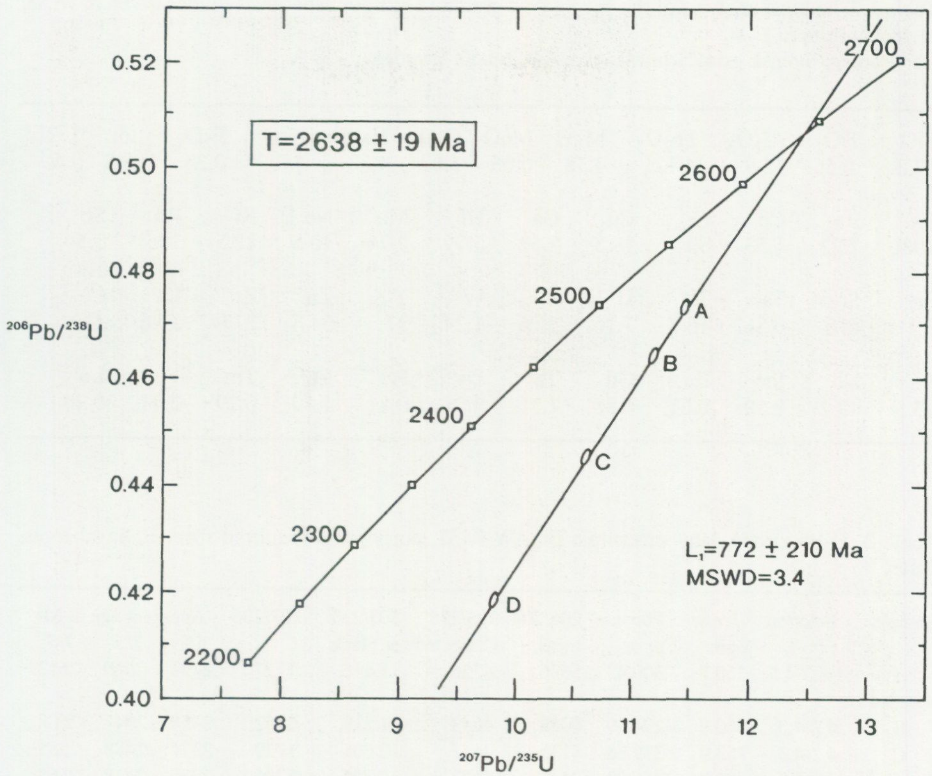


Fig. 3. U-Pb concordia diagram for zircons from the porphyritic granitoid at Bälingsberget.

mersion it is obvious that about 70 % of the grains are subhedral and turbid irrespective of crystal habit. Neither zonation nor inclusions could therefore be observed.

The analyzed fractions exhibit a normal distribution on the concordia plot, i.e. they become more discordant as the uranium content increases. An interesting feature is that, in spite of the use of lighter (and consequently more uranium-rich) fractions than usual, all analyses are relatively little discordant. The scatter of the calculated discordia line is slightly in excess of analytical error as demonstrated by the MSWD of 3.4. This may be a consequence of Proterozoic processes, but the effect is in any case very slight.

The upper intercept age of 2638±19 Ma as well as the $^{207}Pb/^{206}Pb$ ages for all fractions conclusively prove the Archaean origin of the rock studied.

Table 1. Chemical analysis of the porphyritic granitoid at Bälingsberget. (Oxides given in wt.%, elements in ppm.)
Laboratory: Svensk grundämnesanalys AB, Luleå, Sweden.

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5	tot	LOI
67.3	0.56	15.9	4.12	1.18	0.06	3.03	4.3	4.08	0.23	100.8	0.4
Ba	Ba	Co	Cr	Cu	Ga	Hf	Mo	Nb	Ni	Rb	Sc
1080	2.22	6.53	30	18.5	7.52	5.79	2.74	10.5	12.5	106	3.54
Sn	Sr	Ta	Th	U	V	W	Y	Zn	Zr	La	Ce
3.1	410	0.512	16.7	1.16	56.6	1.24	17	54.8	277	59.6	119
Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
13.5	49.2	8.59	0.61	6.88	1.1	3.98	0.81	1.89	0.29	2.41	0.30

Table 2. U-Pb zircon data of sample BQAW 9452, porphyritic granitoid from Bälingsberget, Luleå.

Sample	Fraction	Uconc	Pbconc	206/204	206/238	207/235	207/206	Apparent age in Ma		
		ppm	ppm	meas.	Corrected for blank			6/8	7/5	7/6
A	4.3-4.5	560.7	300.43	5696	.4726	11.446	.1757	2494	2560	2612
abraded										
B	4.2-4.3	560.8	294.59	6088	.4643	11.218	.1752	2458	2541	2608
C	4.2-4.3	753.9	379.88	4133	.4447	10.601	.1729	2371	2488	2585
D	4.0-4.2	989.2	466.82	3441	.4177	9.825	.1706	2250	2418	2563

Common lead correction 6/4: 13.4; 7/4: 14.6; 8/4: 33.2.

A TONALITE FRAGMENT IN THE BÄLINGE MAGMATIC BRECCIA AT MÅTTSUNDSBERGET, LULEÅ

Apart from the Bälingsberget hill, which is the reference locality for the "Bälinge conglomerate", some other localities of this rock have been reported by Åhman & Ödman (1952) and Ödman (1972). Still another occurrence outside Luleå has for some time been known at the Måttsundsberget hill (Öhlander, pers.comm. 1992). A sample (c. 1 kg) from this place (national coordinates: 728670/178260) was collected for U-Pb zircon dating at the Laboratory for Isotope Geology, Stockholm.

The general geological environment of the magmatic breccia at Måttsundsberget is similar to the Bälingsberget bedrock geology with fragment-containing metavolcanic rocks adjacent to rocks with a suspected Archaean age. The magmatic breccia at

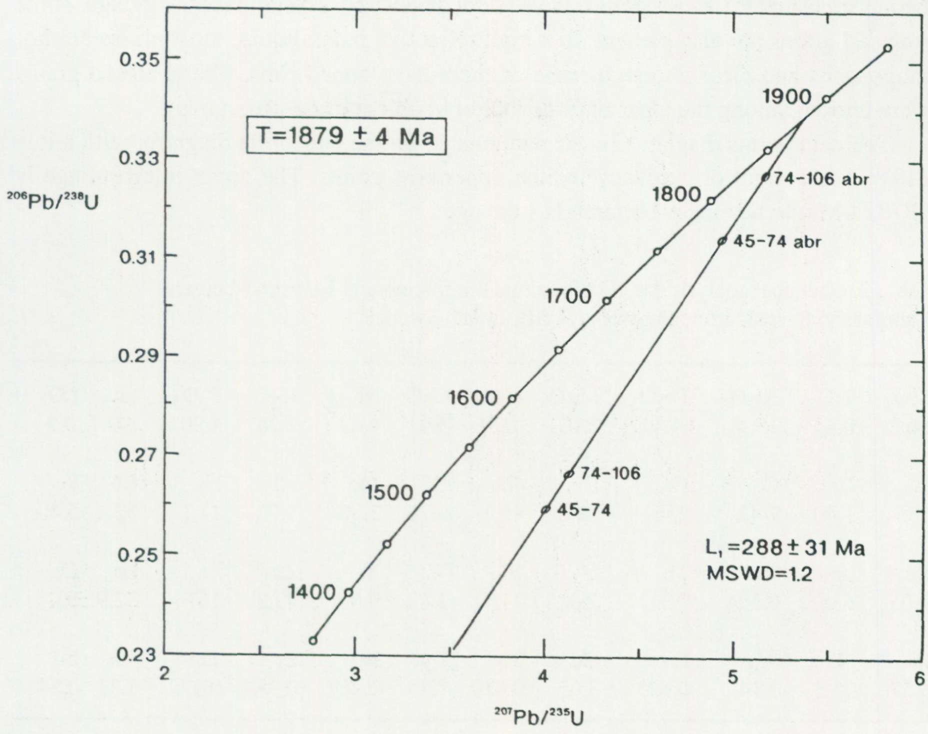


Fig. 4. U-Pb concordia diagram for zircons from a tonalite fragment in the Bälinge magmatic breccia at Måttsundsberget, Luleå.

Måttsundsberget consists of fairly well-rounded, irregular, dm-sized, tonalite fragments in a fine-grained dioritic matrix. Subordinate fragments of supposed Archaean age have also been observed. At places, the granitoid fragments seem to disintegrate into the matrix.

Microscopically the investigated tonalite consists of a slightly zoned plagioclase (An_{30-25}), quartz and biotite with subordinate amounts of microcline and hornblende. A chemical analysis is presented in Table 3.

ANALYTICAL DATA

Most of the zircons are turbid but a minor amount of them are clear. The colour varies between beige and colourless. Short prismatic crystals dominate, elongated ones being subordinate. Most grains have well developed crystal faces although some rounded grains are also present. In a high refractive index liquid, most grains are homogeneous and clear although some of them have zoned rims. The analysed grains were chosen among the clear ones devoid of visible internal structures.

The data points display a linear relationship on the concordia diagram, with a low MSWD and small discordancy for the uppermost points. The upper intercept age is 1879±4 Ma, indicating a Haparanda suite age.

Table 3. Chemical analysis (wt.%) of the tonalite fragment at Måttsundsberget. Laboratory: Svensk grundämnesanalys AB, Luleå, Sweden.

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5	tot	LOI
66.2	0.46	15.5	4.49	2.16	0.05	3.91	4.42	2.34	1.20	99.7	0.5
Ba	Be	Co	Cr	Cu	Ga	Hf	Mo	Nb	Ni	Rb	Sc
755	1.40	7.42	236	22.2	16.1	5.76	3.30	7.73	11.1	52.4	5.40
Su	Sr	Ta	Th	U	V	W	Y	Zn	Zr	La	Ce
2.05	636	0.594	7.31	2.32	71.4	1.82	9.63	42.2	167	32.9	63.1
Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
6.57	23.3	3.14	0.625	3.03	0.410	1.83	0.267	0.984	0.179	1.31	0.243

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

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

Table 4. U-Pb zircon data of sample TL 92:9. Tonalite fragment from the Bälinge magmatic breccia at Måttsundsberget, Luleå, Sweden.

Fraction (µm)	Weight (mg)	U(ppm)	Pb(tot) (ppm)	206/204 (a)	206/238 (b)	207/235 (b)	207/206 (b)	206/238 age	207/238 age	207/206 age
45-74	0.17	221.5	65.2	2116	0.2608+/-5	4.023+/-16	0.1119+/-1	1494	1639	1830
45-74ab	0.05	221.1	77.5	4348	03156+/-6	4.966+/-20	0.1141+/-1	1768	1814	1866
74-106	0.07	312.9	94.1	2408	0.2677+/-5	4.154+/-17	0.1125+/-2	1529	1665	1841
74-106ab	0.05	153.2	55.9	6140	0.3284+/-8	5.192+/-21	0.1146+/-2	1831	1851	1875

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

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

DISCUSSION

The obtained Archaean ages as published by Lundqvist *et al.* (this volume) and in the present work, have greatly contributed to the understanding of the geology of the Luleå area. The porphyritic granitoid has a characteristic texture recognizable in the field and most of the area in Fig. 1 with an Archaean signature is occupied by rocks with this particular texture. The porphyritic granitoid is also abundantly found as fragments in some subvolcanic and plutonic rocks adjacent to the larger bodies of Archaean granitoids found between Alhamn and Bälingsberget (Fig.1).

The tonalite fragment from Måttsundsberget on the other hand has an age coinciding with the "Haparanda suite" (Lundqvist *et al.* 1996). The majority of the fragments within the Bälinge magmatic breccia has this composition. They are mainly tonalites and show fragmentation and dissolution (mixing) within the dioritic matrix, features which are diagnostic for the interpretation of the magmatic origin of these rocks.

The geographical juxtaposition (a preliminary result after one field season) between the outcropping Archaean granitoids and the volcanic/plutonic breccias has so far not got a satisfactory explanation. The breccias which are supposed to have formed in a volcanic to high-level plutonic environment bear witness of a violent evolution. A large body of Archaean continental crust has apparently been present at the site of these, mainly explosive processes.

These newly found Archaean bedrock areas roughly coincide with the Archaean palaeoboundary as defined by Öhlander *et al.* (1993).

The radiometric dating of the tonalite at Måttsundsberget shows that this process took place in connection with, or slightly after the emplacement of the Haparanda granitoids. Possibly the intrusion of large volumes of gabbroic magma in the vicinity could be the local energy source in this development.

ACKNOWLEDGEMENT

The radiometric analysis of the porphyritic granitoid at Bälingsberget has been performed at the Geological Survey of Finland by Dr Matti Vaasjoki. The text concerning the analytical data from this sample is based on a report presented by him to the Geological Survey of Sweden.

REFERENCES

ÅHMAN, E. & ÖDMAN, O.H., 1952: Konglomeratet på Bälingsberget i Nederluleå s:n. – Sveriges geologiska undersökning C 523, 1–20.

ÅHMAN, E., 1953: Vallen-Alhamnområdet i Nederluleå s:n. – Sveriges geologiska undersökning C 529, 1–21.

LUNDQVIST, T., BØE, R., KOUSA, J., LUKKARINEN, H., LUTRO, O., ROBERTS, D., SOLLI, A., STEPHENS, M. & WEIHED, P., 1996: Bedrock map of central Fennoscandia. Scale 1:1,000,000. Geological Surveys of Finland, Norway and Sweden.

LUNDQVIST, TH, VAASJOKI, M. & SKIÖLD, T., (this volume): Preliminary note on the occurrence of Archaean rocks in the Vallen-Alhamn area, northern Sweden. – Sveriges geologiska undersökning C 828, pp. 48–55.

MELLQVIST, C., 1994: A petrogenetic study of the conglomerate at Bälingsberget near Luleå. – Unpublished B.Sc. thesis, Inst. of Geology and Geochemistry, Stockholm University.

ÖDMAN, O.H., 1957: Berggrundskarta över urberget i Norrbottens län. – Sveriges geologiska undersökning Ca 41.

ÖDMAN, O.H., 1972: Översikt av konglomeratförekomster i Norrbottens urberg och den stratigrafiska betydelsen av dessa. – Sveriges geologiska undersökning C 677, 1–12.

ÖHLANDER, B., SKIÖLD, T., ELMING, S-Å., BABEL working group, CLAESSON, S. & NISCA, D.H., 1993: Delineation and character of the Archaean-Proterozoic boundary in northern Sweden. – Precambrian Res., 87, 67–84.

WIKSTRÖM, A., MELLQVIST, C. & BARBARIN, B., 1993: The Bälinge conglomerate in northern Sweden reinterpreted as a magmatic, hydraulic breccia. – EUG VII, Strasbourg, Terra abstracts 5.

Anders Wikström, Sveriges geologiska undersökning, Box 670, S-751 28 Uppsala, Sweden.
Claes Mellqvist, Avd för tillämpad geologi, Tekniska högskolan i Luleå, S-971 87 Luleå, Sweden.
Per-Olof Persson, Laboratoriet för isotopgeologi, Naturhistoriska riksmuseet, S-104 05 Stockholm, Sweden.

Recognition of basement rocks in the metamorphic Seve Nappes: the U-Pb zircon age of the Nuortenjuone Gneiss, Upper Allochthon, central Swedish Caledonides

By

Ebbe Zachrisson, Reinhard O. Greiling and Per-Olof Persson

ABSTRACT

Zachrisson, E., Greiling, R.O. & Persson, P.-O., 1996: Recognition of basement rocks in the metamorphic Seve Nappes: the U-Pb zircon age of the Nuortenjuone Gneiss, Upper Allochthon, central Swedish Caledonides. Sveriges geologiska undersökning, Ser. C 828, pp. 57–71. ISBN 91-7158-556-7

The Seve Nappes of the Upper Allochthon form a major Caledonian metamorphic complex in Scandinavia, characterized by amphibolite to eclogite grade metamorphism. Earlier isotopic age-dating has yielded only provenance ages of metasedimentary rocks (c. 900–1700 Ma) or metamorphic ages (c. 500 Ma for a high-P event and c. 420–430 Ma for a lower pressure overprint of variable metamorphic grade). Pre-Caledonian rocks have not previously been identified. Therefore, the Nuortenjuone Gneiss, an augen gneiss of suspected basement origin in the Eastern Schist and Amphibolite Belt of the Seve Nappes, has been analysed and dated.

The Nuortenjuone Gneiss occurs as several lenticular bodies, which are up to 600 m thick and extend over more than 17 km along strike, within a sequence of metasedimentary, metabasic and subordinate ultramafic rocks, comprising the lowermost of the three major Seve Nappes in the area. The mineralogy is dominated by K-feldspar and quartz, with plagioclase, biotite and hornblende as other major components, implying a classification as a granitic orthogneiss. Chemically, the Nuortenjuone Gneiss is an alkaline granite of within-plate characteristics. U/Pb radiometric work on zircons revealed a linear trend of four zircon fractions in a concordia diagram with one point nearly concordant and an upper intercept at 1645±4 Ma (MSWD=0.5). This age is the first Proterozoic protolith age for a Seve rock constituent.

Together with recent mapping results, the detection of a basement slice within a Seve Nappe implies a basement-cover imbricate sequence in the lower part of the nappe complex.

Ebbe Zachrisson, Sveriges geologiska undersökning, Box 670, S-751 28 Uppsala, Sweden.
Reinhard O. Greiling, Geologisch-Paläontologisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 234, D-69120 Heidelberg, Germany.
Per-Olof Persson, Laboratoriet för isotopgeologi, Naturhistoriska riksmuseet, S-104 05 Stockholm, Sweden.

INTRODUCTION

Metamorphic nappes are major constituents of the internal parts of mountain belts. Consequently, their structural and metamorphic development has been widely studied in both Phanerozoic and Precambrian orogenic belts. However, due to their complex tectonic evolution, metamorphic nappes are notorious for the problems concerning the assessment of their protoliths, the primary character of the rocks in general and the early structure. In particular, the distinction of pre-orogenic basement from cover successions can be quite difficult and is, therefore, the cause for much scientific debate. Examples of such metamorphic nappes are well exposed in the higher allochthons of the Scandinavian Caledonides. In fact, the tectonic position of the major Caledonian metamorphic Seve Nappes, overlying little metamorphosed Lower Palaeozoic sedimentary sequences, led to the first recognition of the large-scale nappe transport in the Scandinavian Caledonides (Törnebohm 1888, Asklund 1962). Subsequent work has revealed the character of this mountain range as a classic example of an orogen dominated by thrust nappe tectonics with transport of the Caledonian metamorphic nappes for several hundred km onto Baltica, the present Baltic Shield (e.g. Gee 1975, Stephens 1988, Gayer & Greiling 1989).

Although the Caledonian metamorphic nappes and the Seve Nappes, in particular, have been studied in much detail (e.g. Zachrisson 1973, Zwart 1974, Sjöström 1984, Van Roermund & Bakker 1984, Kullerud *et al.* 1990, Andréasson 1994), there has, as yet, been no unambiguous evidence for the existence of pre-Caledonian, continental basement rocks in this allochthon. Therefore, sampling of the Nuortenjuone Gneiss for radiometric dating was suggested, this granitoid augen gneiss being suspected to be a pre-Caledonian element in the Seve Nappes. The radiometric work and the results are presented here and their regional and general significance will be discussed.

REGIONAL GEOLOGICAL CONTEXT

A broad, five tier subdivision is generally used as a regional tectonostratigraphic frame for the Scandinavian Caledonides, with the Autochthon of the Baltica foreland lithosphere at the base, overlain, in ascending order by the Lower, Middle, Upper and Uppermost Allochthons, respectively (Kulling 1972). These units represent elements related to the tectonically shortened margin of the continent Baltica as well as exotic terranes comprising arc-basin successions and active continental margins derived from outboard of Baltica (e.g. Stephens & Gee 1989). The results presented here are related to the lower, relatively high-grade Seve part of the Upper Allochthon.

Available age information in the Swedish segment of the orogen varies across the tectonic units. In the Autochthon and Lower Allochthon, preserved fossils give Cambrian, Ordovician and Silurian (to Wenlockian) ages of the sedimentary sequences.

Underlying Precambrian basement slices are well-preserved, although not yet dated. The Köli Nappes of the Upper Allochthon contain Ordovician and Silurian fossils, and volcanic and intrusive rocks have been dated at 488-438 Ma by radiometric methods (e.g. Stephens et al. 1993). The greenschist grade rocks of the Middle Allochthon and the greenschist to eclogite grade Seve part of the Upper Allochthon, however, lack fossils, and age determinations by radiometric dating are few and often difficult to interpret (e.g. Dallmeyer & Gee 1986, 1988, Page 1992). In the Middle Allochthon, a sequence of basement-cover imbricates can be clearly distinguished (e.g. Claesson 1980, Greiling 1985). The age and origin of the Seve rocks have been the subject of debate for many decades. Asklund (e.g. 1962, in Jämtland) considered most of the Seve (even the amphibolites) to be Precambrian. Kulling (1972, in Norrbotten and Västerbotten), on the other hand, principally regarded the schist/gneiss/amphibolite assemblage as a high-grade equivalent of the metasedimentary and metavolcanic Köli sequences. More recent interpretations suggest that both Precambrian basement and Late Precambrian–Cambrian cover sequences are involved (e.g. Stephens & Gee 1989). The Seve as a whole is proposed to represent a segment closely related to the Baltica margin: the schists are mainly epiclastic rocks derived from Baltica and deposited as a clastic wedge on the Baltica continental slope; mafic and ultramafic rocks are related to the break-up of a pre-existing continent and formation of the Iapetus Ocean, i.e. newly-formed ocean floor of late Proterozoic-early Palaeozoic age. Minor remnants of the Precambrian basement were suspected to occur but their character and distinction from the other Seve rocks has remained unclear (e.g. Andréasson 1994).

The Seve Nappes extend along the strike of the orogen from north to south through most of the mountain belt (Fig. 1), although with variable lateral extension and thickness. In the thrust direction (NW–SE), the geometry is strongly wedge-shaped with a maximum thickness (>2000 metres) in the east (Swedish Caledonides), thinning or completely wedging out towards the west (Zachrisson 1973). In the present area of southernmost Västerbotten County, the Seve has been subdivided (Trouw 1973) into three major units: the lower Eastern Schist and Amphibolite Belt, the central (granulite facies) Marsfjället Gneiss, and the upper (western) Svartsjöbäcken Schists (schist and amphibolite). Further south, in Jämtland, the lower belt contains eclogites; in Norrbotten County, the lowermost Seve unit (Vaimok Lens) is also eclogite-bearing and the upper Seve (Tsäkkok Lens) contains both eclogites and blueschists (Stephens & Van Roermund 1984, Kullerud *et al.* 1990, Andréasson 1994). Recent radiometric dating (e.g. Dallmeyer & Gee 1988) revealed the high-P metamorphism in the Seve to be of 'Finnmarkian', late Cambrian – early Ordovician age, with a lower pressure 'Scandian' overprint in Silurian to early Devonian times (cf. Table 3).

In the Kultsjön area (Fig. 2), the Eastern Belt is composed of a sequence of metasedimentary mica-schists, gneisses, quartzites and intercalated amphibolites with subordinate ultramafic bodies. Partly within the mica-schists and partly at the boundary

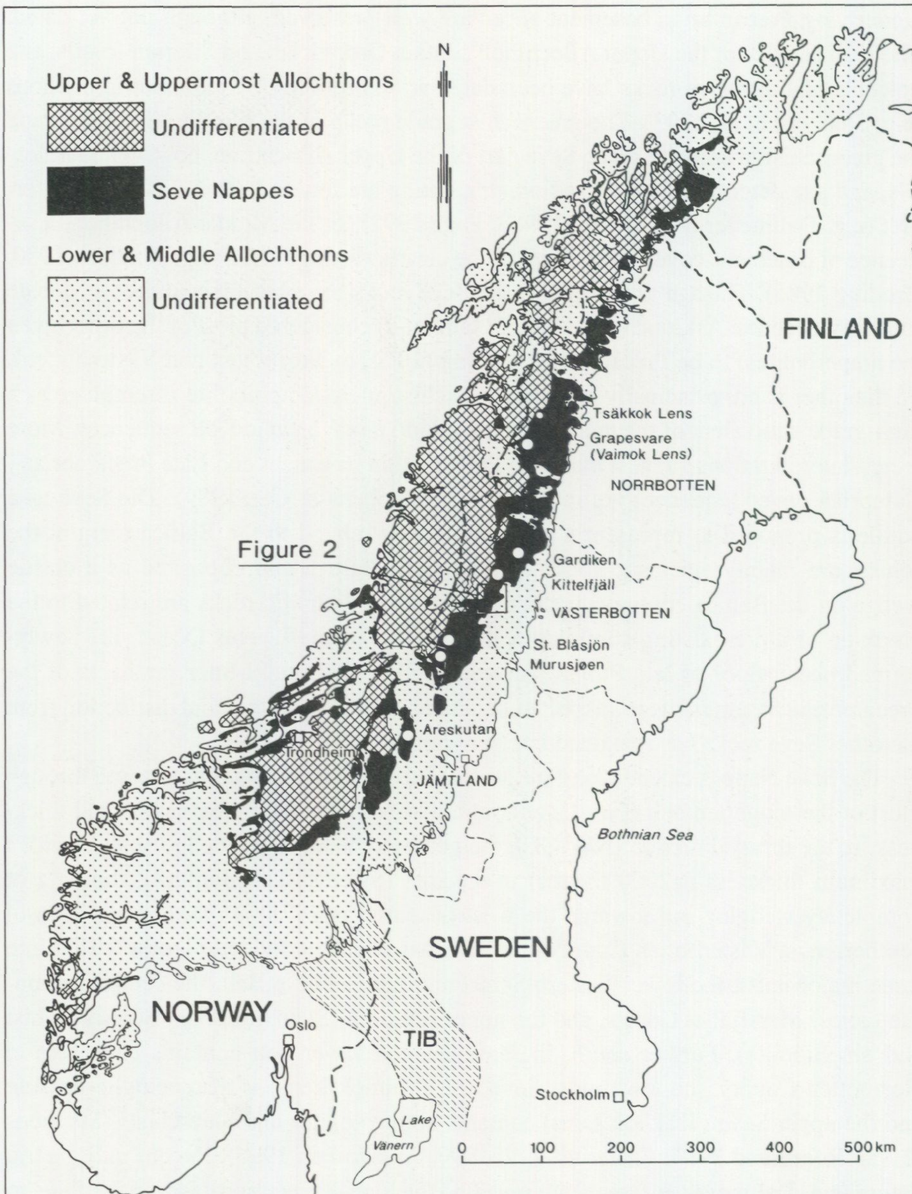


Fig. 1. Extension of the Seve Nappes within the Scandinavian Caledonides (modified from Zachrisson 1973). Possible equivalents of the Seve Nappes in Norway, northwest of Trondheim, are of uncertain tectonostratigraphic position. Locations (white circles) of radiometric age determinations of Seve rocks refer to Table 3. Quadrangle indicates the position of map area for Figure 2. The extension of TIB rocks north of Lake Vänern (southwestern Sweden, into Norway) is also indicated.

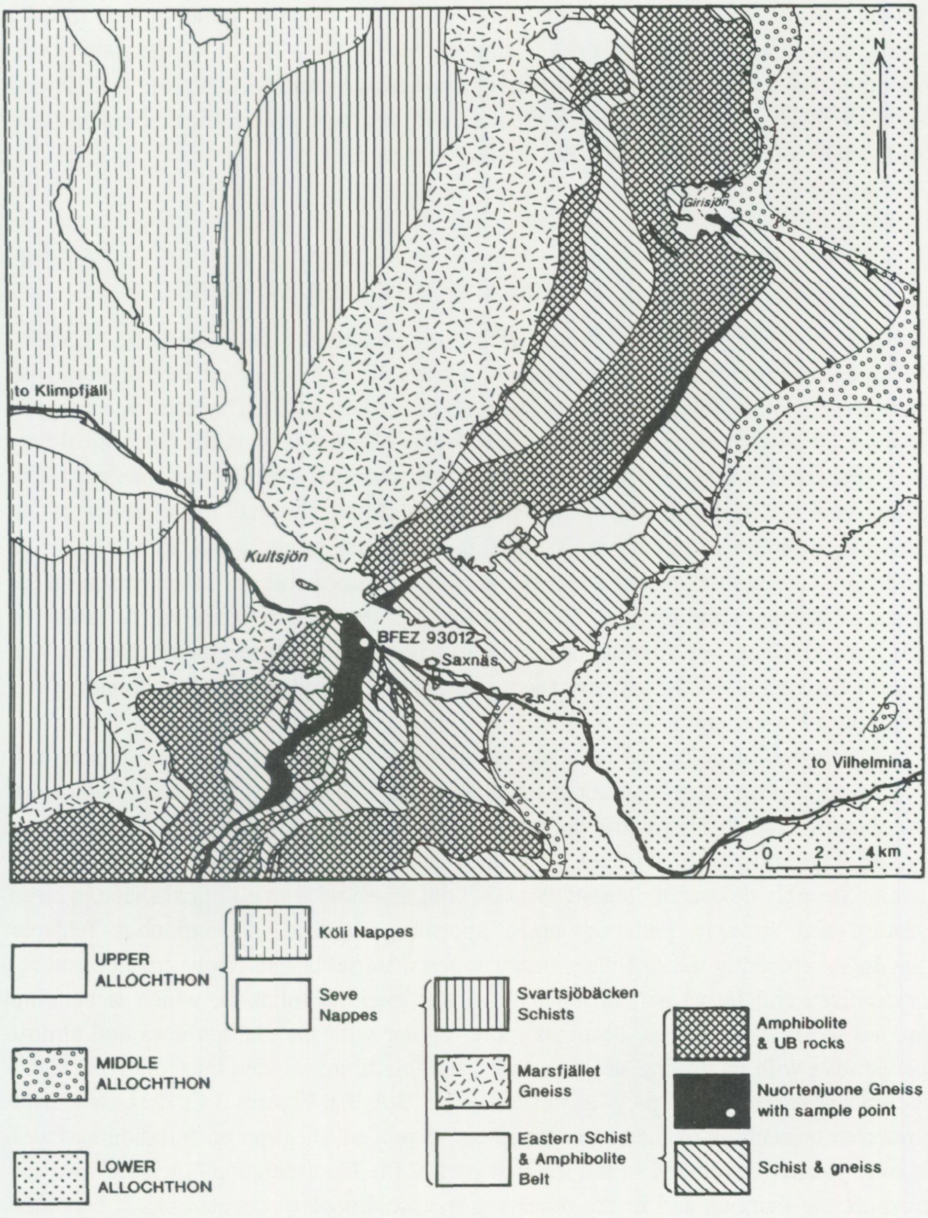


Fig. 2. Schematic geological map of the Seve Nappes in the southern part of Västerbotten County. Compilation from the geological map sheets Fatmomakke, 1:50 000 (Zachrisson 1993, Zachrisson & Greiling 1993). Sample BFEZ 93012 has the coordinates 720933/147531 in the national grid system.

towards the amphibolites, a granitic augen gneiss, the Nuortenjuone Gneiss, forms a third, minor unit (Zachrisson 1993, Zachrisson & Greiling 1993). Whereas metasedimentary rocks and gneisses are clearly derived from continental crust (e.g. Claesson 1987, Williams & Claesson 1987), the amphibolites have geochemical characteristics of E-MORB (e.g. Andréasson 1994, Kullerud *et al.* 1990).

THE NUORTENJUONE GNEISS AND SAMPLE DESCRIPTION

During the 1970's, a team of Dutch geologists working in the Västerbotten Caledonides under Prof. H.J. Zwart recognized a zone of coarse-grained Seve orthogneiss within the Eastern Schist- and Amphibolite Belt (Trouw 1973). This zone was mapped in more detail and traced over a longer distance in connection with the Geological Survey of Sweden's 1:50 000 bedrock mapping programme, 1990-92 (Zachrisson 1993, Zachrisson & Greiling 1993). Maps and sections show the major occurrence of the Nuortenjuone Gneiss as a sheet-like lens. It extends for more than 17 km along strike with a maximum thickness of about 600 m and is conformable with the layering in the mica-schists and amphibolites (Zachrisson 1993). Two minor lenses with a length of 9.5 km and 3 km, respectively, occur along strike towards the northeast (Fig. 2). The lens at Girisjön is overlain by mica-schist, amphibolite and a second orthogneiss lens of about 1 km in length.

The degree of deformation of the Nuortenjuone Gneiss is variable. Where best preserved, it is an augen gneiss consisting of c. 80% of composite 'augen', which are dominantly reddish microcline perthite with orthoclase and minor, white plagioclase grains. The feldspar augen may be up to 6 cm but decrease in size with increasing strain. Strongly deformed domains contain both augen with an elliptical shape in cross section and strongly flattened augen appearing as thin, discontinuous feldspar 'layers'. Apparently most of the primary augen material is also finely crushed and recrystallized and forms part of the matrix. The gneissic foliation, which is bending around the feldspar augen, becomes more regular with parallel surfaces and almost penetrative with increasing strain. Locally, the foliation is folded into relatively tight, recumbent folds at the dm- to 10 m scale (Figs. 3 A, B). Figures 3 C, D show a clear preferred orientation of the augen long axes. A related lineation on foliation surfaces is only weakly developed in the internal part of the Nuortenjuone Gneiss. However, towards the margins and in the overlying metasedimentary cover rocks it becomes more pronounced and develops into a strong stretching lineation. The deformation increases towards the margins, accompanied by a change in mineralogy, leading to increased contents of muscovite and biotite. As a consequence, the marginal basement rock is transformed into a schist which is nearly impossible to distinguish from the metasedimentary schists above, below and along-strike.

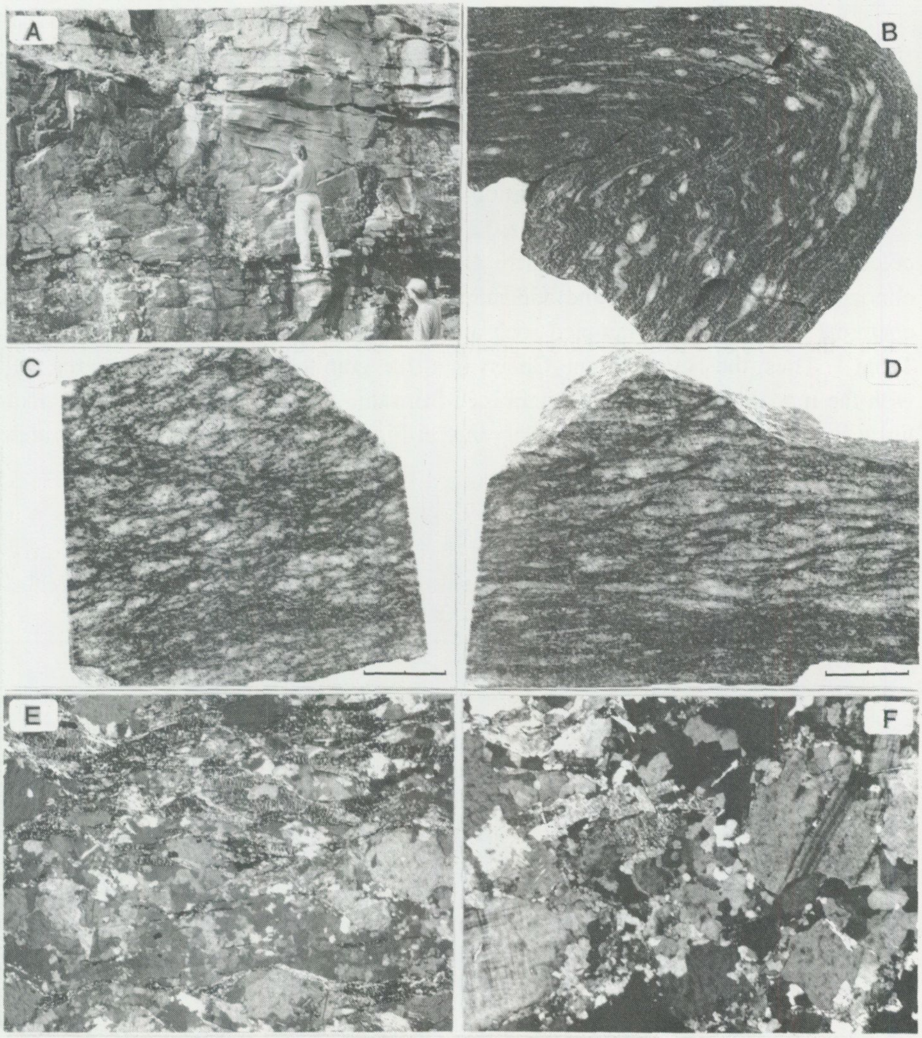


Fig. 3. The Nuortenjuone Gneiss. A: Recumbent, post-schistosity fold. Sample site (road section) south of Kultsjön, looking southwest. B: Polished section of hand specimen-sized fold closure. C: Do., cut perpendicular to lineation and foliation (scale bar = 2 cm). D: Do., but parallel with lineation. E: Micrograph (crossed polarizers) of protomylonitic orthogneiss (lower margin = 2 mm). F: Do., of more well-preserved orthogneiss (lower margin = 4 mm).

A locality with well-preserved Nuortenjuone Gneiss on the Fatmomakke SE map sheet (Zachrisson & Greiling 1993), along the road c. 3 km west of Saxnäs (Fig. 2), was sampled for dating (BFEZ 93012). From the same locality, samples of the Nuortenjuone Gneiss (Fig. 3 E–F) were analyzed microscopically for its modal mineralogical contents. The average from two thin sections parallel with and normal to the lineation, respectively, gives a composition of c. 57% K-feldspar (34% orthoclase + 23% microcline-perthite), 19% quartz, 12% plagioclase, 10% biotite of greyish green colour, with minor hornblende (partly also other mafic minerals, such as epidote–clinozoisite etc.) and muscovite and minor amounts of accessories (e.g. garnet). A chemical analysis of the sampled rock and a CIPW norm calculation are shown in Table 1. Thus, the Nuortenjuone Gneiss is a true granite. This result compares well with the modal composition as determined from thin sections. According to its alkalinity index it is alkaline and the diagrams in Figure 4 indicate within-plate granite affinity.

Table 1. Major element composition (%), trace element analyses (ppm) and CIPW norm calculation of sample BFEZ 93012, Nuortenjuone Gneiss.

%		ppm		ppm		CIPW norm	
SiO_2	68.7	Ba	1130	La	58	ap	0.53
Al_2O_3	14.4	Be	3	Ce	143	il	1.43
CaO	1.82	Co	10	Pr	17	or	31.56
Fe_2O_3	3.44	Cr	24	Nd	67	ab	33.42
K_2O	5.34	Cu	12	Sm	11	an	5.79
MgO	0.92	Ga	41	Eu	2	di	1.48
MnO	0.09	Hf	16	Gd	9	hy	6.79
Na_2O	3.95	Mo	1	Tb	1	wo-	0.73
P_2O_5	0.23	Nb	27	Dy	8	en-	2.29
TiO_2	0.75	Ni	10	Ho	2	fs-	5.25
LOI	0.3	Rb	138	Er	6	qz	18.65
		Sc	4	Tm	1	lc	0.00
Total	99.7	Sn	6	Yb	7	di*	0.49
		Sr	201	Lu	1	he*	0.99
		Ta	3			en*	2.06
		Th	11			fs*	4.73
		U	3			100*fe2(fe2+mg)	63.58
		V	32				
		W	2			Total	99.64
		Y	39				
		Zn	58				
		Zr	489				

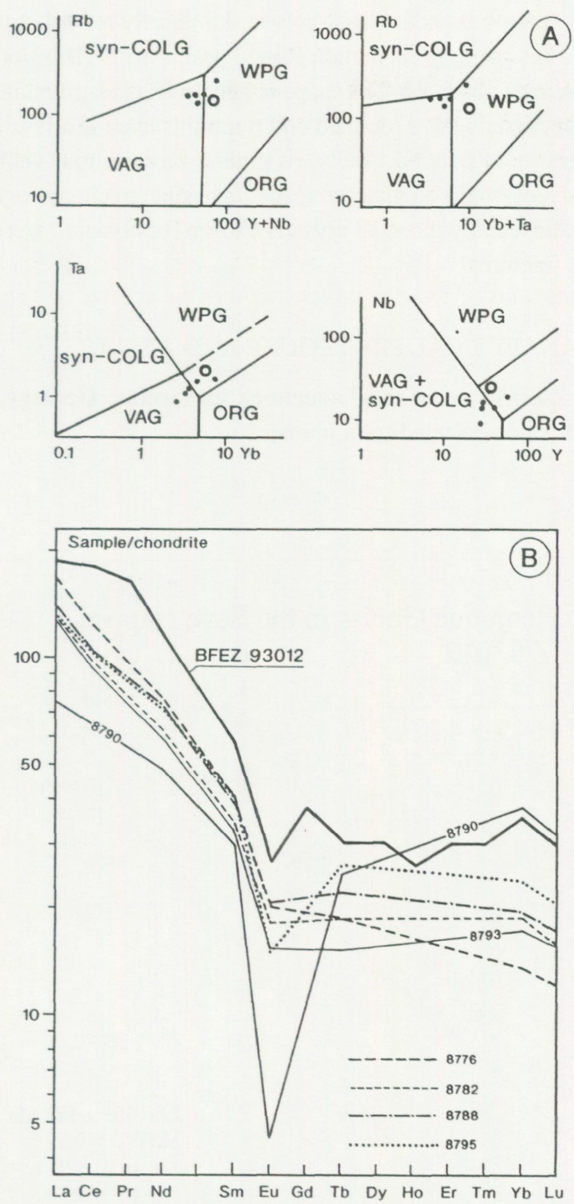


Fig. 4. A. Tectonic discrimination diagrams (acc. to Pearce et al. 1984) for the Nuortenjuone Gneiss (open circle). All concentrations are in ppm. ORG = ocean ridge granites; syn-COLG = syn-collision granites; VAG = volcanic arc granites; WPG = within-plate granites. B: REE pattern for the Nuortenjuone Gneiss (BFEZ 93012). For comparison, data from a granitoid immediately west of TIB (Gösta granite, Lindh & Johansson 1995) are also shown (dots in A, thin lines in B).

The dated rock contains abundant light-coloured to faintly reddish zircons, most of which are unzoned, but strongly metamict. Zoned grains with clear cores and metamict edges are sometimes observed. The shape is generally short prismatic, sometimes more elongate. Most crystals have rounded end pyramids even if a few, and especially the short ones, are more pointed. Analyzed grains were without visible cores and overgrowths. Abundance of zircon material made it possible to choose crystals of good quality for analysis. Especially those 13 crystals chosen for abrasion were of excellent quality and without fractures.

ANALYTICAL PROCEDURE AND RESULTS

The analyses were carried out at the Laboratory for Isotope Geology, Museum of Natural History, Stockholm. See editor's preface.

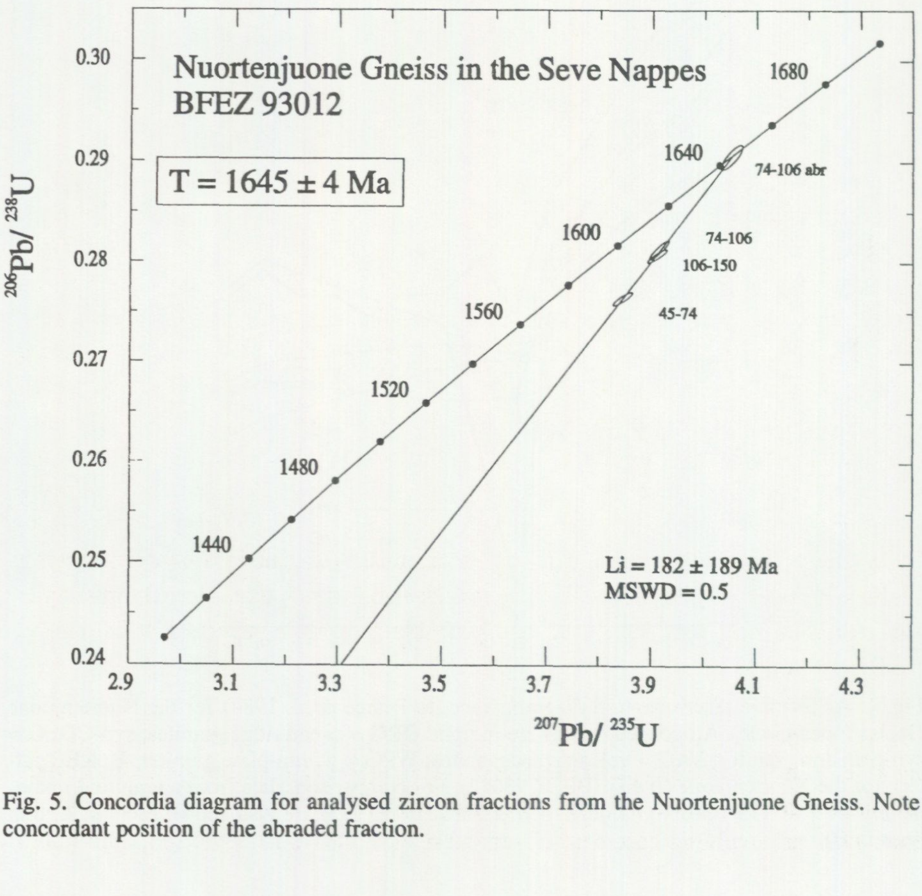


Fig. 5. Concordia diagram for analysed zircon fractions from the Nuortenjuone Gneiss. Note concordant position of the abraded fraction.

U and Pb analyses, U/Pb ratios and apparent radiometric ages for the different zircon fractions of sample BFEZ 93012 are displayed in Table 2. On a concordia diagram (Fig. 5), they form a well-defined linear trend (MSWD=0.5). The upper intercept (and the concordant abraded zircon fraction) give an age of 1645±4 Ma.

Table 2. U-Pb isotopic data for zircon fractions from the Nuortenjuone Gneiss (sample BFEZ 93012).

Size fraction (µm)	Weight (mg)	U (ppm)	Pb tot. (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)
45-74	0.14	228.3	67.8	18558	80.2 - 8.1 - 11.7	0.2764±6	3.844±15	1640
74-106	0.09	228.5	68.9	14499	80.2 - 8.1 - 11.7	0.2813±8	3.914±16	1641
74-106 ab	0.04	132.6	42.0	5481	79.2 - 8.0 - 12.8	0.2906±10	4.053±17	1646
106-150	0.13	239.9	73.2	16309	79.2 - 8.0 - 12.8	0.2807±6	3.910±16	1643

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

DISCUSSION AND CONCLUSIONS

The presence of Precambrian basement rocks in the Lower and Middle Allochthons is well established and some of them have been dated (e.g. Claesson 1980). Attempts have also been made to distinguish similar rocks within the Seve Nappes. A summary of datings of Seve rocks is presented in Table 3. Early Rb-Sr work gave an indication that old material was involved as did the first dating by the U-Pb method on zircon concentrates. Ion probe analysis of single zircons (Williams & Claesson 1987) proved that the high-grade gneisses and migmatites contain detrital zircon grains of an age of 1000–1700 Ma, a measure of the age of the provenance area.

The dating of the Nuortenjuone Gneiss has revealed for the first time a Proterozoic protolith age for a rock constituent within the Seve Nappes. This orthogneiss occurs in the lower eastern Seve unit, which is thought to have been derived from a pre-Caledonian position along the margin of continent Baltica, inboard of the overlying middle and upper Seve thrust sheets. The results also indicate that internal thrusting is present within the lower Seve unit, and probable tectonic contacts exist below the orthogneiss zones. Therefore, at the map scale, it is possible for the first time to subdivide the Eastern Schist and Amphibolite Belt into several distinct tectonostratigraphic units, composed of basement and cover. This is of general importance since it shows that at least the lower Seve part of the Upper Allochthon is an imbricate unit and thus comparable in its structure with the underlying Middle and Lower Allochthons, where thrust systems involving basement-cover imbricates are well known (e.g. Björklund

Table 3. Selected, published isotopic age data for Seve rocks from the Swedish Caledonides. For location, see Figure 1.

Location	Method	Age (Ma)		Reference
		Metamorphism, cooling (uplift)	Provenance	
Åreskutan	U-Pb		1570±25	Claesson 1982
Åreskutan	$^{40}Ar/^{39}Ar$ (hbl)	455-484		Dallmeyer, Gee & Beckholmen 1985
Grapesvare	$^{40}Ar/^{39}Ar$ (hbl)	491±8		Dallmeyer & Gee 1986
Murusjøen	U/Pb zircon (convent.)	423±26	1512±36	Claesson 1987
	Sm-Nd (T_{CHUR}, T_{DM})		1430, 1780	"
St. Blåsjön	U/Pb zircon (convent.)	369±38	1449±47	"
	Sm-Nd (T_{CHUR}, T_{DM})		1570, 1910	"
Åreskutan	Sm-Nd		1470, 1820	"
Kittelfjäll	Sm-Nd		1750, 2060	"
Gardiken	Sm-Nd		1510, 1880	"
St. Blåsjön	U/Pb zircon (ion probe)	423±5	1000-1700	Williams & Claesson 1987
Gardiken	"	453±19	941-1613	"
Åreskutan	"	441±10	769-1248	"
Gäddede	$^{40}Ar/^{39}Ar$ (hbl)	460-470 433-436		Dallmeyer & Gee 1988
Savotjåkka	$^{40}Ar/^{39}Ar$ (hbl)	490		Page 1992

1985, Greiling 1985, Gayer & Greiling 1989, Greiling *et al.* 1993). The proportion of basement and cover components is difficult to evaluate. Basement is probably quite restricted.

The tectonostratigraphic position of the Nuortenjuone Gneiss implies that this unit of the Seve Nappes has been thrust from an original position considerably west of the present Norwegian coast (Asklund 1962, Gayer & Greiling 1989). Such large distances make it difficult to suggest a correlation with the Precambrian rocks of the platform. It is evident that rocks of a similar age are probably not present in the Proterozoic areas of the Västerbotten or Norrbotten Counties (e.g. Lundqvist 1979). In tectonic discrimination diagrams (Fig. 4) the Nuortenjuone Gneiss shows WPG characteristics similar to some granitoids immediately west of the Transscandinavian Igneous Belt (TIB) in southwestern Sweden (Fig. 1). The TIB can be followed on the basis of aeromagnetic data far below the Caledonian thrust sheets into western Norway (e.g. Gaál & Gorbatschev 1987). The new evidence provided here apparently supports such a model.

ACKNOWLEDGEMENTS

Fieldwork and analyses were financed by the Geological Survey of Sweden (SGU) within the frame of the inter-Nordic Mid-Norden Project. Norm calculations by R. Altherr and technical assistance by J.M. Bartusch, I. Knapp and K. Schacherl (all University of Heidelberg) are gratefully acknowledged as well as suggestions and comments from D.G. Gee and A. Lindh. M.B. Stephens read and improved the final manuscript.

REFERENCES

ANDRÉASSON, P.G., 1994: The Baltoscandian Margin in Neoproterozoic-early Palaeozoic times. Some constraints on terrane derivation and accretion in the Arctic Scandinavian Caledonides. – Tectonophysics 231, 1–32.

ASKLUND, B., 1962: Berggrunden inom fjällkedjan och dess randområden. *In* Beskrivning till karta över Sveriges berggrund. – Sveriges geologiska undersökning Ba 16, 171–224.

BJÖRKLUND, L., 1985: The Middle and Lower Allochthons in the Akkajaure–Tysfjord area, northern Scandinavian Caledonides. *In* Gee, D.G. & Sturt, B.A. (eds.): The Caledonide Orogen – Scandinavia and Related Areas. – John Wiley & Sons, Chichester, 515–528.

CLAESSON, S., 1980: A Rb-Sr isotope study of granitoids and related mylonites in the Tännäs Augen Gneiss Nappe, southern Swedish Caledonides. – Geologiska Föreningens i Stockholm Förhandlingar 102, 403–420.

– 1982: Caledonian metamorphism of Proterozoic Seve rocks on Mt. Åreskutan, southern Swedish Caledonides. – Geologiska Föreningens i Stockholm Förhandlingar 103, 291–304.

– 1987: Isotopic evidence for the Precambrian provenance and Caledonian metamorphism of high grade paragneisses from the Seve Nappes, Scandinavian Caledonides. I. Conventional U-Pb zircon and Sm-Nd whole rock data. – Contributions to Mineralogy and Petrology 97, 196–204.

DALLMEYER, R.D. & GEE, D.G., 1986: 40Ar/39Ar mineral dates from retrogressed eclogites within the Baltoscandian miogeocline: implications for a polyphase Caledonian orogenic evolution. – Bulletin of the Geological Society of America 97, 26–34.

– 1988: Polyorogenic 40Ar/39Ar mineral age record in the Seve and Köli Nappes of the Gäddede area, northwestern Jämtland, Central Scandinavian Caledonides. – Journal of Geology 96, 181–198.

DALLMEYER, R.D., GEE, D.G. & BECKHOLMEN, M., 1985: 40Ar/39Ar mineral age record of early Caledonian tectonothermal activity in the Baltoscandian miogeocline, central Scandinavia. – American Journal of Science 285, 532–568.

GAÁL, G. & GORBATSCHEV, R., 1987: An outline of the Precambrian evolution of the Baltic Shield. – Precambrian Research 35, 15–52.

GAYER, R.A. & GREILING, R.O., 1989: Caledonian nappe geometry in north-central Sweden and basin evolution on the Baltoscandian margin. – Geological Magazine 126, 499– 513.

GEE, D.G., 1975: A tectonic model for the central part of the Scandinavian Caledonides. – American Journal of Science 275A, 468–515.

GREILING, R.O., 1985: Strukturelle und metamorphe Entwicklung an der Basis grosser, weittransportierter Deckeneinheiten am Beispiel des Mittleren Allochthons in den zentralen Skandinavischen Kaledoniden (Stalon-Deckenkomplex in Västerbotten, Schweden). – Geotektonische Forschungen 69, 129 pp.

GREILING, R.O., GAYER, R.A. & STEPHENS, M.B., 1993: A basement culmination in the Scandinavian Caledonides formed by antiformal stacking (Bångonåive, northern Sweden). – Geological Magazine 130, 471–482.

KULLERUD, K., STEPHENS, M.B. & ZACHRISSON, E., 1990: Pillow lavas as protoliths for eclogites: evidence from a late Precambrian-Cambrian continental margin, Seve Nappes, Scandinavian Caledonides. – Contributions to Mineralogy and Petrology 105, 1–10.

KULLING, O., 1972: The Swedish Caledonides. *In* de Sitter, L.U. (ed.): Scandinavian Caledonides. – Wiley Interscience, London, 149–285.

LINDH, A. & JOHANSSON, I., 1995: Granitic rocks as a source of granite: The Gösta and Sundsta Granites, south-west Sweden. – Geologische Rundschau 84, 164–174.

LUNDQVIST, T., 1979: The Precambrian of Sweden. – Sveriges geologiska undersökning C 768, 87 pp.

PAGE, L.M., 1992: 40Ar/39Ar geochronological constraints on timing of deformation and metamorphism of the Central Norrbotten Caledonides, Sweden. – Geological Journal 27, 127–150.

PEARCE, J.A., HARRIS, B.W.H. & TINDLE, A.G., 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. – Journal of Petrology 25, 956–983.

SJÖSTRÖM, H., 1984: The Seve-Köli Complex of the Handöl–Storlien—Essandsjöen area, Scandinavian Caledonides. – Geologiska Föreningens i Stockholm Förhandlingar 105, 93–118.

STEPHENS, M.B., 1988: The Scandinavian Caledonides: a complexity of collisions. – Geology Today 4, 20–26.

STEPHENS, M.B. & GEE, D.G., 1989: Terranes and polyphase accretionary history in the Scandinavian Caledonides. – Geological Society of America, Special Paper 230, 17–30.

STEPHENS, M.B. & VAN ROERMUND, H.L.M., 1984: Occurrence of glaucophane and crossite in eclogites of the Seve Nappes, southern Norrbotten Caledonides, Sweden. – Norsk Geologisk Tidsskrift 64, 155–163.

STEPHENS, M.B., KULLERUD, K. & CLAESSON, S., 1993: Early Caledonian tectonothermal evolution in outboard terranes, central Scandinavian Caledonides: new constraints from U-Pb zircon dates. – Journal of the Geological Society London 150, 51–56.

TÖRNEBOHM, A.E., 1888: Om fjällproblemet. – Geologiska Föreningens i Stockholm Förhandlingar 10, 328–336.

TROUW, R.A.J., 1973: Structural geology of the Marsjällen area, Caledonides of Västerbotten, Sweden. – Sveriges geologiska undersökning C 689, 155 pp.

VAN ROERMUND, H.L.M. & BAKKER, E., 1984: Structure and metamorphism of the Tången-Inviken area, Seve Nappe, Central Scandinavian Caledonides. – Geologiska Föreningens i Stockholm Förhandlingar 105, 301–319.

WILLIAMS, I.S. & CLAESSON, S., 1987: Isotopic evidence for the Precambrian provenance and Caledonian metamorphism of high grade paragneisses from the Seve nappes, Scandinavian Caledonides. II. Ion microprobe zircon U-Th-Pb. – Contributions to Mineralogy and Petrology 97, 205–217.

ZACHRISSON, E., 1973: The westerly extension of Seve rocks within the Seve-Köli Nappe Complex in the Scandinavian Caledonides. – Geologiska Föreningens i Stockholm Förhandlingar 95, 243–251.

– 1993: Berggrundskartorna 23F Fatmomakke NV och SV, 1:50 000. – Sveriges geologiska undersökning Ai 75–76.

ZACHRISSON, E. & GREILING, R.O., 1993: Berggrundskartorna 23F Fatmomakke NO och SO, 1:50 000. – Sveriges geologiska undersökning Ai 77–78.

ZWART, H. J., 1974: Structure and metamorphism of the Seve-Köli Nappe Complex (Scandinavian Caledonides) and its implications concerning the formation of metamorphic nappes. *In* Belliere, J. *et al.* (eds.): Geologie des Domains Cristallins. – Société géologique de Belgique, Liège, 129–144.

Distribution

SGU
Box 670
S-751 28 UPPSALA
Sweden
Tel 018-17 90 00
Fax: 018-17 93 70

ISBN 91-7158-556-7
ISSN 1103-3371

Printed by Gotab, Stockholm 1996