Research Papers

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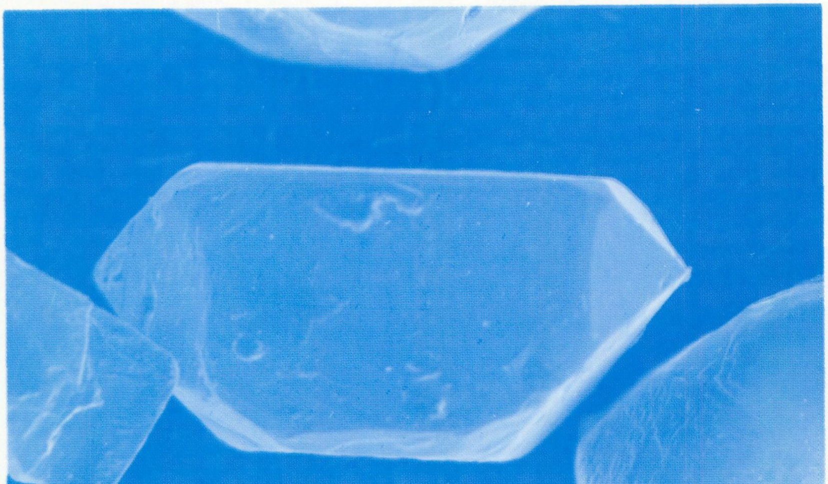
Forskningsrapporter

Radiometric dating results

Division of Bedrock Geology

Geological Survey of Sweden

Edited by Thomas Lundqvist



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Geological Survey of Sweden

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EDITOR'S PREFACE

During the latest years, a number of radiometric age determinations have been carried out on assignment from the Bedrock Section of the Geological Survey of Sweden (SGU). The datings form part of the bedrock mapping programme of the Survey.

Since it is not possible to give but a very brief account of the dating results in the descriptions to the various bedrock maps, it has been considered highly desirable to summarize the results in the SGU series C 823. In this way, the results will, with no great delay, be available also to colleagues of other institutions, involved in research etc. in which geochronological data form an integral part. According to the plans, papers containing dating results will continuously be published in SGU series C as soon as a sufficient number of age determinations are available.

Two isotope laboratories have carried out the analyses and datings of the present paper: The Laboratory for Isotope Geology, Swedish Museum of Natural History, Stockholm (head Prof. Stefan Claesson) and the Unit for Isotope Geology, Geological Survey of Finland, Espoo (head Dr. Matti Vaasjoki). Each paper contains information on which laboratory has done the dating.

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 summarized as follows:

The zircons were separated using standard magnetic and heavy liquid techniques and were dissolved in $HF:HNO_3$ in Teflon bombs according to the method of Krogh (1973). A ^{235}U tracer was added to the solution, which then was aliquotted. One aliquot was spiked with a ^{208}Pb tracer. After evaporation, the sample aliquots were dissolved in 3.1 N HCl and loaded onto cation exchange columns with 50 µl resin volume for extraction of Pb and U. The isotopic analyses were carried out on a Finnigan MAT 261 mass spectrometer with five Faraday cups. The calculation of the corrected isotope ratios and the error propagation were made using the equations of Ludwig (1980), and the decay constants recommended by Steiger and Jäger (1977) were used. The calculation of the intercept age and the concordia plot were made with version 2.53 of the program by Ludwig (1991). The Pb blank level was 40–100 pg. The assigned composition of common Pb is: $^{206}Pb/^{204}Pb$=15.5, $^{207}Pb/^{204}Pb$=15.3 and $^{208}Pb/^{204}Pb$=35.1, calculated according to the Pb evolution model of Stacey and Kramers (1975). All analytical errors are given as 2 σ.

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Acknowledgements: The authors are much indebted to Birgitta Bygghammar and Agneta Ek for their valuable help with the editorial work, to Barbro Landerborg for drawing maps and diagrams and to Kerstin Finn for typing.

Uppsala, May 1993

Thomas Lundqvist

U-Pb zircon dating of a trondhjemite and a quartz monzonite in the southeastern part of Västerbotten County, northern Sweden

By
Leif Björk

INTRODUCTION

The sketch map in Fig. 1 shows a small part of the currently remapped area in the southeastern part of Västerbotten County (Björk & Kero 1992). The bedrock in this region is composed of Svecofennian supracrustals, mainly more or less migmatized metagreywackes, which have been intruded by acid and basic magmas resulting in early-, late- and postorogenic plutons.

The rock forming events in this region are similar to those in the neighbouring northern part of Västernorrland County described by Lundqvist *et al.* (1990). The events can be summarized as follows: Nearly 1900 Ma ago greywackes with conglomerates as well as acid and basic volcanic rocks including pillow lavas and agglomerates built a volcano-sedimentary sequence. Both the basement and the overlying rocks of this sequence are unknown. Early-orogenic gabbroid and granitoid magmas intruded the supracrustal rocks about 1880 Ma ago. 1850–1820 Ma ago folding and metamorphism gave rise to veining and stronger migmatization. Shortly after this, about 1780 to 1820 Ma ago late-orogenic magmas, belonging to the Härnö suite, and postorogenic magmas, belonging to the Revsund suite, intruded. The magmas of the latter suite gave rise to some folding and contact metamorphism of the supracrustal rocks. Faulting, occasionally with major vertical movements, occurred. Dolerite dykes postdate all the other rocks in the area and are presumably about 1200 Ma in age.

During the field work attention was drawn to intrusives of trondhjemitic and quartz monzonitic composition. Contact relations to the surrounding bedrock are too poorly exposed to allow a chronologically accurate estimate of the age of intrusion. An attempt to solve the problem by U-Pb zircon dating was therefore made.

TRONDHJEMITE

The trondhjemite in this area is a pale to reddish grey, fine-grained, massive rock which has a field appearance quite similar to that of the fine-grained late-kinematic Härnö granites. Mineralogically it consists of 63% plagioclase, 32–35% quartz, 3–5% biotite and accessory amounts of apatite, zircon, tourmaline and opaque minerals. Susceptibility is low, 0–5 x 10^{-5} SI units, and the trondhjemite is a low-radiating rock with a radium index of 0.04 ±0.04. Lundqvist *et al.* (1990) favour the conclusion that trondhje-

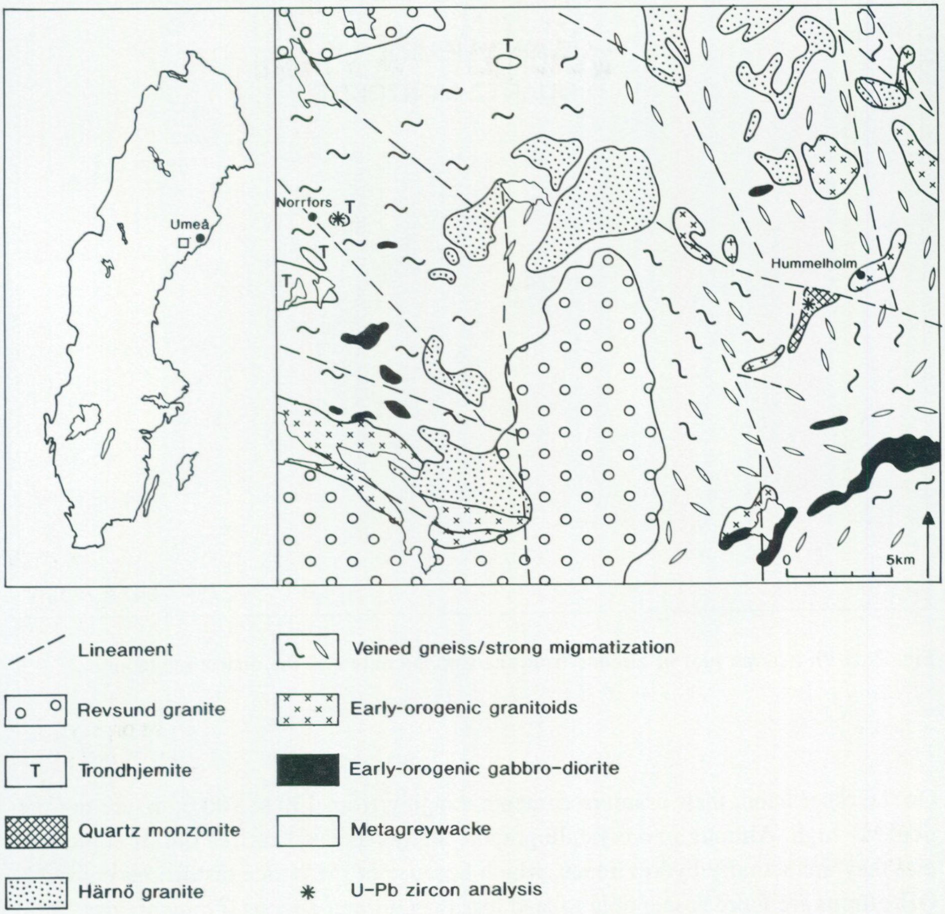

Fig. 1. Sketch map showing the geology and sample sites.

mites in Västernorrland County belong to the postorogenic Revsund suite of granitoids, but they also point out the possibility that these rocks in fact may belong to other events of intrusion, namely to the early-orogenic suite, as is the case in other parts of Sweden.

A sample of trondhjemite was taken from a minor massif near Norrfors (map-sheet 20J Vännäs, 707755/165810) and the U-Pb zircon analyses were carried out at the Unit for Isotope Geology, Geological Survey of Finland, under supervision of Dr. Matti Vaasjoki. The results are shown in Tables 1 and 2 and in Fig. 2. Vaasjoki summarizes the results of the analyses: "The zircons in the rock are relatively fine-grained (90% < 70 µm), turbid, pale brown and rounded crystals with scarce well-defined crystal faces. A striking feature is their low density, reflecting a high degree of metamictization.

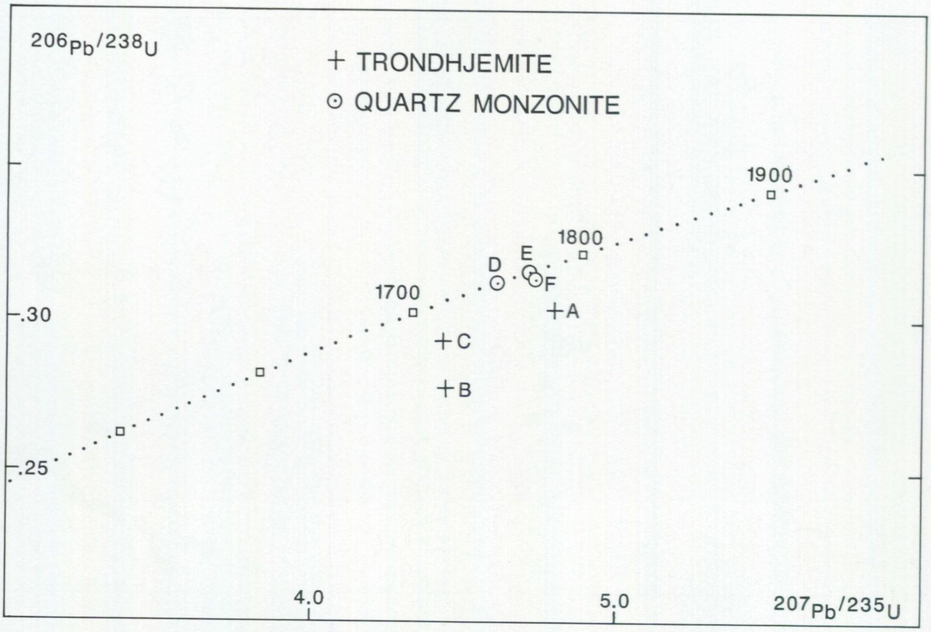

Fig. 2. U-Pb isotope plot of zircons from the trondhjemite and the quartz monzonite.

On the other hand, their uranium contents, ranging from 130 to 700 ppm, are not particularly high. Although no crystallographic study has been carried out, it is probable that they are actually hydrozircons, which because of the lattice distortions caused by OH-groups are more susceptible to lead loss than normal zircons (Grunenfelder 1963). The occurrence of hydrozircons would also fit the water-rich conditions under which trondhjemites are formed.

The three analyzed fractions exhibit a random scatter on the concordia diagram with $^{207}Pb/^{206}Pb$ ages ranging from 1790 to 1900 Ma. This scatter may be interpreted either as a function of multiple episodic events and a superimposed continuous diffusion since the formation of the minerals about 1900 Ma ago or as an indication of an originally heterogeneous zircon population inherited from a sedimentary source to a rock formed at least 1800 Ma ago. The present data are insufficient to discriminate between the two interpretations and additional Sm-Nd and Rb-Sr analyses on both mineral and whole rock samples as well as careful petrological studies are required to discriminate between the two alternative solutions. It should be noted in this context that, according to Finnish experience (Patchett & Kouvo 1986) inconclusive zircon ages from trondhjemites are by no means a rarity."

QUARTZ MONZONITE

The quartz monzonite south of Hummelholm (map-sheet 20J Vännäs, 707315/168030) was also subjected to U-Pb zircon analyses. It is a dark grey, in places reddish grey, medium-grained, massive rock. Mineralogically it is composed of 32% plagioclase, 24% microcline, 18% biotite, 15% quartz, 9% hornblende, 1% sphene, 1% apatite, 1% opaque minerals and rare small grains of zircon, allanite and calcite. Its susceptibility is ranging from 15 to 250 x 10^{-5} SI units and its radium index is 0.22 ± 0.11. The quartz monzonite cuts migmatized metagreywackes which clearly indicates a postmigmatitic age. However, no contacts against intrusive rocks have been found.

Gavelin (1955, p. 34) reports quartz monzonitic rocks occurring in connection with Sorsele granitoids in the northern part of Västerbotten County. He furthermore mentions results by Högbom and Grip, strongly indicating that these rocks belong to the Sorsele granitoid suite. The U-Pb zircon age of Sorsele granite is 1791 ±22 Ma (Skiöld 1988).

Persson (1978), in his geochemical and petrological studies of the Revsund granitoid suite, has shown a differentiation trend from quartz monzodiorite to granite. According to these results and to the similarity of the regional geology, the quartz monzonite most likely belongs to the postorogenic Revsund suite. The granitoids of the latter have U-Pb zircon ages ranging from 1778 ±16 Ma in the northern part of Västerbotten County (Skiöld 1988) to 1798 ±8 Ma in the northern part of Västernorrland County (Claesson & Lundqvist 1990). In Jämtland County U-Pb dating has yielded 1787 ±9 Ma (Patchett *et al.* 1987).

The U-Pb zircon analyses of the quartz monzonite were carried out at the Unit of Isotope Geology, Geological Survey of Finland. The results are shown in Tables 1 and 2 and in Fig. 2. Dr. Matti Vaasjoki writes in his report: "The quartz monzonite contains relatively little zircon, which is euhedral with some growth zoning and sporadic inclusions of older, somewhat resorbed zircons. The grain size of the zircon is fairly large, about 90% of the separated material being more than 150 µm in diameter.

Three fractions were analyzed for the present study. All are relatively concordant, which probably is a result of the low U contents of all fractions (200–300 ppm). The apparent ages vary from 1740 to 1790 Ma, suggesting that the rock belongs to the Revsund suite.

However, the data do not plot on a straight line, and, moreover, there is a discrepancy in the $^{207}Pb/^{206}Pb$ ages, as one of the fractions (F) has a significantly higher Pb/Pb age than the other two. Also, in contrast to the pattern generally observed in magmatic rocks, the abraded fraction (D) is slightly more discordant than the others. This feature suggests that the zircons may contain older, inherited cores in a similar fashion as described for the 1830 Ma old Hangö-type granites, which unequivocally consist of remobilised Svecokarelian crust (cf. Huhma 1986 and Suominen 1991).

In summary, the present result suggests that while the quartz monzonite no doubt belongs to the Revsund granitoid suite it probably consists of older remobilized

TABLE 1. U-Pb analyses of zircons from the trondhjemite and the quartz monzonite.

Sample	Fraction	Concentrations			Lead ratios, 206=100		
		^{238}U	Pb(tot)	$^{206}Pb/^{204}Pb$	^{204}Pb	^{207}Pb	^{208}Pb
Trondhjemite							
A	>4.0/>70µm	134.4	42.30	2412	0.04145	12.04	7.03
B	>4.0/<70µm	215.7	66.19	1123	0.08905	12.82	13.00
C	3.3-4.0	691.5	204.74	2324	0.04303	11.57	4.39
Quartz monzonite							
D	>4.5/>150µm/abr	234.4	77.69	7001	0.0142	11.07	11.80
E	>4.5/>150µm	226.9	76.30	6514	0.0154	11.07	11.96
F	4.3-4.5	274.9	74.32	4659	0.0215	11.24	12.32

Concentrations in µg/g; corrected for blank.

TABLE 2. U/Pb ratios and apparent radiometric ages for zircons from the trondhjemite and the quartz monzonite.

Sample	Atomic ratios			Apparent ages (Ma)		
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	T (6/8)	T (7/5)	T (7/6)
Trondhjemite						
A	0.3030	4.794	0.1147	1706	1783	1875
B	0.2773	4.439	0.1161	1577	1719	1897
C	0.2928	4.432	0.1098	1655	1718	1796
Quartz monzonite						
D	0.3106	4.656	0.1087	1743	1759	1778
E	0.3147	4.713	0.1086	1763	1769	1776
F	0.3124	4.716	0.1095	1752	1770	1790

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

Svecokarelian crust. This conclusion could be tested by further work on zircons combined with whole rock analyses utilizing the U-Pb, Sm-Nd and Rb-Sr methods."

CONCLUSIONS

The additional work suggested by Vaasjoki has not been carried out, due to decreasing fundings. Thus, the precise age of the trondhjemites in the southeastern part of Västerbotten County still remains unsolved, although it can safely be considered to fall in the interval 1790–1900 Ma.

The results and the conclusions drawn by Vaasjoki regarding the age of the quartz monzonite are in agreement with Persson's (1978) field observations: intrusion of quartz monzonite in the western parts of the province of Ångermanland is closely related to the intrusion of Revsund granite.

Acknowledgements. Professor Thomas Lundqvist has participated in several excursions in the area and his contribution both to the field work and this manuscript has been of greatest value. Dr. Matti Vaasjoki has, despite the minimal fundings, managed to increase our knowledge of the geochronology and made many suggestions regarding further work.

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The radiometric age of the Ljusdal granodiorite of central Sweden

By
Hans Delin

GEOLOGICAL SETTING

The Ljusdal granitoid intrusion belongs to the Svecofennian part of the Svecokarelian province, and it occurs in a vast area in Hälsingland, southern Norrland, from the coast of the Gulf of Bothnia and about 100 km westwards (Lundegårdh 1967, Lundqvist 1968 and 1979). Its northern margin is an almost continuous intrusive contact against meta-sedimentary rocks of the Bothnian Basin, mainly of greywacke composition (Lundqvist *et al.* 1990), while in the south there is a more complex connection with the Bergslagen volcanic lithologies. The western part of the intrusion is cut by the Transscandinavian Granite-Porphyry Belt.

The granitoid body has a mostly granodioritic to tonalitic composition, but the northern margin shows more felsic granitic types. Most of these rocks are coarsely porphyritic with numerous microcline megacrysts of different size and shape. Xenoliths of metasupracrustal rocks are quite frequent, in part on a mega-scale. Some minor, mafic bodies are also included in the Ljusdal intrusion. High-grade metamorphism has affected the whole region, and garnet, cordierite and sillimanite co-existing with potassium feldspar frequently occur. From the Ljusdal area hypersthene-bearing tonalite is reported (Lundegårdh 1967). Strong Svecokarelian deformation has worked upon this region, and the Ljusdal intrusion is considered to have an early-orogenic or synorogenic tectonic position.

BACKGROUND

During the regional mapping of the northern Hälsingland area, a number of different granitoids were defined (cf. Delin 1989). Both their relative and absolute ages were in several cases unknown, and therefore five granitoids were sampled for age determination. The sample from the Ljusdal granodiorite, which is supposed to be the oldest intrusion, will be reported here. Radiometric ages of four other granitoids have been published in the short description of the geological map-sheets 16F Kårböle (Delin & Aaro 1991) and will also be reported in a future issue of this publication.

SAMPLE HD86018

The sample site is located at lake Gryttjen, about 10 km east of Ljusdal community in map-sheet 16G Ljusdal SO, coordinates 665370/152800. This rock is a strongly

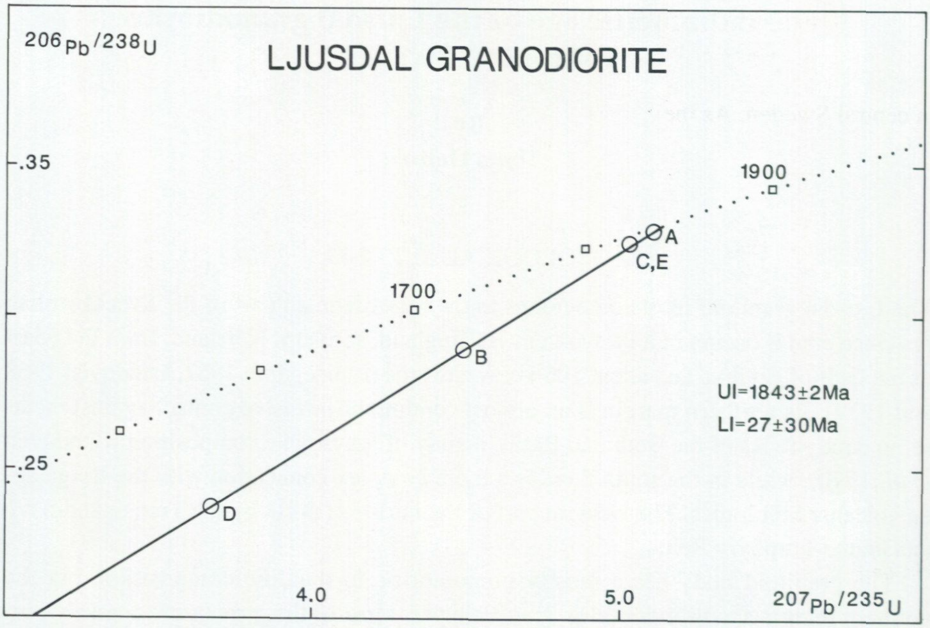

Fig. 1. Concordia diagram for analyzed zircon fractions from the Ljusdal granodiorite, sample HD86018.

deformed, coarsely porphyritic grey granodiorite with an abundance of microcline megacrysts. Metamorphism in this region has reached the grade of upper amphibolite facies, in places even higher (granulite facies).

AGE DETERMINATION

The radiometric dating was carried out at the Unit for Isotope Geology, Geological Survey of Finland, under the supervision of Dr. Matti Vaasjoki.

The rock contains two types of zircon: turbid, pale brown simple prismatic-pyramidal crystals with a L/B ratio of 2–5 and translucent, brown grains with poorly defined crystal faces. Two representative fractions of the former and three of the latter morphological type were handpicked for analysis. The results are surprising in that the morphologically poor fractions are almost concordant with fraction A having a concordancy degree of 99.2%. The most discordant data point (D) has also the highest uranium content, while the other four fractions are almost equal at around 650 ppm (Tables 1 and 2).

When all five data points are used for the age calculation, they define a linear array with an upper intersect at 1843±2 Ma and a lower intersect at 27±30 Ma (Fig. 1). If the morphologically well formed, more discordant zircons (fractions B and D) are ex-

TABLE 1. U-Pb analyses of zircons from the Ljusdal granodiorite, sample HD86018.

Sample	Fraction	Concentrations			Lead ratios, 206=100		
		^{238}U	Pb(tot)	$^{206}Pb/^{204}Pb$	^{204}Pb	^{207}Pb	^{208}Pb
A	>4.5/undef.	644.6	224.33	2474	0.0404	11.84	9.72
B	>4.5/long	669.2	167.64	2016	0.0496	11.93	9.58
C	4.3-4.5/undef.	646.6	221.30	2768	0.0361	11.74	9.43
D	4.3-4.5/long	1280.4	333.99	947	0.1055	12.68	12.01
E	4.3-4.5/<70µm	642.7	218.43	4111	0.0243	11.59	8.93

Concentrations in µg/g; corrected for blank.

TABLE 2. U/Pb ratios and apparent radiometric ages for zircons from the Ljusdal granodiorite, HD86018.

Sample	Atomic ratios			Apparent ages (Ma)		
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	T (6/8)	T (7/5)	T (7/6)
A	0.3283	5.109	0.1129	1830	1837	1846
B	0.2895	4.491	0.1125	1639	1729	1840
C	0.3241	5.028	0.1125	1809	1824	1840
D	0.2372	3.676	0.1124	1372	1566	1838
E	0.3242	5.033	0.1126	1810	1824	1841

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

cluded from the calculation, the results become 1852 +25/-8 and 699 +545/-529 Ma. In this case the large error estimate is a mathematical artifact, as fractions A, C and E plot close to each other.

If the first calculation is accepted, it follows that the zircon data reflect either the age of intrusion or the occurrence of a high-grade thermal metamorphism, i.e. granulite facies. As no other isotopic data are readily available from the area, the decision between the two alternative interpretations must rely on petrological data.

The second calculation implies that fractions B and D would represent an inherited zircon phase, considerably older than the other analyzed fractions. As the $^{207}Pb/^{206}Pb$ ages of all the five fractions are in the order of 1840 Ma, this supposition is not supported by analytical data. Thus, the best age estimate for the zircons in sample HD86018 is 1843±2 Ma.

CONCLUSIONS

The estimated zircon age of the Ljusdal granodiorite is somewhat low compared to the results of age determinations of other synorogenic granitoids in central Sweden. As the metamorphism in places has reached a very high grade (i.e. granulite facies), the zircon age 1843 ±2 could reflect a metamorphic event rather than the true age of the intrusion. It also defines the minimum age of the granodiorite. One more sample of this rock (in prep. 1993) will be age-determined and this result may give a more definite age of the Ljusdal intrusion.

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U-Pb zircon ages of three granite samples from Blekinge County, south-eastern Sweden

By
Karl-Axel Kornfält

INTRODUCTION

Not far from the E–W Småland–Blekinge county border, and in the same direction, runs the boundary between the Småland granite (belonging to the Transscandinavian Granite-Porphyry Belt) in the north, and a grey gneissic granitoid (Tving granite) in the south. The latter is actually as a rule a granodiorite or tonalite.

The character of this border zone, the Småland-Blekinge zone, is so far rather unknown as the outcrops are very few in the most interesting area. No unambiguous intrusive relationship between the two rock units has been observed during the mapping. A few observations of strongly deformed granitoids point instead to a tectonic origin (at least in part) of the zone. The first one to suggest a tectonic lineament along the border was Wiklander (1974).

The Småland-Blekinge zone has since the earliest geological mapping of this region appeared very conspicuous on the maps, owing to the fact that different colours have been chosen in order to reflect the different ages of the two rock units, of which the Tving granite was regarded as the oldest. Hedström (in Hedström & Wiman 1906) pointed out the similarity between the Tving granite and the grey Växjö granite (a variety of Småland granite). And so did Norin (1936), who believed that the gneissic granites of Tving granite type from western Blekinge were more or less metamorphic equivalents of the Småland granites.

According to another opinion the Tving granite is definitely older than the Småland granite (Wiklander 1974).

An earlier dating of the Tving granite from the Tving village, c. 7 km south of the Småland-Blekinge zone, has given an U-Pb age of 1771±4 Ma (Johansson & Larsen 1989). The nearest Småland granite which has been dated is from a road cut 14 km ESE of Växjö, and more than 60 km NW of the zone. This U-Pb dating has yielded 1769±9 Ma (Jarl & Johansson 1988).

It thus seemed quite important to get new datings of the rocks on each side of the Småland-Blekinge zone and close to it. Sample KK 90:100 was taken from a Småland granite c. 3 km north of the zone, and KK 90:101 from a Tving granite c. 1 km south of the zone.

Another question which has arisen during the mapping of south-eastern Blekinge is whether the porphyritic, weakly migmatized, gneissic granites occurring there, at a considerable distance from the Småland-Blekinge zone, and which are very similar to the

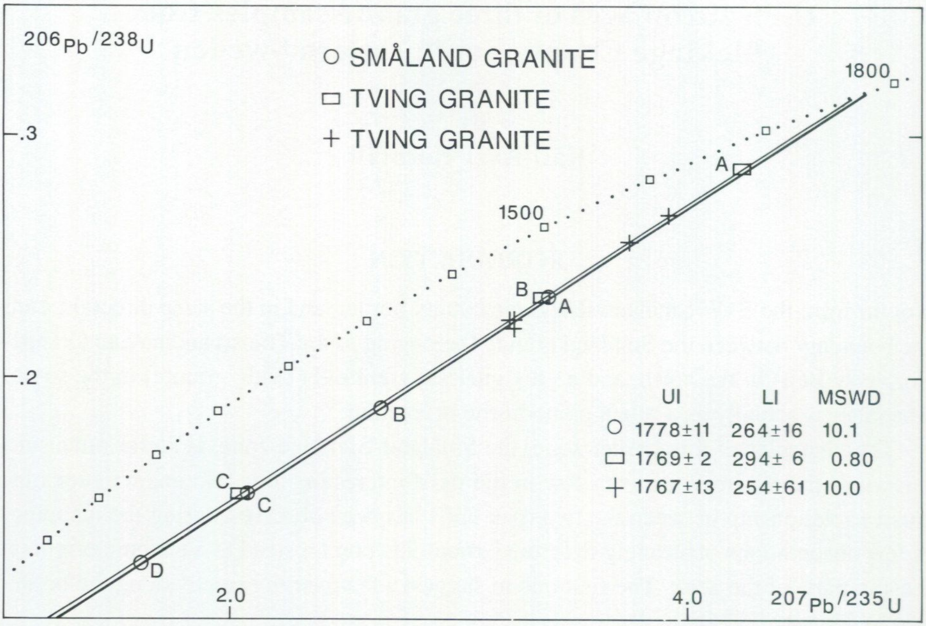

Fig. 1. Concordia diagram for analyzed zircon fractions from Småland granite (KK 90:100, circle) and Tving granite (KK 90:101, square) compared with recalculated values from the Tving granite published by Johansson & Larsen 1989 (cross).

Filipstad granite (a variety of Småland granite) actually could be of Småland granite age. Another interpretation could be that they are deformed varieties of a similar porphyritic rock occurring in the neighbourhood, the Karlshamn granite, which has yielded an U-Pb age of c. 1400 Ma (Åberg *et al.* 1985). The only way to get an answer of this question was to determine the age of the alleged Filipstad granite (sample KK 90:102).

SAMPLES

Sample KK 90:100 was a reddish grey, medium-grained Småland granite from a road cut at Falan, 11.5 km north of Rödeby church, along the road between Rödeby and Buggamåla. Map-sheet 3F Karlskrona NO; coordinates in the Swedish National grid: 624850/149014.

Sample KK 90:101 was a reddish grey, porphyritic (megacrysts 1–2 cm) gneissic granitoid (Tving granite) from a road cut at Strågedal, 2.8 km SE of Flymen church, along the road between Rödeby and Flyeryd. Map-sheet 3F Karlskrona NO; coordinates in the Swedish National grid: 624328/149757.

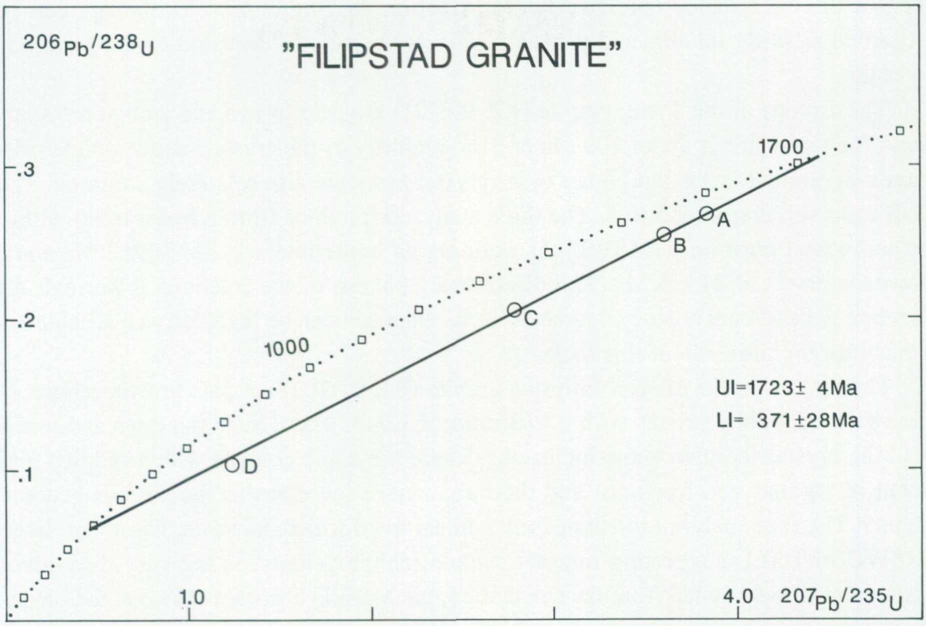

Fig. 2. Concordia diagram for analyzed zircon fractions from the alleged Filipstad granite.

Sample KK 90:102 was a reddish grey, porphyritic gneissic granite (similar to Filipstad granite) from a road cut at Torstäva, 2 km SW of Ramdala church, along the road between Lösen and Tjurkö. Map-sheet 3F Karlskrona NO; coordinates in the Swedish National grid: 622700/149570.

U-Pb ZIRCON DATING

The following section is quoted from a dating report from the Unit for Isotope Geology at the Geological Survey of Finland. The dating work has been performed there under the supervision of Dr. Matti Vaasjoki. See Figs. 1 and 2 and Tables 1 and 2.

The zircons of the Småland granite (sample KK 90:100) are pale brown translucent-transparent with occasional growth zoning but no cores detectable under normal light. The crystal habit is generally simple prismatic-pyramidal, but occasional higher index faces do occur. The length/breadth (L/B) ratio is 1.5–4 with a median at 2. The four analyzed fractions form a linear trend with an upper intersect at 1778±11 Ma (MSWD=10.06) and a lower intersect at 264±16 Ma. The discordancy pattern is normal, i.e. the discordancy increases with an increasing uranium content. Although the degree of concordancy is relatively low, fraction A lying at 69.4 %, the age can be regarded as fairly reliable and probably reflects the time of intrusion of the granite in question.

The zircons of the Tving granite (KK 90:101) are pale brown and almost transparent. The grain size is about 100 µm and the majority of the crystals show simple prismatic-pyramidal faces, but higher order crystal faces are also relatively common. The L/B ratio varies from 1.5 to 3. The three analyzed fractions form a linear trend within experimental error only (MSWD<1), defining an upper intersect at 1769±2 Ma and a lower intersect at 294±6 Ma. The discordancy pattern of the fractions is normal. As fraction A has a concordancy degree of 89 %, the result can be regarded as a reliable estimate for the intrusion of this rock.

The zircons of the alleged Filipstad granite (KK 90:102) are pale brown, relatively fine-grained stubby prisms with a L/B ratio of 1.5–3. The lighter fractions are zoned and the crystals contain some inclusions. There are some crystals with a reddish pigment in all analyzed fractions, and their abundance increases as the zircons become lighter. The four analyzed fractions form a linear trend which, however, has a very large MSWD of 100.1, suggesting internal sample inhomogeneity. If the very discordant data point D is excluded from the calculation, the MSWD becomes 0.63, i.e. the deviations from the best line for fractions A, B and C arise from analytical error only. This rejection is comparable to an assumtion that the discordancy pattern arises mainly from volume diffusion induced by radiation damage (e.g. Wasserburg 1963). This is in concert with the fact that the discordancy pattern of the samples is normal and the uranium content of fraction D is very high at 1700 ppm. When fraction D is excluded from the calculation, the upper intersect age is 1723±4 and the lower intersect age 268±33 Ma.

When compared to the published U-Pb zircon age of the Tving granite (Johansson & Larsen 1989), 1771±4 Ma, it seems that the ages of the Småland and Tving granites overlap within experimental error. Considering the Tving result of Johansson and Larsen, it should be noted, though, that evidently the deviating fraction C has been omitted from the calculation and the error has not been multiplied by the square root of the MSWD, which is the proper procedure. A recalculated value using the method of York (1969) and applying the error algorithm of Ludwig (1980) is 1767±13 Ma. Thus the present result for KK 90:100 and the previously published data for the Tving granite would allow the two rock units to be regarded as coeval within experimental error. However, the result from KK 90:101 renders this conclusion unlikely as the upper intersect age estimates for samples KK 90:100 and KK 90:101 barely overlap within the 95 % confidence interval. As the ages of the two Tving granite samples coincide, it is probable that 1770 Ma is very close to the true intrusion age of this rock.

TABLE 1. U-Pb analyses of zircons from the Blekinge area.

Sample	Fraction	Concentrations			Lead ratios, 206=100		
		^{238}U	Pb(tot)	$^{206}Pb/^{204}Pb$	^{204}Pb	^{207}Pb	^{208}Pb
KK 90:100-Falan (Småland granite)							
100A	>4.5	406.4	106.12	1545	0.0647	11.45	16.28
100B	4.3-4.5/>70μm	745.0	160.86	952	0.0105	11.73	18.66
100C	4.2-4.3/>70μm	1281.6	252.53	429	0.2333	13.13	30.20
100D	4.0-4.2/>70μm	1796.5	290.27	383	0.2608	13.15	31.96
KK 90:101-Strågedal (Tving granitoid)							
101A	>4.5	278.5	88.15	4538	0.0220	11.02	16.04
101B	4.3-4.5	559.5	144.18	2184	0.0458	11.11	15.45
101C	4.2-4.3	1192.9	207.13	933	0.1072	11.26	17.92
KK 90:102-Torstäva							
102A	>4.5/abr	237.0	70.32	1335	0.0749	11.41	14.68
102B	>4.5	272.7	74.43	2764	0.0362	10.78	12.36
102C	4.3-4.5	520.9	123.78	547	0.1830	12.46	18.13
102D	4.2-4.3	1811.8	321.34	116	0.8634	20.91	50.31

Concentrations in μg/g; corrected for blank; abr = abraded.

TABLE 2. U/Pb ratios and apparent radiometric ages for zircons from the Blekinge area.

Sample	Atomic ratios			Apparent ages (Ma)		
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	T (6/8)	T (7/5)	T (7/6)
KK 90:100						
100A	0.2332	3.395	0.1056	1725	1503	1351
100B	0.1877	2.661	0.1877	1675	1317	1109
100C	0.1524	2.080	0.0990	914	1142	1604
KK 90:101						
101A	0.2865	4.232	0.1071	1623	1680	1751
101B	0.2332	3.369	0.1048	1351	1497	1710
101C	0.1523	2.052	0.0977	914	1133	1581
KK 90:102						
102A	0.2683	3.838	0.1038	1531	1600	1692
102B	0.2542	3.607	0.1029	1460	1551	1677
102C	0.2036	2.787	0.0993	1194	1352	1610
102D	0.1026	1.247	0.0881	629	821	1384

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

DISCUSSION

As the age difference between the Småland granite and the Tving granite is no more than c. 8 Ma, it is very likely that the two rock units are the result of the same event. It is possible that after the intrusion of the Småland granite, an uplift of the southern Blekinge block relative to the Småland block followed, along the E–W Småland–Blekinge zone.

If this was the case a supposed retarded cooling of the deeper section of the crust, now forming the Tving granite, could explain the small difference in age between the two rock units.

The uplift of the southern block relative to the northern, which is confirmed by a few observations of the C/S fabric in the rocks, took place after the intrusion of the Småland granites, but before the intrusion of the 1400 Ma old Karlshamn granite.

The age of 1723 Ma obtained for the alleged Filipstad granite is too low for a typical Småland granite. It is on the other hand too high for a Karlshamn granite. The rock in question is foliated and weakly migmatized in contrast to the common Småland granites. Perhaps the deformation and migmatization of an original massive Filipstad granite could have caused an adjustment of its U-Pb age.

If the existence of Småland granites in south-eastern Blekinge can be unambiguously verified (which requires more datings) it would be natural to regard this part of Blekinge as belonging to the Transscandinavian Granite-Porphyry Belt but affected by deformation, and in part migmatization, in the interval c. 1750–1400 Ma.

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U-Pb zircon dating of volcanic rocks of the Åmål Group, western Sweden

By
Inger Lundqvist and Torbjörn Skiöld

Radiometric dating of rocks in the Baltic Shield has revealed a succession of ages from an Archaean nucleus in the northeastern part of the shield (Gaál and Gorbatschev 1987) to a Mid-Proterozoic terrain in the southwest. Thus there is a successive younging of the formation of crust towards the southwest where rocks have intruded in the time interval 1.8 Ga to 0.9 Ga ago. During 1.2 to 0.9 Ga ago, once linked with the Grenvillian of present north America, the Sveconorwegian orogeny affected the rocks of southwestern Sweden and southern Norway. This province is separated from the Svecofennian province to the east (Fig. 1) by the Transscandinavian Igneous Belt (Gorbatschev 1980, Gaál & Gorbatschev 1987). The Sveconorwegian province can be subdivided into north-south trending segments separated by major shear zones, the Göta Älv Zone, the Mylonite Zone and the Protogine Zone. The easternmost segment to the east of the Mylonite Zone is dominated by intermediate and felsic, veined, in some places banded orthogneisses (Ahlin *et al.* 1985, Samuelsson *et al.* 1988, Larson *et al.* 1986, 1990). Along the Swedish west coast, in the western segment, supracrustal rocks and granitoids dominate. They are foliated or veined. The supracrustal rocks are included in the Stora Le-Marstrand formation (Östfold-Marstrand Belt of Daly *et al.* 1983) and are dominated by metagreywackes and elements of volcanic rocks (Åhäll 1984). The volcanic rocks are dated to 1.76 Ga using the Sm-Nd method (Åhäll & Daly 1989).

To the east of the Östfold-Marstrand Belt and to the west of the Mylonite Zone there is another sequence of supracrustal rocks which has been intruded by calc-alkaline granitoids. In the neighbourhood of Horred, about 50 kilometres southeast of Göteborg, there are relatively well preserved supracrustal rocks and granitoids intruding these. The U-Pb zircon ages of the rocks are about 1.60 Ga (Åhäll *et al.* in prep.), and the granitoids have been related to the Åmål granitoids (Gorbatschev 1975) and the B-granitoids (Samuelsson & Åhäll 1985). In the same way supracrustal rocks of the Horred area have been related to the metavolcanics and the metasediments of the Åmål Group (Törnebohm 1870, Gorbatschev 1971, 1977). These calc-alkaline intrusives and connected supracrustal rocks have been collectively named the Åmål-Horred Belt (Åhäll *et al.* in prep.).

The best preserved components of the Åmål-Horred Belt are found within an area at Tösse some ten kilometres south of Åmål. This area measures about 7 x 20 km and is restricted to the south and west by faults and to the north and east by granitoid intrusions. Törnebohm (1870) distinguished between volcanics and sediments of the Åmål Group. The rocks of the Åmål Group and their relations to the surrounding rocks were

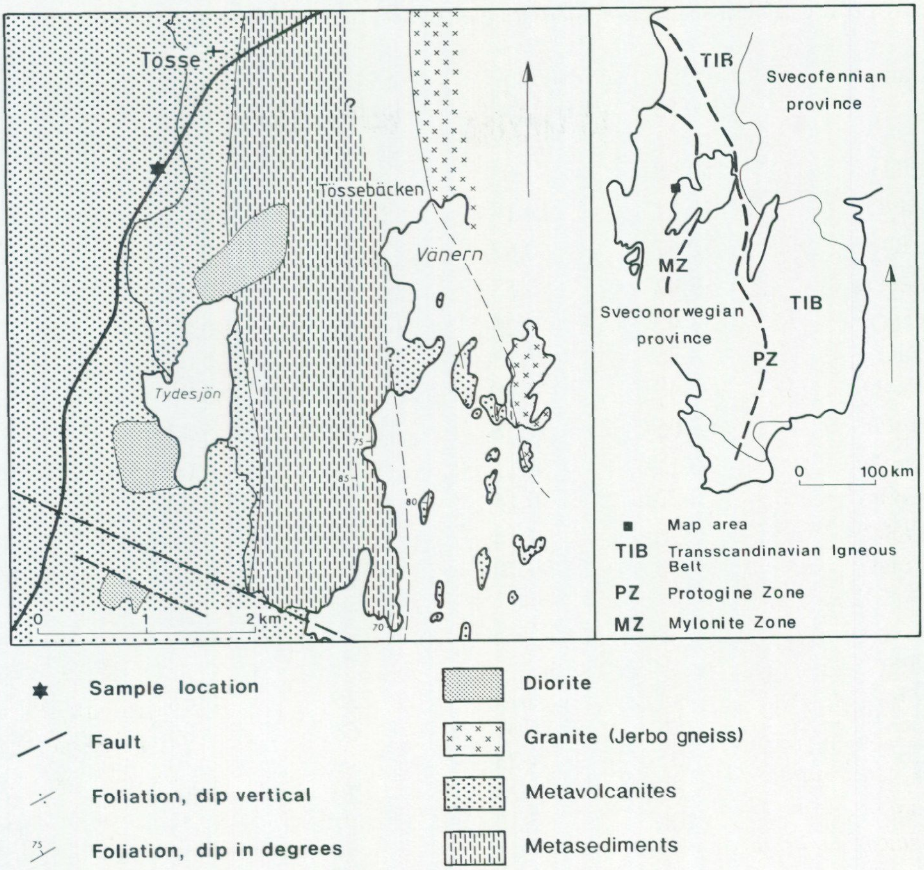

Fig. 1. Generalized geological map of the Tösse area.

also described by Larsson (1947) and Gorbatschev (1971, 1977). U-Pb zircon dating of the Åmål granodiorite yielded an age of 1616±12 Ma (Welin *et al.* 1982) but it has not been possible to decide whether it intrudes rocks of the Åmål Group or not. The basement to the Åmål Group has not been identified.

The rocks of the Åmål Group in the Tösse area have suffered greenschist grade of metamorphism and show primary volcanic textures, and sedimentary structures. Most of the supracrustal rocks are volcanics. They are dominantly felsic to intermediate lavas and tuffs, but more mafic varieties are also present. (Cf. Table 1.) Both flow-banded, welded (ignimbritic) and non-welded varieties can be identified. Some of the lavas have a cryptocrystalline matrix preserved. Most of the rocks are porphyries with phenocrysts measuring up to 1 cm in diameter. The felsic volcanics have phenocrysts of plagioclase, quartz ± K-feldspar ± biotite. The intermediate volcanics have phenocrysts of

TABLE 1. Chemical analyses of volcanics (porphyries) from the Tösse area (weight %).

Sample	N65398 E13155	N65439 E13168	*N65426 E13164	N65374 E13143	N65391 E13153
SiO_2	52.68	54.64	64.88	71.82	73.24
Al_2O_3	17.11	19.14	15.09	14.05	13.39
TiO_2	0.67	0.62	0.61	0.31	0.28
Fe_2O_3	9.92	8.53	5.41	2.05	1.96
MgO	3.92	3.29	1.73	0.23	0.25
CaO	8.35	7.23	4.44	1.01	1.02
Na_2O	2.48	3.48	2.88	3.96	3.29
K_2O	2.05	1.38	3.48	5.42	5.53
MnO	0.17	0.11	0.13	0.04	0.05
P_2O_5	0.22	0.14	0.14	0.03	0.04
LOI	2.16	1.14	0.86	0.63	0.71
Total	99.73	99.70	99.65	99.55	99.76
ppm					
Ba	514	614	725	1168	1062
Ce	28	37	68	86	83
Co	35	23	9	0	3
Cr	60	26	20	16	6
Cu	108	10	17	5	19
La	12	11	25	34	36
Mo	1	0	0	0	0
Nb	4	2	11	18	16
Ni	40	20	10	7	6
Pb	16	11	17	16	18
Rb	58	46	129	165	194
S	365	33	297	41	49
Sr	540	451	240	140	122
Th	0	5	10	15	19
U	0	0	2	4	4
V	169	134	72	14	14
Y	19	15	35	39	37
Zn	78	58	57	23	28
Zr	84	50	200	269	239

* Dated sample

plagioclase, quartz ± biotite ± hornblende ± pyroxene. The phenocryst content varies between 10 and 30%.

The eastern contact of the Åmål Group is found immediately to the east of the Tösse village. Its southern extension is possible to trace via Tössebäcken and in the Tösse archipelago, e.g. on the island Stensön. On this island the Åmål Group consists of volcanics interbedded with sedimentary rocks (Bjurquist & Årebäck 1992). The granite which borders the supracrustal rocks is the homogeneous, medium-grained, light greyish red, somewhat foliated so-called Jerbo gneiss ("Tösse gneiss") according to Törnebohm (1870). The supracrustal rocks of the Åmål Group have been metamorphosed by the intruding granite magma (Törnebohm 1870, Bjurquist & Årebäck 1992). An attempt to date the metavolcanics of the Åmål Group by the U-Pb method was done by Welin *et al.* (1982). A reference line gave an age of 1574 Ma. The sample was probably taken from a part of the volcanics close to the granite and may thus have been influenced by contact metamorphism.

The sedimentary sequence is found in the eastern part of the area and consists of strata with a N–S strike and a steep dip to the west. Both reworked volcanics and quartz-rich sandstones are present. They are coarse-grained to fine-grained rocks and are banded from millimetre to metre scale. The more coarse-grained bands contain in some cases rounded clasts of volcanics (porphyries). Troughs, current lamination, ripple marks and graded bedding are some primary features observed. Way up structures indicate younging to the west. Several contacts between reworked volcanics and porphyries have been observed. Some of these indicate intrusion of porphyries into wet sediments but also into consolidated sediments.

The dated rock was sampled from a grey, somewhat foliated porphyry about 1 km southwest of Tösse church (map-sheet 9C Mellerud NV, coordinates 65426-13164). The phenocrysts are less than 6 mm in diameter and are rounded or rectangular. The angular plagioclase phenocrysts are somewhat saussuritized and sericitized. The quartz phenocrysts are rounded, corroded and undulous. Some phenocrysts are pseudomorphs after other minerals, consisting of biotite, epidote, quartz, opaque minerals and very fine-grained unidentified minerals. The fine-grained matrix consists of quartz, biotite, plagioclase, microcline and sphene.

DESCRIPTION OF ZIRCONS

As in many volcanic rocks, foreign inclusions are abundant in the zircons of the Tösse volcanite. Only about one percent of the zircon crystals in the less magnetic zircon concentrate were of the kind suitable for U-Pb dating, e.g. without detectable inclusions or zircon cores and with the transparency of crystals almost devoid of cracks. The crystal habit of the Tösse zircons is simple with few crystal faces, which also seems to be a characteristic feature of volcanic rocks in general. They are long-prismatic with a length to width ratio of 5:1 or higher. The prisms are sub-quadratic in a plane perpendicular to the c-axis. The development of (110) compared to (100) is commonly small, which makes the termination almost perfect pyramids (101). According to the classification of Pupin (1980) these crystals closely resemble tight P5. A minority of very long-prismatic, needle-like zircons and crystals of somewhat tabular appearance have been excluded from the analyses. Two selected populations have been abraded/polished, according to the technique described by Krogh (1982), in order to remove possibly damaged outer parts of the crystals and to increase the degree of concordancy in the concordia diagram.

ANALYTICAL TECHNIQUE AND A DISCUSSION OF THE OBTAINED ISOTOPIC DATA

The number of crystals used for each zircon analysis ranges from 50 to about 200 and has permitted a rigorous selection of those used for analysis. At the time of sample preparation our total lead blank level was in the range of 30 to 50 pico-grams, which includes sample dissolution in a mixture of concentrated hydrofluoric and nitric acid in 1" diameter teflon "Krogh"-capsules; hydrochloric ion exchange procedure in 50 μl resin; evaporation and loading on Re filaments with silica gel and phosphoric acid.
Lead was measured in a static mode as composition and 208-spiked aliquots with a Finnegan MAT 261 multi-collector mass spectrometer. The analytical zircon data are given in Table 2.

The accuracy of the individual analysis is c. 3–6 Ma. A glance at Fig. 2 immediately reveals that the coarsest size fraction plots away from the other ones, suggesting disturbances that are separated from the time of primary rock crystallization. Thus we may concentrate on the four fractions left, and in particular on those two which contain

TABLE 2. Analytical results of the age determination of the Tösse porphyry.

Fraction (μm)	Sample weight (mg)	U (ppm)	Pb_{rad} (ppm)	$^{206}Pb/^{204}Pb$ (meas)	Radiogenic (at.%) ^{206}Pb	^{207}Pb	^{208}Pb	Atomic ratios $^{206}Pb/^{238}U$ ± 2σ	$^{207}Pb/^{235}U$ ± 2σ	$^{207}Pb/^{206}Pb$ ± 2σ age (Ma)
90-100 ab	0.27	136.6	43.22	1723	75.31	7.52	17.17	0.2774 ± 5	3.802 ± 9	1613 ± 3
74-90 ab	0.19	117.1	37.41	4300	74.87	7.49	17.64	0.2785 ± 7	3.821 ± 13	1615 ± 4
74-90	0.44	173.6	52.51	245	73.73	7.35	18.92	0.2596 ± 5	3.549 ± 14	1609 ± 6
60-74	0.22	161.6	49.09	439	74.13	7.45	18.42	0.2621 ± 5	3.613 ± 13	1623 ± 5
100-150	0.56	198.0	52.91	972	75.00	7.11	17.89	0.2343 ± 4	3.046 ± 8	1514 ± 3

ab = abraded zircon

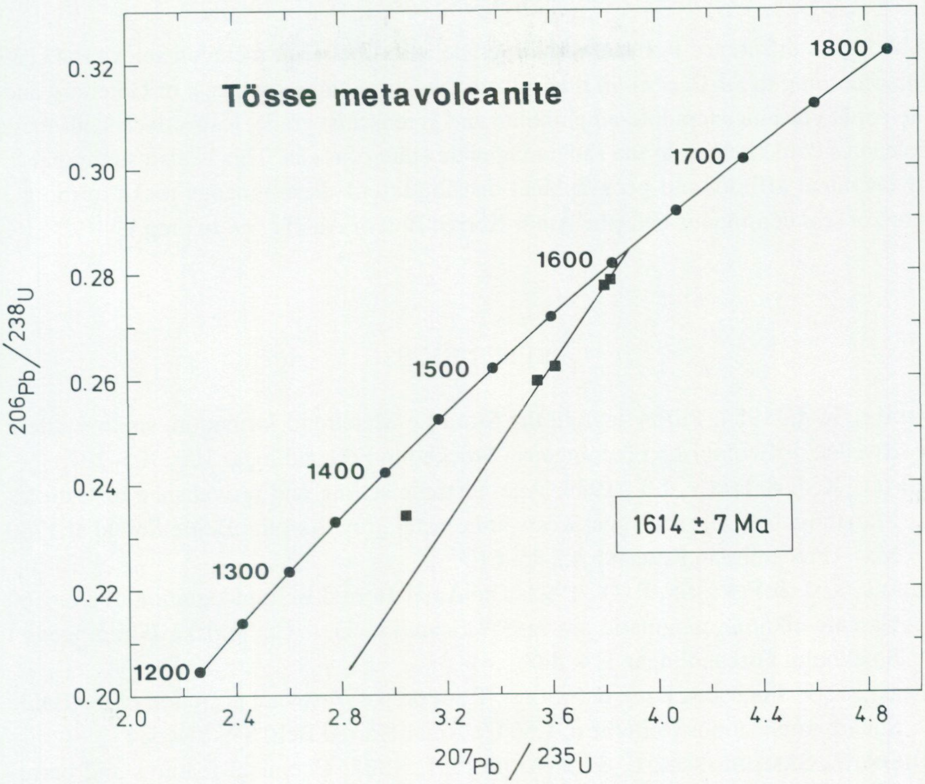

Fig. 2. Concordia plot of zircons from a volcanic rock from the Åmål Group.

zircons from which the outer parts have been abraded away and constitute a greater proportion of undamaged crystals and a low degree of secondary metamorphic overgrowth.

A regression analysis including these four fractions based on Ludwig (1991) indicates an age of 1614±44 Ma. The less concordant fractions deviate from the discordia more than those that are almost concordant and create a high MSWD-value of 5. However, taking into account the $^{207}Pb/^{206}Pb$ ages of the abraded, almost concordant and thus more reliably plotting zircons (1613±3 and 1615±4 Ma), the error of that regression seems to be unrealistically large. Instead, if utilizing the regression analysis of York (1969), which was previously reported in the form of an extended abstract by Lundqvist and Skiöld (1992), we obtain an age of 1614±7 Ma. For this particular case with two reliable almost concordant fractions, we favour the York method as representing the better estimate for the time of primary crystallization of the Tösse volcanic rocks.

DISCUSSION

Although a difference in metamorphic grade exists between metavolcanics (1643±29 Ma according to Åhäll *et al.* in prep.) from the Horred area southeast of Göteborg and the Åmål volcanics (epidote-amphibolite and greenschist grade, respectively), all these volcanics could belong to the same magmatic suite of rocks. This is also strengthened by chemical affinity and geographical distribution of these igneous rocks forming a more or less continuous belt (the Åmål-Horred Belt of Åhäll *et al.* in prep.).

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The U-Pb zircon age of the Sala "granite" of south-central Sweden

By
Lars Persson

GENERAL GEOLOGY

In the vicinity of Sala, approximately 120 km NW of Stockholm, metasedimentary and metavolcanic rocks occur. The sedimentary rocks consist of tuffitic arenites (greywackes) with thin intercalations of argillitic material. Among the volcanites there are both rhyolites and basalts. The famous Sala silver mine with abundant galena is associated with these supracrustal Svecofennian rocks. Crystalline limestones and dolomites occur abundantly in several horizons, e.g. near Sala and to the north at Armanbo.

Plutonic rocks belonging to the early-orogenic or synorogenic Svecokarelian intrusions intersect the supracrustals. They show compositional variations from gabbro and diorite to tonalite, granodiorite and granite. The lithological variations are great, i.e. the granites can be fine- to medium-grained, grey, red or pink, even-grained or porphyritic. They can be foliated or massive. Immediately to the north and northwest of Sala (map-sheet 12G Avesta SO; mapped by the author), a granitoid exists which has been called the Sala "granite" (cf. Magnusson *et al.* 1963). Here it is more or less massive and an age determination was considered as highly valuable.

Further 40 km to the north late-orogenic, fine- to medium-grained, grey granites and the coarse-grained, porphyritic, pinkish Hedesunda granite exist.

THE SALA "GRANITE"

This rock north and northwest of Sala (cf. geological map-sheets Sala, Gumælius 1868, and Möklinta, Asklund 1946) is predominantly greyish, medium-grained and massive. In some places it can be somewhat pinkish in colour. Modal contents of quartz, K-feldspar and plagioclase are 30, 21 and 41%, respectively. The biotite content is about 6% and amphibole may occur subordinately. Thus the rock is a granodiorite (Fig. 1). A sample for age determination was selected in this massif. Transitions occur in the neighbourhood to monzogranitic compositions. 10 km further to the north the monzogranites and granodiorites grade into a K-feldspar-porphyritic, foliated (lineated) granite of pinkish color.

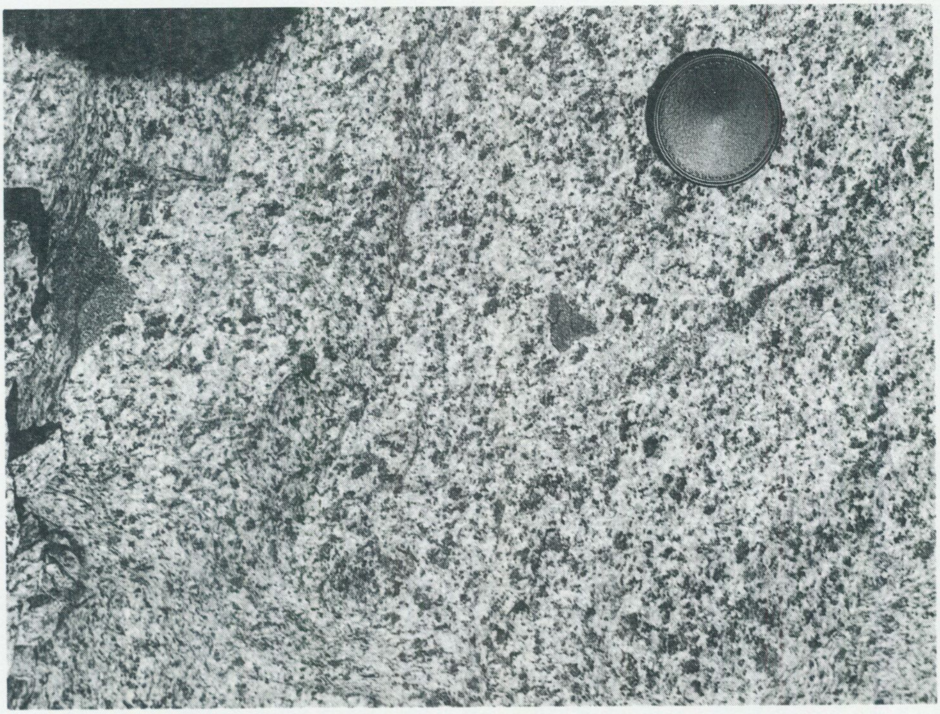

Fig. 1. Sala "granite". Locality of sampling. The sample for U-Pb dating was taken on map-sheet 12G Avesta SO, coordinates: 665592/153435, from a rock storage.

ISOTOPIC ANALYSES

The laboratory work and the age determination were made by Dr. Matti Vaasjoki, Unit for Isotope Geology, Geological Survey of Finland.

The investigated Sala "granite" contains small amounts of brown, fine-grained zircons. Morphologically the mineral is sub- to euhedral and exhibits a large number of simple prismatic and pyramidal faces. The crystals are rather stubby with a length/breadth ratio of 2–3. No significant inhomogeneities within the zircons were found under the microscope.

The three analysed fractions of zircons exhibit relatively high uranium contents (600–1600 ppm) and display a normal discordancy, increasing with an increasing uranium content (cf. Tables 1 and 2). The common lead contents are low, as evidenced by the high $^{206}Pb/^{204}Pb$ ratios. The analyses define a good linear trend (MSWD<1) with an upper intercept age of 1890±3 Ma and a lower intercept age of 326±18 Ma (Fig. 2).

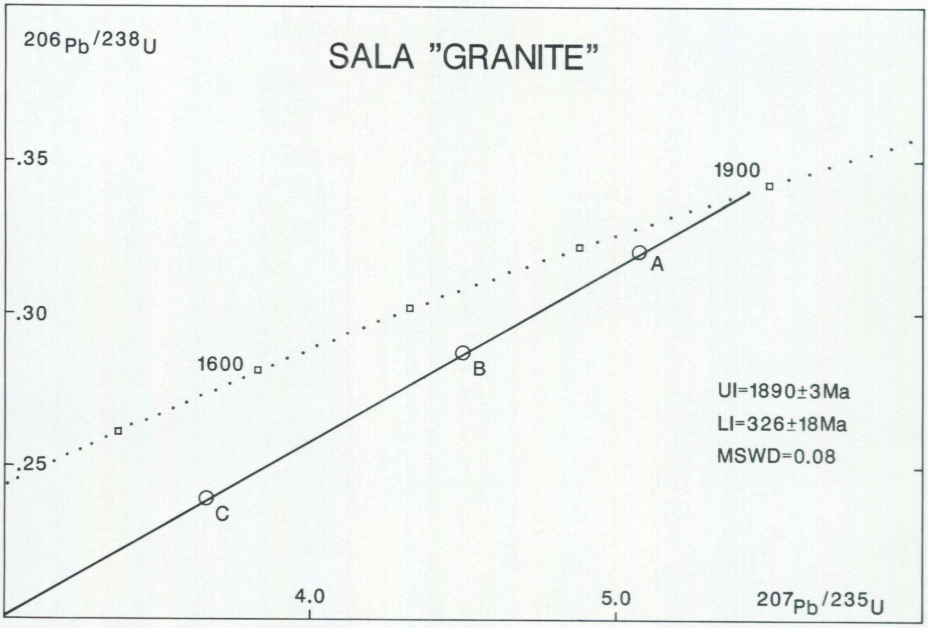

Fig. 2. $^{206}Pb/^{238}U$ versus $^{207}Pb/^{235}U$ plot of the zircon data from the Sala "granite".

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

Sample	Fraction	Concentrations			Lead ratios, 206=100		
		^{238}U	Pb(tot)	$^{206}Pb/^{204}Pb$	^{204}Pb	^{207}Pb	^{208}Pb
A	>4.3	621.1	207.51	8316	0.0120	11.66	8.42
B	4.2-4.3	941.5	284.35	3942	0.0254	11.71	8.95
C	4.0-4.2	1580.0	400.31	2674	0.0374	11.60	9.56

Concentrations in µg/g; corrected for blank.

TABLE 2. U/Pb ratios and apparent radiometric ages for zircons from the Sala "granite".

Sample	Atomic ratios			Apparent ages (Ma)		
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	T (6/8)	T (7/5)	T (7/6)
A	0.3205	5.079	0.1149	1792	1832	1879
B	0.2877	4.507	0.1136	1630	1732	1857
C	0.2399	3.668	0.1109	1386	1564	1814

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

CONCLUSIONS

Granitoids of different ages and tectonic position can be difficult to separate from each other. The Sala "granite" is highly heterogeneous in chemical and modal composition, and structurally partly isotropic, partly strongly foliated. Radiometric data support the conclusion that the Sala "granite" is a true early-orogenic Svecokarelian plutonic rock. The 1890 Ma age is in the upper part of the age range for such rocks.

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U-Pb dating of a porphyritic metarhyolite of the Lower Dala "Series", northern Dalarna, central Sweden

By
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BACKGROUND

The Jotnian Dala sandstone of northern Dalarna, central Sweden, is surrounded by volcanic rocks belonging to what Hjelmqvist (1966) called the Lower and Upper Dala Series. These were both ascribed to the sub-Jotnian, and together with Dala granites and Värmland granites (the latter named Gothian granites by Hjelmqvist, op. cit.) constitute the basement of the sandstone. The Jotnian and sub-Jotnian complexes of Dalarna and the Värmland granites form part of what Gorbatschev (1985) has called the Transscandinavian Granite-Porphyry Belt.

Subsequent work in the Dalarna region has raised some questions concerning the stratigraphic position of the Lower Dala "Series" (LDS). In the Noppikoski area of the Los-Hamra region Lundqvist (1968) found that a metarhyolite ascribed by Hjelmqvist to the LDS had been folded, metamorphosed and silicified before the Upper Dala "Series" (UDS) volcanic rocks, in Lundqvist´s work termed Dala Volcanics Formation, were deposited. Mapping in the region in the early 1980s (Sjöblom & Aaro 1987) confirmed this view. Lundqvist included the metarhyolite in the early Svecofennian supracrustal formations, since it was affected by the same folding and metamorphism as the Svecofennian complexes to the east. Furthermore, a meta-argillite situated stratigraphically not far below the metarhyolite, and by Hjelmqvist (op. cit.) included in the LDS, was found to have been intruded by an early-orogenic (primorogenic) granite. A sub-Jotnian stratigraphic position would have required the reverse age relationship between the granite and the rhyolite. A U-Pb age for the metarhyolite at Noppikoski in the normal range of the early Svecofennian supracrustals was confirmed by Welin (1987): 1867±9 Ma.

Similarly, Kresten (1985) and Kresten & Aaro (1987) considered a supposedly LDS ignimbritic rhyolite at Älgberget c. 25 km southwest of Leksand to belong to the Svecofennian supracrustals and to parallel in age the metarhyolite at Noppikoski. The Älgberget rock, however, forms an inclusion in the post-Svecokarelian Järna granite, and evidence for its stratigraphic position is therefore indirect.

The LDS rocks of Hjelmqvist thus at least in part correspond to the early Svecofennian supracrustals. Especially for the western occurrences, however, the possibility remains that they belong either to the c. 1790–1840 Ma old Småland and related porphyries occurring in the belt of Småland-Värmland granites, or to yet undated age groups. The present dating should be regarded as a first attempt to solve this problem.

THE SAMPLE AND ITS GEOLOGICAL SETTING

A foliated metarhyolite from a road-cutting south of Kvarnberget, north-west of Malung (topographic map-sheet 13D Malung NO, coordinates 673320-137845 in the National Grid) was chosen for U-Pb dating on zircon. The rock is porphyritic with mm-size phenocrysts of perthitic alkali feldspar set in a microcrystalline matrix of mainly alkali feldspar and quartz. Accessories include fluorite, zircon, apatite, carbonate and sulphide(s). The foliation is marked by streaks of fine-grained biotite and muscovite crystals oriented in the foliation plane. Vein quartz occurs in fissures.

From a general geological point of view the Kvarnberget LDS metarhyolite could be a deformed porphyry of the UDS of Hjelmqvist, dated by Welin (1992) at 1691±5 Ma, or belong to an older formation, e.g. of an age corresponding to the Småland porphyries further south. The observation of Hjelmqvist that dikes correlated with the LDS rocks cut the "Gothian" Småland-Värmland granites would seem to exclude the latter possibility. It must, however, be emphasized that the LDS may be heterogeneous with regard to age and that the character of the contact between the Kvarnberget metarhyolite and the Värmland granite in the west is unknown. The foliation in the metarhyolite, although as yet radiometrically undated, is probably Sveconorwegian (c. 1000 Ma) and of the same age as the deformation of the Jotnian sandstone further east (cf. Hjelmqvist 1966). This deformation in all evidence also involved an uplift of the block west of the Västerdalälven river in relation to the (stratigraphically overlying) Jotnian sandstone etc. east of the river.

ISOTOPIC ANALYSES

The isotopic dating was performed by the first author (P.-O.P.) at the Laboratory for Isotope Geology, Swedish Museum of Natural History. The zircons of the sampled metarhyolite (SGU-7) are euhedral, with well developed prism and pyramid faces. They are generally light brown, but a minor part is colourless. Practically all zircons are rich in microfissures. The analysed zircons have been chosen among those with the fewest fissures. Colourless crystals were analysed separately. An euhedral zoning is evident when the zircons are studied in a high-refractive immersion liquid under the microscope. Distinct evidence of relict cores or late overgrowths has not been found.

The concordia plot (Fig.1) shows that the five analysed fractions (Table 1) are fairly discordant and spread relatively little along the discordia. The large discordancy is probably explained by the existence of the microfissures. The upper intercept age is 1787 +34/-24 Ma. The error is given as 2σ. MSWD = 1.7. The lower intercept age is 700 +178/-182 Ma.

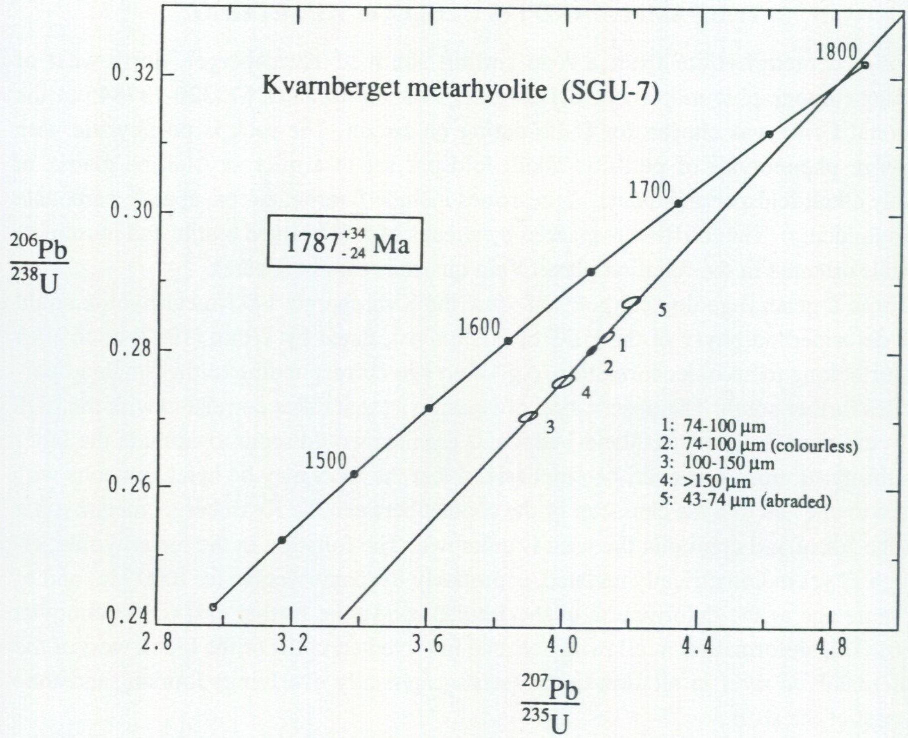

Fig. 1. Concordia diagram for analysed zircon fractions from the Kvarnberget metarhyolite (SGU - 7).

CONCLUSIONS

If, in spite of the relatively high discordancy and small spread in isotope composition, the upper intercept is taken to indicate the approximate age of the porphyry volcanicity, some important conclusions can be drawn. A comparison with available U-Pb datings of early Svecofennian volcanic rocks (c. 1870–1900 Ma; Welin *et al.* 1980, Welin 1987) and with the only presently existing U-Pb dating of an UDS Dala porphyry (1691 Ma; Welin 1992) shows that the Kvarnberget metarhyolite belongs to neither of these two groups. Instead, it appears likely to correlate it with the (late- or post-Svecofennian) Småland porphyries in the approximate time interval 1790–1840 Ma (Åberg & Persson 1985, Wikman, this volume, Wikström, this volume) and with an 1803 Ma porphyry at Dobblon in Västerbotten County (Skiöld 1988). Continued radiometric dating of LDS units in the Proterozoic bedrock of northern Dalarna is necessary to establish the chronology of these rocks, and such work has now been initiated at the Geological Survey of Sweden.

TABLE 1. Chemical and isotope analyses.

Fraction (µm)	Weight (mg)	U (ppm)	Pb_{rad} (ppm)	Pb_{com} (ppm)	^{208}Pb (at. %)
74-100	0.56	323	102	0.72	14.6
74-100, colourless	0.33	186	59	0.10	15.5
100-150	0.44	257	75	7.50	12.9
>150	0.38	238	74	0.67	16.1
43-74, abraded	0.27	298	95	2.63	15.3

Fraction (µm)	$^{206}Pb/^{204}Pb$ a	$^{206}Pb/^{238}U$ b	$^{207}Pb/^{235}U$ b	$^{207}Pb/^{206}Pb$ age (Ma)
74-100	6800	0.2824±6	4.129±16	1733
74-100, colourless	10700	0.2804±6	4.083±12	1725
100-150	579	0.2707±6	3.894±23	1703
>150	4800	0.2758±8	3.999±27	1717
43-74, abraded	1855	0.2874±6	4.199±22	1731

a = measured, uncorrected ratio
b = corrected for blank, common lead, spike and mass fractionation (0.08 and 0.10 % per a.m.u. for Pb and U, respectively)

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U-Pb zircon dating of a Järna-type granite in western Bergslagen, south-central Sweden

By
Per-Olof Persson and Magnus Ripa

INTRODUCTION

When regular mapping started on the 12E Säfsnäs SO map-sheet, a discrepancy was recognized between older mapping in the area and recent mapping in adjacent areas regarding the classification of a granitoid complex in the SW corner of the map-sheet. The older map of the area (the Grängesberg map-sheet, Magnusson & Lundqvist 1933) classifies the granitoids as of "Järna-type", implying a genetic link to the so-called Dala granites (cf. Lundqvist 1979), which were later determined to be c. 1.70 Ga old (Wilson *et al.* 1985; Patchett *et al.* 1987) and of I-type (Kresten 1986). More recent mapping in neighbouring areas (the Filipstad NV map-sheet, Björk 1986; the Filipstad NO map-sheet, Ingmar Lundström, SGU pers. comm.), into which the massif extends, relates the rocks to the 1.84–1.76 Ga (cf. Johansson 1988) suite of Småland–Värmland, I-type (Nyström 1982; Wilson *et al.* 1986) or S-type (Kresten 1986) granitoids.

To solve this problem, a U-Pb zircon dating was carried out.

GEOLOGICAL SETTING

The investigated rock belongs to a complex, which intrudes an older suite of Svecofennian rocks. The latter are dominated by c. 1.9 Ga (Åberg *et al.* 1983) felsic metavolcanic and -sedimentary rocks. The supracrustals were intruded by comagmatic (Kresten 1986), c. 1860 Ma (Welin *et al.* 1980; Åberg *et al.* 1983) subvolcanic intrusions and granitoids, and by swarms of mafic dykes. The Svecofennian rocks were deformed and metamorphosed, and the peak of metamorphism varies from low- to high-grade (Lundqvist 1979). As stated in the introduction, the investigated rock may belong to either the suite of Småland-Värmland granitoids or to the Dala granites (cf. Lundqvist 1979). In either case, the rock is considered to be post-orogenic in relation to the Svecofennian orogeny.

LOCAL GEOLOGY

The geology of the sampling area is schematically outlined in Fig. 1. The granitoid complex is bordered by the Svecofennian metavolcanic and -plutonic rocks on its eastern side. The complex consists of an older phase of intermediate rocks (the one which is dated in this study; denoted "Järna-type" in Fig. 1), which was intruded by more felsic "Siljan-type" granites, and of gabbroid rocks.

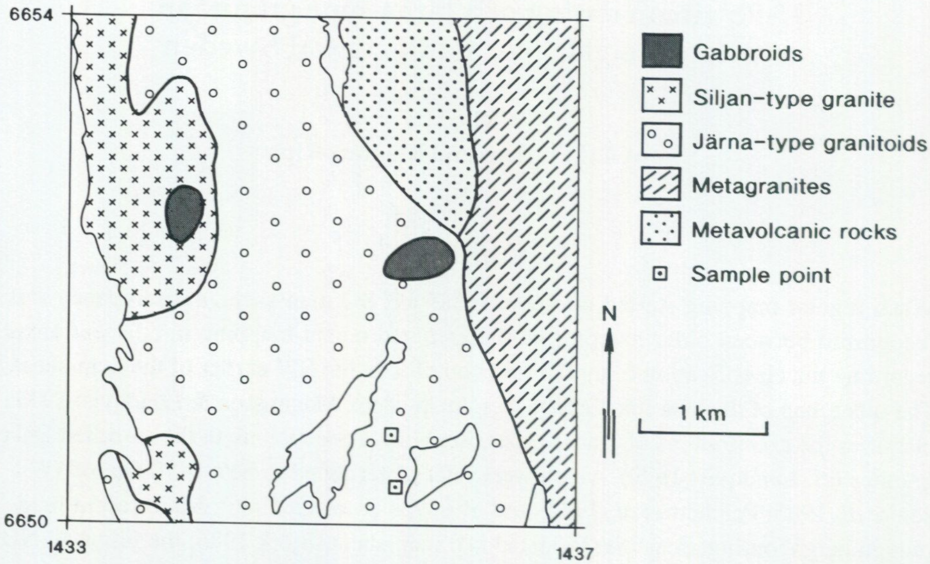

Fig. 1. Schematical geology of the sampling area. Coordinates on the national grid are indicated.

PETROGRAPHY

The "Järna-type" granite is a greyish, coarse- to medium-grained, feldspar-phyric to even-grained, isotropic rock with various amounts of biotite and hornblende and with locally blue quartz. Significant features are high magnetic susceptibility and locally abundant, dm-size, ellipsoidal, fine-grained enclaves of intermediate to mafic composition.

Microscopically, the rock consists of K-feldspar *augen* in a seriate matrix of microcline, plagioclase, quartz, biotite and hornblende. The quartz grains show undulous extinction and the plagioclase is variably sericitized. Retrograde chlorite grows on biotite and hornblende. Accessory minerals are epidote, allanite, prehnite, apatite, zircon and opaques.

SAMPLING

C. 60 kg of rock was taken from two road-cuts. The locations are shown in Fig. 1. The coordinates are 665032/143558 and 665064/143554 on the national grid.

No enclaves are included in the sample.

ZIRCON DESCRIPTION AND ANALYTICAL RESULTS

The analytical work was performed by P.-O. Persson at the Laboratory for Isotope Geology, Swedish Museum of National History, Stockholm.

The zircons are reddish brown and strongly coloured. Most of them have euhedral shape with well developed prism and pyramid faces and sharp edges. As far as colouring and shape are concerned, the Järna granite zircons are similar to those of the Filipstad and Askersund granites (Jarl & Johansson 1988; Persson & Wikström in prep.). Most crystals display euhedral, magmatic zonation. A minority of the zircons (<5%) have rounded cores, which probably are inherited. About the same percentage of grains have thin overgrowths.

The five analyzed zircon fractions (Table 1; Fig. 2) define a discordia with intercept ages of 1786 +14/-12 and 49 +172/-171 Ma. MSWD=20. The fraction 43-74 μm is markedly more discordant than the others, but no obvious explanation for this behaviour can be found. The finest fraction plots to the left of the discordia, possibly indicating that the smallest grains contain a greater proportion of young material as compared to the larger grains. However, the visible internal structures, in terms of core-overgrowth relationships, are similar in all size fractions. The upper-intercept age is interpreted as the crystallization age of the granite.

TABLE 1. U-Pb analyses of zircons from the Järna-type granite.

Fraction (μm)	Weight (mg)	U (ppm)	Pb_{rad} (ppm)	Pb_{com} (ppm)	^{208}Pb (at %)
<43	1.0	463	152	1.38	8.3
43-74	1.8	475	114	1.40	7.9
106-150	1.2	388	123	1.98	8.0
>210	1.5	394	126	0.61	8.0
106-150 abr	2.5	330	107	0.29	8.8

Fraction (μm)	$^{206}Pb/^{204}Pb$ a	$^{206}Pb/^{238}U$ b	$^{207}Pb/^{235}U$ b	$^{207}Pb/^{206}Pb$ age (Ma)
<43	6100	0.3155±5	4.728±11	1778
43-74	4640	0.2327±4	3.484±6	1775
106-150	3600	0.3061±7	4.595±38	1780
>210	11000	0.3083±5	4.648±14	1789
106-150 abr	19000	0.3103±6	4.687±12	1792

a = measured, uncorrected ratio.
b = corrected for blank, common lead, spike and mass fractionation (0.08 and 0.10 % per a.m.u. for Pb and U, respectively).
abr = abraded.

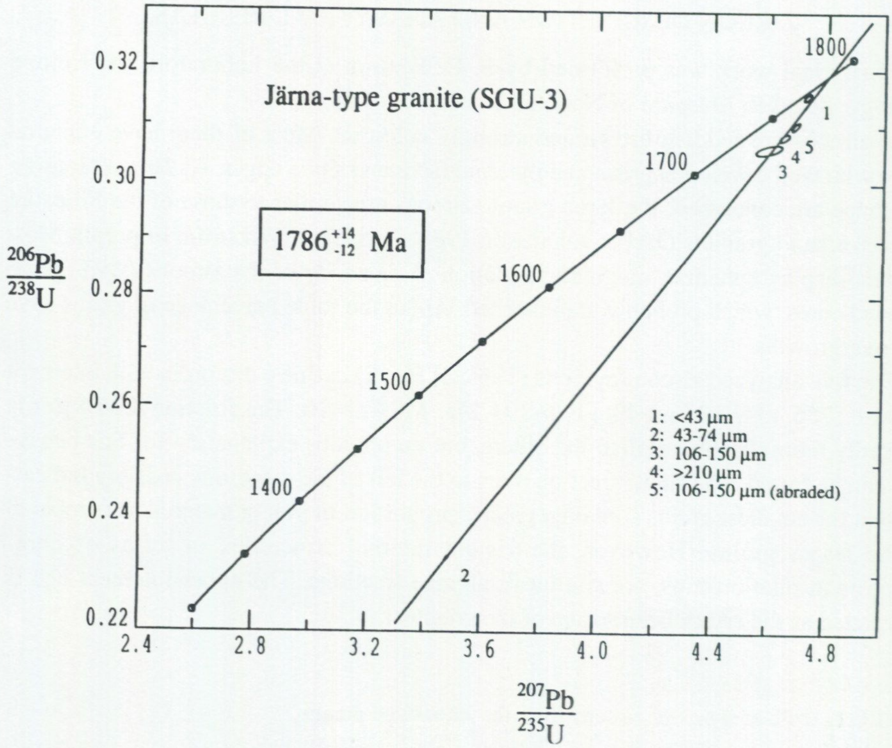

Fig. 2. Concordia-discordia diagram showing the U-Pb analyses of zircons from the Järna-type granite.

CONCLUSION

The result obtained in this study (1786 +14/-12 Ma) shows that the analyzed rock is coeval with the early phase of the Småland–Värmland magmatism (1.84–1.76 Ga). The age is within error identical to that of the petrographically similar Filipstad granite (Jarl & Johansson 1988). We conclude that the Järna-type granite should be ranged among the early Småland-Värmland granitoids.

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U-Pb zircon dates in two younger suites of Palaeoproterozoic intrusions, Karlskoga area, south-central Sweden

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ABSTRACT

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New age determinations using the U-Pb multiple zircon technique have been carried out on two younger suites of Palaeoproterozoic intrusions in the Karlskoga area, south-central Sweden. Inferred protolith ages of 1786±8 and 1807±5 Ma were obtained for an equigranular and a porphyritic granite, respectively. Both granites are correlated with the so-called late-tectonic granites situated mostly east of the Transscandinavian Igneous Belt (TIB). A locally charnockitic granite and a quartz monzodiorite in the TIB suite of rocks to the west have yielded inferred protolith ages of 1796±7 and 1699±7 Ma, respectively.

The 1786±8 Ma age for the equigranular granite provides a minimum age for the peak of high-grade metamorphism in the surrounding metasupracrustal rocks. The locally charnockitic granite is inferred to belong to the early-stage family of TIB intrusions (so-called TIB 1). Although the new age determinations support previous studies which suggest that the late-tectonic suite of intrusions and the TIB 1 rocks are of similar age, these two younger suites of intrusions form together a zoned granitoid belt in the Svecokarelian orogen of south-central Sweden, distinctive at least on the basis of their petrography and field relationships. The quartz monzodiorite belongs to a distinctively younger episode of intrusive activity in the TIB (so-called TIB 2), comparable in age to the Dala and Rätan granites to the north.

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INTRODUCTION

Intrusions in the Svecokarelian orogen in the Swedish segment of the Baltic Shield are traditionally classified according to their time relationship with respect to Svecokarelian deformation c. 1800–1850 Ma ago. Recently, a limited number of radiometric age determination studies (see review in Welin 1992) in the Proterozoic rocks of south-central Sweden have set in doubt the inferred time difference between several of the so-called late- and post-tectonic granitoids (Patchett *et al.* 1987, Jarl & Johansson 1988, Johansson 1988). Furthermore, structural studies (Wikström 1991a, Wahlgren *et al.* 1993) in this region have confirmed the problems attached to this type of classification. In particular, intrusions in the Transscandinavian Igneous Belt (TIB), which occur along the western exposed part of the Svecokarelian orogen and which are traditionally referred to as post-tectonic with respect to this orogenic event, are affected, at least in part, by Palaeoproterozoic deformation. Radiometric age dating studies within the TIB have also documented a long, complex history of intrusive activity from c. 1810 to 1650 Ma (Larson & Berglund 1992). Age determination work by Persson & Wikström (in prep.) suggests that the older age limit of this activity may extend back to c. 1845 Ma. It is, therefore, apparent that intrusion of TIB rocks initiated prior to and continued after the Svecokarelian deformation.

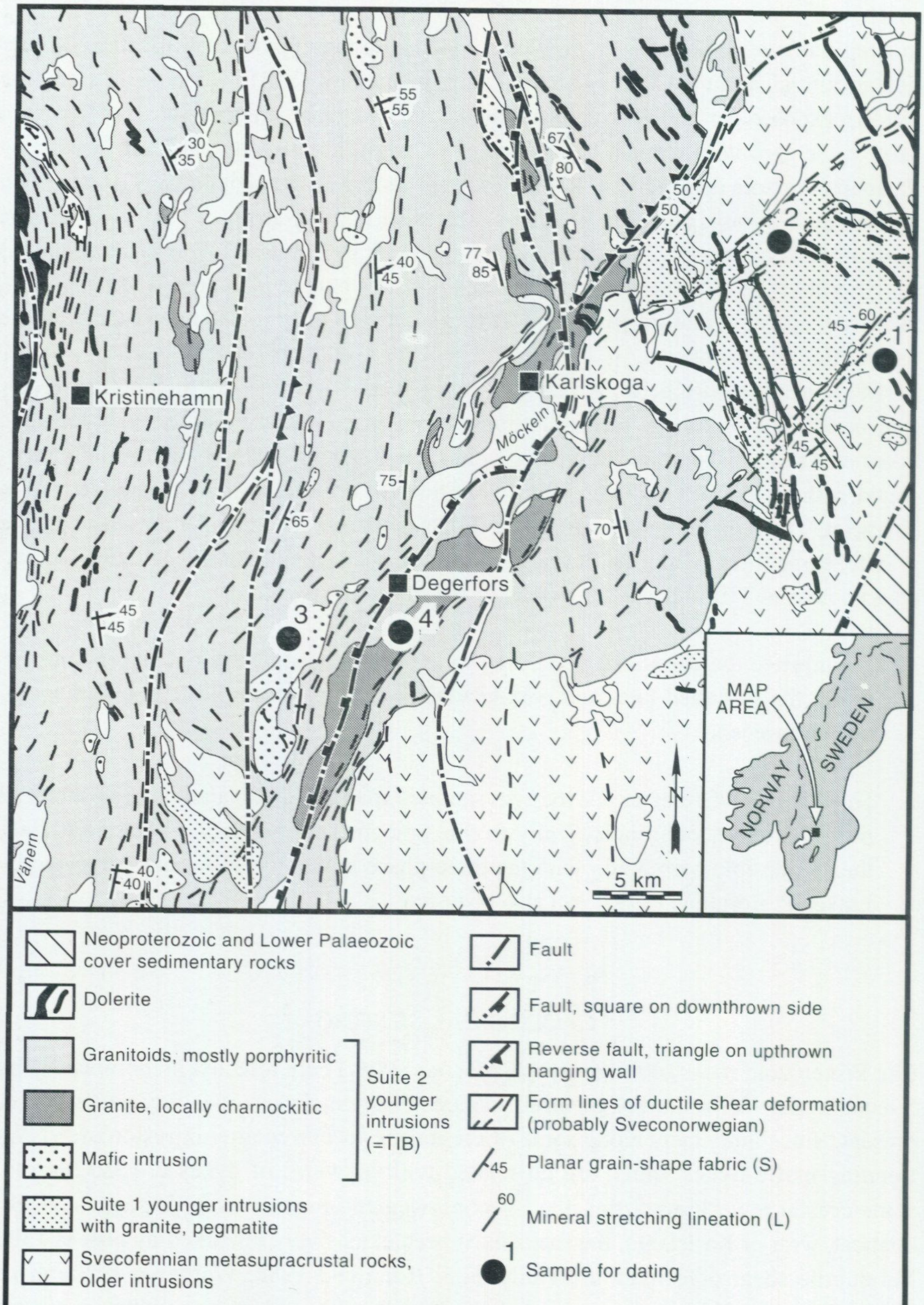
In connection with bedrock mapping in the Karlskoga area, south-central Sweden, four new U-Pb zircon age determinations were carried out. Two of the samples were taken east of Karlskoga in a suite of granites and pegmatites which are spatially associated with migmatites and which have traditionally been referred to as late-tectonic in character. The remaining two samples, a quartz monzodiorite and a locally charnockitic granite, came from southwest of Karlskoga. Both occur in intrusions spatially associated with normal TIB rocks. The purpose of the study was two-fold:

1. To improve the data-bank pertaining to the critical geochronological relations between the so-called late- and post-tectonic intrusions in the Proterozoic of south-central Sweden.

2. To establish whether or not the two samples spatially associated with normal TIB rocks belong geochronologically to this igneous suite. If they do belong to TIB, then a possible correlation with the three-phase model for TIB rocks presented by Larson & Berglund (1992) can also be tested.

GEOLOGICAL SETTING

The Proterozoic rocks to the east of Karlskoga (Fig. 1) are affected predominantly by Svecokarelian deformation. Several younger discrete shear zones are, nevertheless, present. Since movement along some of these zones occurred after intrusion of WNW-trending mafic dykes which are correlated with a swarm of dykes c. 1530 Ma old, some crustal reworking during the Sveconorwegian orogenic event is suggested. By contrast, west of Karlskoga, the rocks have been extensively reworked by post-c. 1500 Ma ductile shear deformation (Wahlgren & Rönnlund 1988, Wahlgren & Stephens 1990). Thus, the Karlskoga area lies along the critical boundary zone which separates two Proterozoic orogens. The youngest structures in the area are Neoproterozoic(?) and Phanerozoic faults.


Kristinehamn
Karlskoga
Degerfors
Möckeln
Vänern
MAP AREA
NORWAY
SWEDEN
N
5 km
1
2
3
4
Neoproterozoic and Lower Palaeozoic cover sedimentary rocks
Dolerite
Granitoids, mostly porphyritic
Granite, locally charnockitic
Mafic intrusion
Suite 2 younger intrusions (=TIB)
Suite 1 younger intrusions with granite, pegmatite
Svecofennian metasupracrustal rocks, older intrusions
Fault
Fault, square on downthrown side
Reverse fault, triangle on upthrown hanging wall
Form lines of ductile shear deformation (probably Sveconorwegian)
Planar grain-shape fabric (S)
Mineral stretching lineation (L)
Sample for dating

The oldest rocks in the vicinity of Karlskoga are Svecofennian metasupracrustal rocks and a variety of mafic and felsic intrusions with gabbroic to dioritic and tonalitic to granitic compositions, respectively. This older suite of intrusions are pre-tectonic with respect to the Svecokarelian deformation and both the metasupracrustal rocks and the intrusions may be correlated with rocks c. 1890 to 1850 Ma in age elsewhere in south-central Sweden (Welin 1992).

Two suites of younger intrusions are conspicuous (Fig. 1). East of Karlskoga, granites, both equigranular and porphyritic, and pegmatites are spatially associated with migmatitic rocks. Two samples were taken for dating purposes from this suite which can be correlated with, for example, the granites near Malingsbo (Högbom 1930, Lundström 1985), Örebro (Lundegårdh *et al.* 1972) and Fellingsbro (Gorbatschev 1972) all located to the east and northeast of the map-area shown on Fig. 1. The Fellingsbro granite has yielded a U-Pb zircon age of 1782±6 Ma (Patchett *et al.* 1987). Around and west of Karlskoga, the younger intrusions form a second suite dominated by porphyritic quartz monzonites to granites with mantled textures in the feldspar phenocrysts. Mafic intrusions are a conspicuous component in this group which belongs to the TIB suite of intrusions. A coarsely porphyritic granite in the vicinity of Filipstad, just north of the map-area shown on Fig. 1, has yielded a U-Pb zircon age of 1783±10 Ma (Jarl & Johansson 1988). The sampled quartz monzodiorite forms part of a major mafic intrusion surrounded, in part, by a metamorphic contact aureole (Annertz 1984, Wikström *et al.* 1985). It is inferred to have intruded at a higher crustal level relative to the surrounding more felsic intrusion and, thus, may be considerably younger than this intrusion. Subordinate lithological components in the TIB suite of intrusions include equigranular granites and aplite dykes which intrude the porphyritic varieties and possibly an equigranular to porphyritic granite which is locally modified to charnockite in connection with a presumed contact metamorphic event (Andersson *et al.* 1992). Field relationships indicate that this locally charnockitic granite is older than the porphyritic TIB granitoids. However, it remains uncertain whether it belongs to the TIB suite or the older, pre-tectonic family of intrusions. The local occurrence of mantled feldspar phenocrysts, the often diffuse contact relationships to the surrounding porphyritic TIB granitoids and the isotropic character of the granite when unaffected by ductile shear zones favour the former. This granite forms the fourth dating object in this study.

Younger rocks in the Karlskoga area, which are truly post-Svecokarelian, include mafic dykes and their deformed and metamorphosed equivalents in the Sveconorwegian orogen to the west. The youngest unit is composed of Neoproterozoic sandstone which lies in fault contact with the older Proterozoic rocks along the eastern side of the lake Möckeln (Fig. 1).

Fig. 1. Geological map of the Karlskoga area based on published maps by Wikström (1991b) and Wahlgren (1992), and compiled but as yet unpublished material by C.-H. Wahlgren and M.B. Stephens. 1, 2, 3 and 4 refer to dating samples BQMS90201, BQMS90202, CHW901101 and CHW901102, respectively.

SAMPLE LOCATION AND DESCRIPTION

EQUIGRANULAR GRANITE

Sample BQMS90201 (map-sheet 10E Karlskoga NO, 658056/144848) is a grey, fine-grained, equigranular granite which displays a cross-cutting (Fig. 2a) and locally diffuse contact relationship to the host Svecofennian migmatitic metasupracrustal rocks. It is intruded by pegmatitic dykes a few dm thick. This granite forms part of a major granite-pegmatite-migmatite complex which dominates the southeastern part of map-sheet 10E Karlskoga NO. The zircons separated from this rock are pale brown, turbid and relatively fine-grained (90% <100 µm) with length/breadth ratios from 1.5 to 3. A zonation is only evident under oil immersion.

PORPHYRITIC GRANITE

Sample BQMS90202 (map-sheet 10E Karlskoga NO, 658684/144135) is a porphyritic granite in which the K-feldspar phenocrysts are rectangular in shape and often exceed 2–3 cm in length (Fig. 2b). Although direct field relationships to the migmatitic metasupracrustal rocks are unclear, this granite also belongs to the same granite-pegmatite-migmatite complex as BQMS90201 and is also considered to be younger than the migmatites exposed at the present level of erosion. The zircons in the rock are brownish, turbid and relatively fine-grained (<150 µm). Partly due to the fine grain size, they appear to be somewhat rounded. However, the few larger crystals show well-developed, simple prismatic and pyramidal surfaces with length/breadth ratios from 1.5 to 2. A faint zonation has been observed under oil immersion.

LOCALLY CHARNOCKITIC GRANITE

Sample CHW901102 (map-sheet 10E Karlskoga SV, 656710/142240) is a greyish red to reddish grey, equigranular, medium-grained granite. It is locally charnockitic and sometimes sparsely porphyritic. The sample is from a major body, about 20 km long and 2–5 km wide, which is surrounded by a porphyritic TIB granitoid (Fig. 1). Field relationships indicate that this granite is older than the porphyritic TIB granitoids (Fig. 2c). The sampled granite occurs within the eastern frontal part of the Sveconorwegian orogen and the eastern contact constitutes a continuous ductile shear zone. Deformation within the body is usually displayed by mesoscopic shear zones. Both these zones and the charnockitic varieties of the granite were avoided during the sampling. The zircons are relatively small (95% <150 µm, 50% <70 µm) with a length/breadth ratio varying between 1 and 3. Simple prisms and pyramids dominate, but surfaces with high-order indices are common. There is sometimes a faint zonation and some crystals have a narrow growth rim (<5 µm).

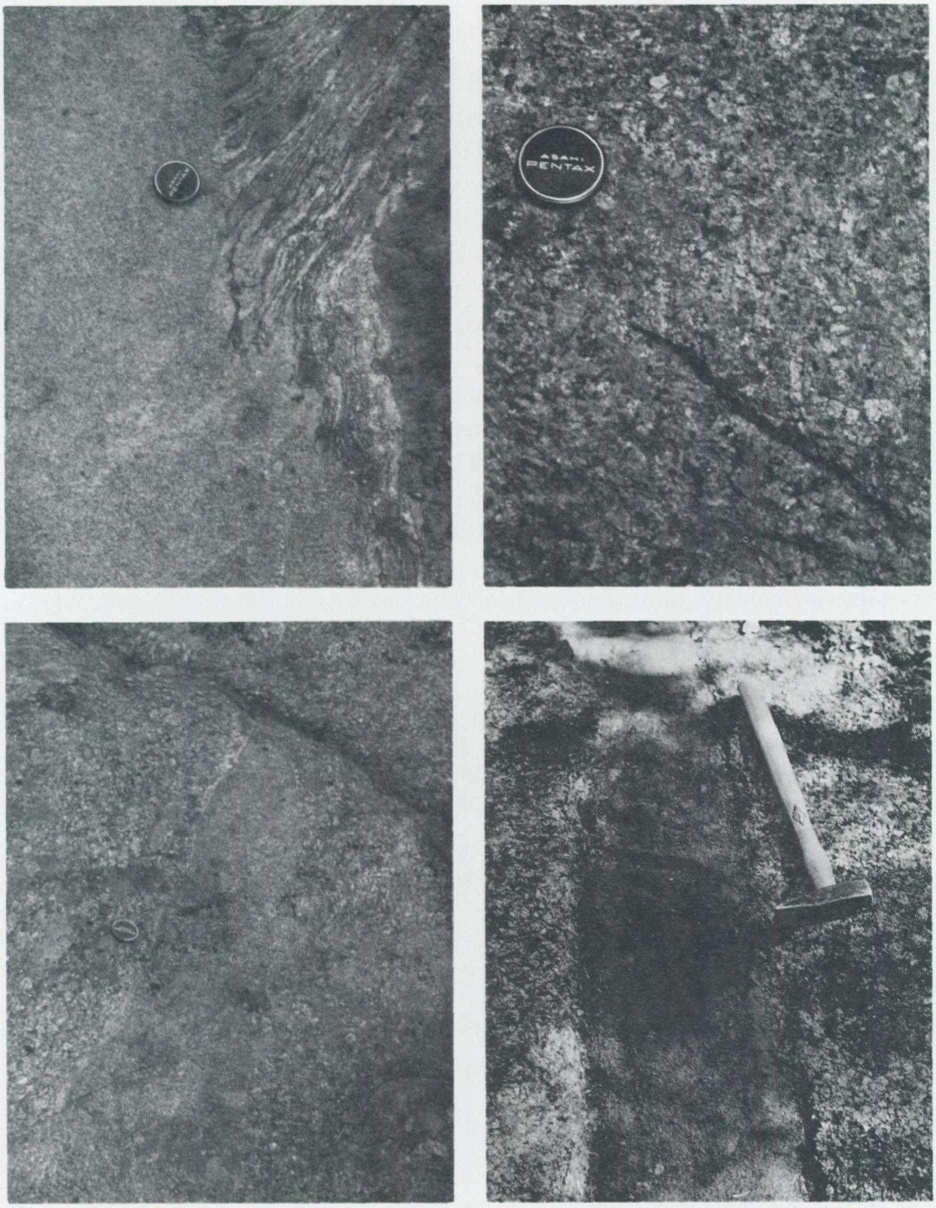


Fig. 2a. Fine-grained, equigranular granite cross-cutting migmatitic metasupracrustal rocks at the sample BQMS90201 locality (10E NO, 658056/144848).

b. Granite with occasionally rectangular-shaped phenocrysts of K-feldspar (10E NO, 658818/144417).

c. Inclusion of the locally charnockitic granite in porphyritic TIB granitoid (10E NO, 658555/143179).

d. Quartz monzodiorite dyke cross-cutting porphyritic TIB granitoid (10E SV, 656295/141380).

QUARTZ MONZODIORITE

Sample CHW901101 (map-sheet 10E Karlskoga SV, 656555/141585) is a grey, medium-grained quartz monzodiorite. It forms part of a major dioritic to quartz monzodioritic intrusion surrounded by the same TIB granitoid as the locally charnockitic granite (Fig. 1). A more detailed chemical and petrographical description has been presented by Annertz (1984). Field relationships, including cross-cutting dykes (Fig. 2d) and a thermal contact aureole involving prograde growth of garnet and hypersthene in the surrounding TIB granitoid, indicate that this intrusion is younger than the granitoid. As for the charnockitic granite, deformed varieties of the quartz monzodiorite were avoided during sampling.

The quartz monzodiorite contains abundant brownish, translucent zircons. Since most crystals occurring in the analyzed fractions (<200 μm) are fragments, the zircons are probably rather coarse-grained. Many of the remaining crystal faces appear to be of a high-index variety, a feature often thought to suggest a complex growth history. No significant zoning or older cores were found. Some crystals contain opaque inclusions (possibly Fe-Ti-oxide), and especially the lighter fractions contain crystals and parts of crystals with a reddish tinge. Zircons displaying such inhomogeneities were avoided in the analyzed samples.

ANALYTICAL PROCEDURE

The analyses were carried out at the Unit for Isotope Geology at the Geological Survey of Finland under the supervision of Matti Vaasjoki. Reference to the techniques used, common for several papers in this volume, can be found in the introductory notes of the volume. Uncertainties in the intercept ages are given as 95% confidence limits.

RESULTS

U-Pb analyses, U/Pb ratios and apparent radiometric ages for the analyzed zircon fractions from all four samples are displayed in Table 1.

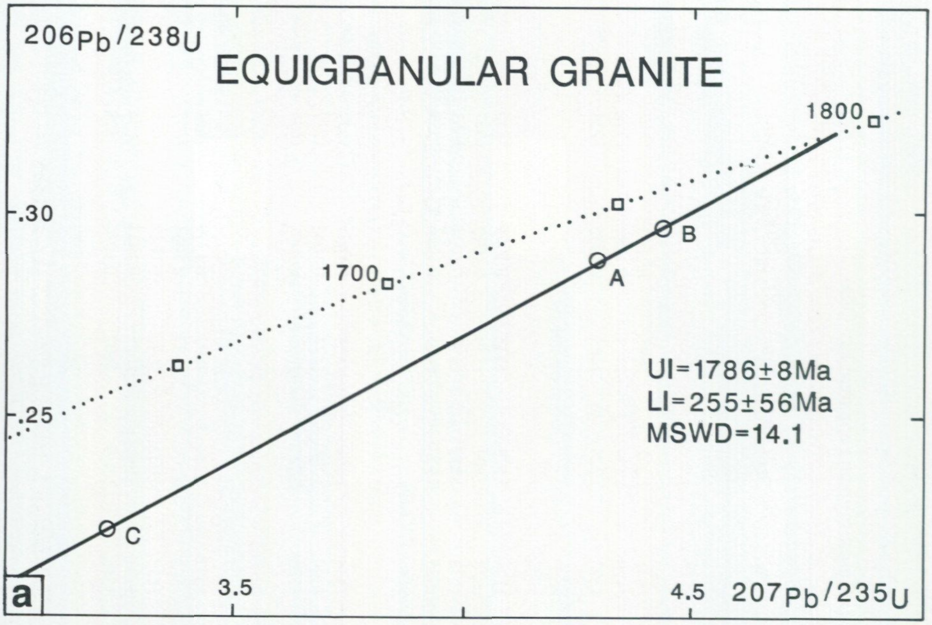
EQUIGRANULAR GRANITE

The zircons in sample BQMS 90201 are very rich in uranium which is reflected in their low densities. Three size fractions form a fairly well-defined linear trend (MSWD=14.1) on a concordia diagram (Fig. 3a) which results in upper and lower intercepts at 1786±8 and 255±56 Ma, respectively. The discordancy pattern is abnormal in as much as fraction B, which contains most uranium, is the most concordant. However, there is a relationship between an increasing content of common lead and an increasing degree of discordancy.

TABLE 1. U-Pb analyses, U/Pb ratios and apparent radiometric ages for analyzed zircon fractions from younger intrusions in the Karlskoga area.

Analysis	Density fraction	Concentration		Atomic ratio and apparent age (Ma)						
		^{238}U	$Pb_{(tot)}$	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{238}U$	Ma	$^{207}Pb/^{235}U$	Ma	$^{207}Pb/^{206}Pb$	Ma
Sample BQMS90201, equigranular granite										
A	>4.2	2699.8	841.67	3889	0.2880	1631	4.292	1691	0.1081	1767
B	4.0-4.2	7584.8	2426.84	4181	0.2958	1670	4.434	1718	0.1087	1778
C	3.8-4.0	2751.2	679.31	1431	0.2216	1290	3.225	1463	0.1055	1724
Sample BQMS90202, porphyritic granite										
A	4.3-4.5	683.4	185.55	712	0.2415	1394	3.528	1533	0.1059	1730
B	4.2-4.3/>70µm	1295.6	252.78	631	0.1721	1023	2.402	1243	0.1013	1647
C	4.0-4.2/>70µm	2124.4	470.29	680	0.1996	1172	2.810	1358	0.1021	1663
D	4.3-4.5/abr	585.5	174.55	751	0.2670	1525	3.962	1626	0.1076	1759
Sample CHW901102, locally charnockitic granite										
A	4.3-4.5/abr	540.2	155.06	6139	0.2749	1565	4.108	1655	0.1084	1772
B	4.3-4.5/>70µm	691.1	162.17	3382	0.2234	1299	3.274	1474	0.1063	1737
C	4.2-4.3	1036.5	206.23	2961	0.1898	1120	2.725	1335	0.1041	1698
Sample CHW901101, quartz monzodiorite										
A	>4.5	306.12	101.97	11053	0.3012	1697	4.314	1696	0.1039	1694
B	4.3-4.5/>150µm	494.07	160.47	10616	0.2984	1683	4.269	1687	0.1038	1692
C	4.3-4.5/<70µm	1039.20	316.95	9528	0.2845	1613	4.033	1640	0.1028	1676
D	4.2-4.3/<70µm	831.35	248.13	10377	0.2781	1581	3.960	1625	0.1033	1684
E	4.2-4.3/>150µm	1527.65	439.08	16165	0.2711	1546	3.849	1602	0.1030	1678

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



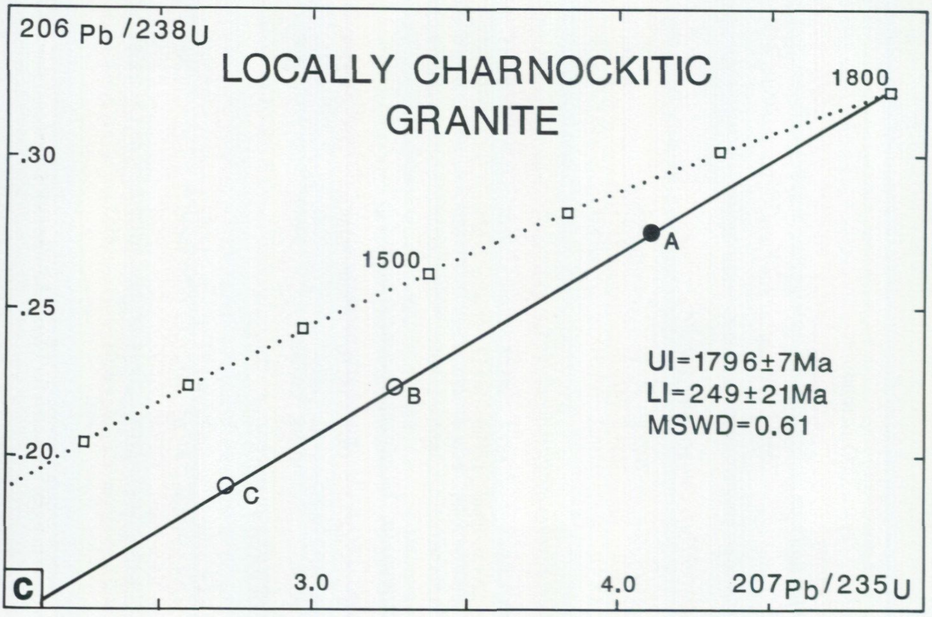
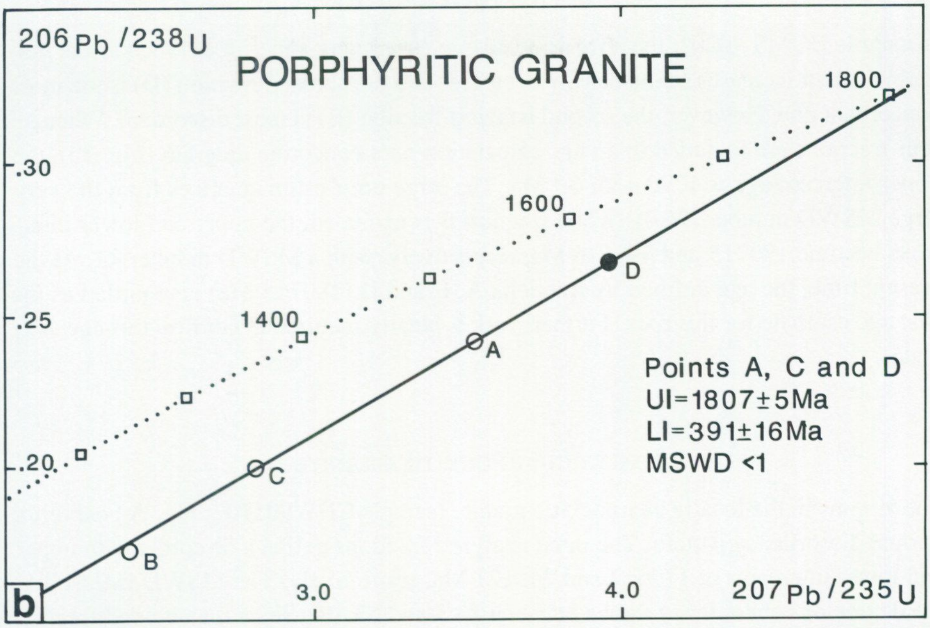


Fig. 3. Concordia diagrams for analyzed zircon fractions from intrusions in the Karlskoga area. Black symbol represents abraded fraction. UI= upper-intercept age, LI= lower-intercept age, MSWD= mean square of weighted deviates.


206Pb/238U
PORPHYRITIC GRANITE
1800
1600
1400
.30
.25
.20
D
A
C
B
Points A, C and D
UI=1807±5Ma
LI=391±16Ma
MSWD <1
b
3.0
4.0
207Pb/235U

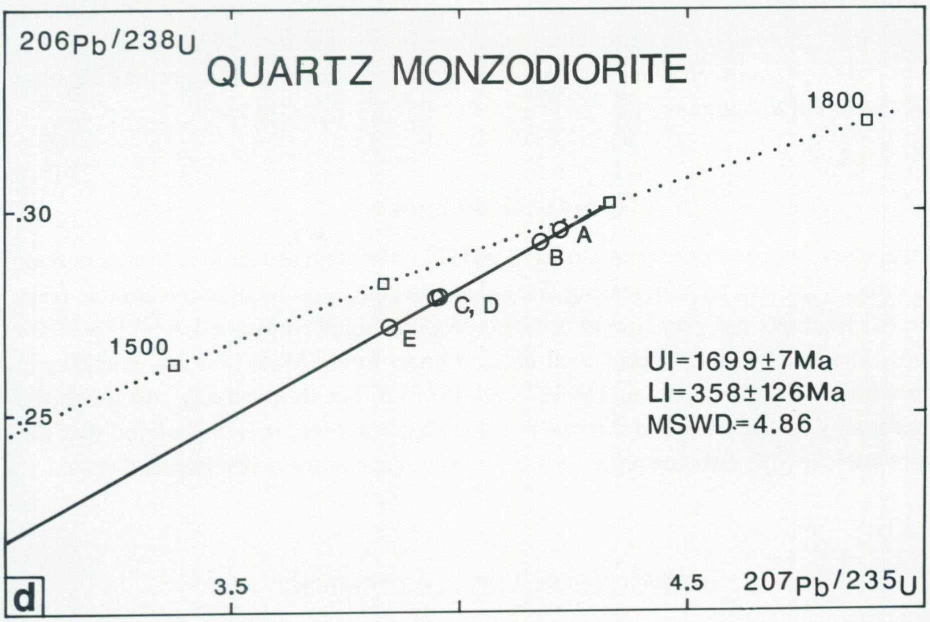

206Pb/238U
QUARTZ MONZODIORITE
1800
1500
.30
.25
A
B
C, D
E
UI=1699±7Ma
LI=358±126Ma
MSWD=4.86
d
3.5
4.5
207Pb/235U

Fig. 3 cont.

PORPHYRITIC GRANITE

In sample BQMS 90202, the zircons behave in a normal manner in as much as the uranium content increases as the density decreases and the abraded fraction (D) is the most concordant one. However, the second heaviest fraction (B) is most discordant. When all four fractions are included in an age calculation on a concordia diagram (Fig. 3b), the upper intercept age is 1790 +35/-30 Ma. The large error estimate arises from the very large MSWD number (96.4). When fraction B is excluded, the upper and lower intercepts become 1807±5 and 391±16 Ma, respectively, with a MSWD number <1. At the present time, the age defined by fractions A, C and D (1807±5 Ma) is regarded as the best age estimate for this rock. Further work is clearly required to confirm this age estimate.

LOCALLY CHARNOCKITIC GRANITE

The zircons in the locally charnockitic granite (sample CHW901102; Fig. 3c) exhibit a normal discordancy pattern. The three analyzed fractions define a discordia with upper and lower intercepts at 1796±7 and 249±21 Ma, respectively. The MSWD is 0.61 and the degree of concordancy varies between 83.5 and 53.4%. Since the abraded fraction does not deviate and the analysis displays a very low MSWD value, it is inferred that the narrow growth rim in some zircon crystals is not significantly younger than the main phase of zircon growth. The upper intercept age is interpreted to reflect the time of intrusion of this granite.

QUARTZ MONZODIORITE

In the quartz monzodiorite (sample CHW901101), the analyzed zircons form a normal discordancy pattern with increasing discordancy with increasing uranium content (Fig. 3d). All fractions are very low in common lead as indicated by the low $^{204}Pb/^{206}Pb$ ratios. The five fractions form a well-defined linear trend (MSWD=4.86), resulting in upper and lower intercepts at 1699±7 and 358±126 Ma, respectively. Although the morphology of the analyzed zircons is somewhat complex, it is considered that the upper intercept age estimate represents the intrusion age of the quartz monzodiorite.

DISCUSSION AND CONCLUSIONS

The restricted number of density fractions analyzed in the four samples, the high MSWD numbers in samples BQMS90201 and BQMS90202 (all four fractions), and the complex morphology of the zircons in especially sample CHW901101 document the preliminary character of the data presented here. Notwithstanding this important restriction, it is clear that the two dates for the granites east of Karlskoga (1786±8 and 1807±5 Ma) give similar age results as other so-called late-tectonic granites in the Proterozoic of south-central Sweden (see review in Welin 1992). It is also apparent that the fine-grained, equigranular granite is somewhat younger than the porphyritic variety. Similar relations between these two types of granite have been inferred within the Fellingsbro granite complex (Öhlander & Zuber 1988). The metamorphic peak which gave rise to migmatites was clearly older than 1786±8 Ma. However, the data do not preclude a causal link between peak metamorphism, migmatite formation and granite generation. The granites may have formed at deeper crustal levels in connection with the peak of metamorphism and subsequently rose upwards through the crust to cool and finally solidify at a higher crustal level, i.e. the present erosion level.

The new analyses presented here and the already published U-Pb zircon ages for these so-called late-tectonic granites (Welin 1992) clearly overlap with the ages for TIB 1 granitoids, i.e. 1810–1770 Ma (Larson & Berglund 1992). Although these two younger suites of granitoid intrusions cannot be separated on the basis of geochronological data or on the basis of their relationships to the Svecokarelian deformation, it is clear that they are distinct from each other on the basis of their petrography and field relations. In particular, the TIB 1 granitoids show a distinctive trend towards monzonitic compositions, show mantled textures in feldspar phenocrysts, are associated with a variety of mafic intrusions and show magma mingling relations (Wikström *et al.* 1985, Andersson 1989, 1991) with at least some of these mafic bodies. It is suggested that the so-called late-tectonic granites in the east and the TIB 1 rocks further west, although of similar age, are petrogenetically different and form a distinctive zoned granitoid belt in the Svecokarelian orogen of south-central Sweden (see also Johansson 1988). More work is needed to document more carefully the nature of this zonation and to compare it with zoned granitoid belts in younger orogens, e.g. southeastern Australia and Japan.

The age of the locally charnockitic granite (1796±7 Ma) implies that it geochronologically falls within the range of documented ages for TIB 1 granitoids (Larson & Berglund 1992). These data support preliminary conclusions based on field relationships (see above) which indicate that this granite is also genetically related to the TIB. According to the three-phase model for TIB rocks suggested by Larson & Berglund (1992), the locally charnockitic granite belongs to the TIB 1 group. The age of this granite also documents the existence of medium-grained, equigranular varieties within the commonly porphyritic TIB granitoids.

The age of the quartz monzodiorite (1699±7 Ma) confirms the field observations which indicate that this body is younger than, and forms a well-defined intrusion into, the surrounding granitoids which are supposed to belong to the TIB 1 group. According to the model by Larson & Berglund (1992), the quartz monzodiorite belongs to the TIB 2 group of intrusions. It is geochronologically similar to the Dala and Rätan granites further to the north in the TIB (see Welin 1992).

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The Knaften granitoids of Västerbotten County, northern Sweden

By
Annika Wasström

GEOLOGY OF THE KNAFTEN AREA

The Knaften area (Fig. 1), south of Lycksele and south of the Skellefte Field, situated in the so-called Bothnian basin, has been interpreted as a primitive Palaeoproterozoic volcanic island arc (Wasström 1989, 1990).

The stratigraphic sequence of the Knaften area starts by basic metavolcanic rocks intercalated with clastic metasediments. The former consist of volcaniclastic rocks and lavas (e.g. pillow lava), and the latter of greywackes, turbidites (e.g. parts of Bouma sequences) and graphite-bearing argillitic rocks.

Granitoids (the Knaften granitoids) have intruded the supracrustal rocks, partly before the end of the volcanic period. They show some subvolcanic structures. Quartz and quartz-feldspar porphyries, probably apophyses from the granitoids, seem to have intruded concordantly with the bedding of the volcanic rocks. A sequence of water-lain rhyodacitic tuffites is probably also related to the granitoids.

During extension, at the end of the volcanic period, gabbroic to ultramafic sills have intruded between the mafic volcanic rocks and the rhyodacitic tuffites. These sills also appear in the volcaniclastics.

The area has been affected by regional greenschist to amphibolite facies metamorphism of Svecokarelian (c. 1800–1850 Ma) age.

DESCRIPTION OF THE GRANITOIDS AND ASSOCIATED DYKES

The Knaften granitoids are lithologically similar to the early orogenic granites to granodiorites of the Svecokarelian province. The more basic varieties occur in the southern part of the area. They differ from the other (late- and postorogenic) granitoids of the region, and remind very much of the Jörn granitoids (c. 1890 Ma; Wilson *et al.* 1987) in the Skellefte Field. The Knaften granitoids are grey to greyish red and 0.5 to 1 cm in grain size. They are usually massive but have a heterogeneous appearance and occasionally show possible flow structures. Some pegmatitic parts, also quartz-rich patches (dm-size) occur. The quartz in the granitoids is often bluish. Locally, quartz porphyritic parts, with idiomorphic quartz, appear, sometimes also numerous irregular quartz and feldspar porphyritic dykes. The dykes are light coloured and more salic than the granitoids. A breccia that has been interpreted as a high level volcanic or a metasomatic breccia (Wasström 1990) has also been found. Spatially associated with the

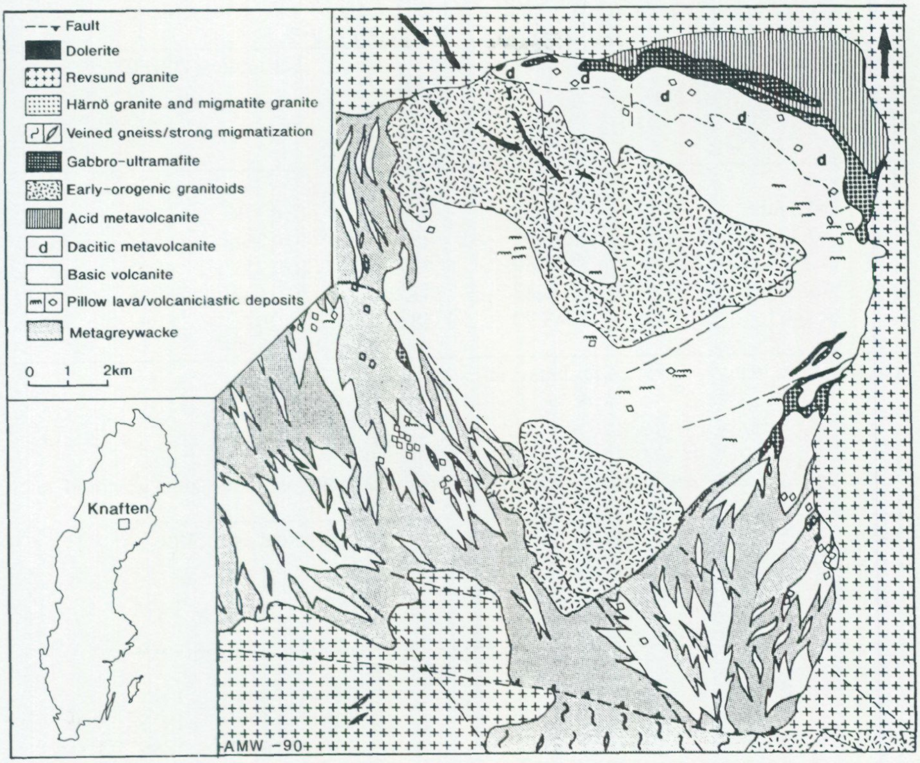

Fig. 1. Geological map of the Knaften area.

breccia is a silicification of the surrounding rocks. The quartz porphyritic parts of the granitoids, the irregular porphyritic dykes and the brecciation indicate that the granitoids are high level intrusions, probably of subvolcanic origin.

The granitoids have also been cut by numerous dykes and patches of quartz and quartz filled joints. The granitoids are sometimes strongly foliated, sheared and brecciated. They are made up of 27–46% quartz, 19–52% K-feldspars, 16–33% plagioclase and 0–12% biotite (formed by biotitization). The K-feldspars consist of pigmented perthite and microcline and the plagioclases are zoned albite-oligoclase-andesine, sometimes sericitized, most strongly in the centre of crystals. Some of the feldspars are mantled and weathered. They are often surrounded by quartz. Accessory minerals are muscovite-sericite (from plagioclase and K-feldspar alteration), apatite, Fe-oxide (hematite), epidote, zircon, and opaque minerals (some ilmenite). Furthermore, some sphene, amphibole and calcite have been found. The feldspars are subhedral, granular, with granophyric perthite-microperthite and myrmekite textures.

TABLE 1. U-Pb analyses of zircons from the Knaften granitoid.

Sample	Fraction	Concentrations		$^{206}Pb/$	Lead ratios, 206=100		
		^{238}U	Pb(tot)	^{204}Pb	^{204}Pb	^{207}Pb	^{208}Pb
MPT-3							
A	>4.3 /abr	493.6	168.42	8493	0.01178	11.87	16.73
B	>4.3	570.7	172.91	7835	0.01264	11.65	16.41
C	4.2-4.3	877.7	251.39	4494	0.02225	11.65	16.52
D	4.0-4.2	1190.0	328.87	4152	0.02409	11.58	16.32
E	4.2-4.3	862.4	248.90	4829	0.02071	11.62	16.64

Concentrations in µg/g, corrected for blank, abr = abraded.

TABLE 2. U/Pb ratios and apparent radiometric ages for zircons from the Knaften granitoid.

Sample	Atomic ratios			Apparent ages (Ma)		
	$^{206}Pb/$ ^{238}U	$^{207}Pb/$ ^{235}U	$^{207}Pb/$ ^{206}Pb	T (6/8)	T (7/5)	T (7/6)
MPT-3						
A	0.3055	4.934	0.1171	1718	1808	1913
B	0.2724	4.312	0.1148	1553	1695	1876
C	0.2569	4.019	0.1135	1473	1638	1856
D	0.2483	3.854	0.1126	1429	1604	1841
E	0.2586	4.046	0.1134	1483	1643	1855

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

The granitoids seem to have intruded into the volcanic rocks as one or more domes, the volcanic rocks dipping away from the centres of the domes. Contacts against the volcanic rocks have not been found in this area of sparse outcropping. However, by geophysical measurements (magnetic and VLF; carried out by Leif Kero, Geological Survey of Sweden) the contact was located between some minor outcrops (< 10 m apart) in the southern part of the area.

Geochemically the granitoids seem to have intruded into a volcanic arc at an active subducting plate margin.

In the volcanic rocks there are some quartz and quartz-feldspar porphyritic dykes that cut the pillow lavas and have chilled margins. They remind very much of the dykes in the granitoids and have been interpreted as associated with the latter (Wasström 1990).

In the northern part of the Knaften area there are rhyodacitic tuffites that seem to be geochemically linked with the granitoids. The tuffites are fine-grained, finely layered and show current bedding, ripple marks, slumping structures and load casts.

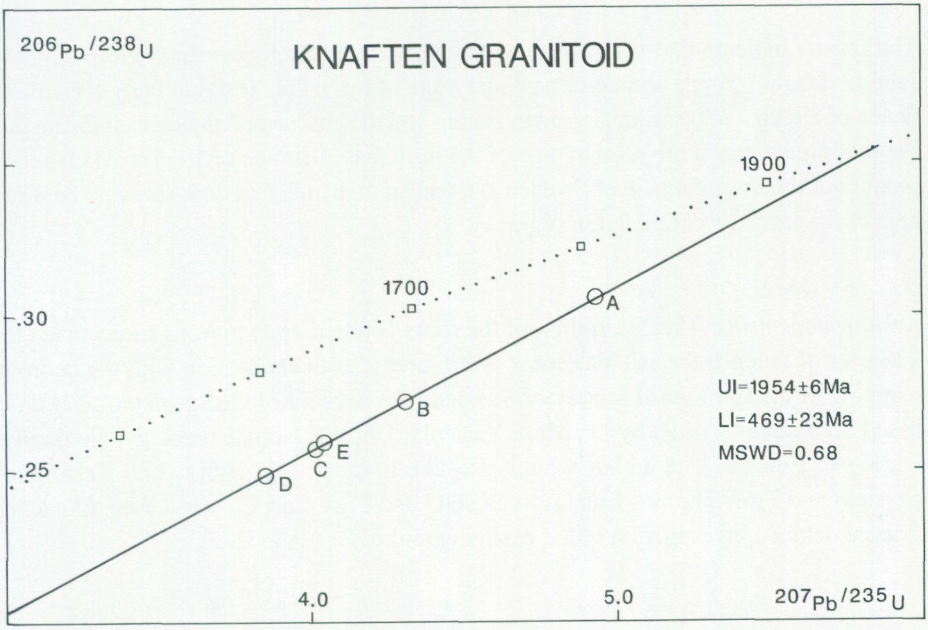

Fig. 2. Concordia diagram for analyzed zircon fractions from the Knaften granitoid.

U-Pb ZIRCON DATING

The Knaften granitoids have been sampled for radiometric age determination at Rönnliden in the central part of the northern granitoid massif (map-sheet 22I SO, coordinates 715710-163498). The dating was performed on zircons at the Unit for Isotope Geology, Geological Survey of Finland, by Dr. Matti Vaasjoki. The zircon population comprises dark brown and rather stubby crystals. They exhibit a faint zonation and no relict cores could be detected. The crystal faces are well developed simple tetragonal prisms and pyramids, but the long side edges are occasionally somewhat rounded.

Five zircon fractions were analyzed (Tables 1 and 2). Together they form a well-defined linear array that intersects the concordia curve at 1954±6 and 469±23 Ma (Fig. 2). All five fractions seem to represent the same zircon population, as the MSWD is 0.68. Although the least discordant fraction (A) has a relatively low degree of concordancy (82.5%), there is a definite correlation between decreasing density, increasing uranium content and increasing degree of discordancy, which is typical for magmatic rocks.

CONCLUSIONS

The results indicate that the zircons of the Knaften granitoid represent either a phase inherited from a single source or a primary age of intrusion. The relatively high abundance of zircon, the occasional growth zoning and the absence of any cores indicate that the interpreted age is the primary age of the intrusion. This age of 1954±6 Ma is today unique for the Svecofennian of Sweden and the Knaften area therefore seems to be a key area of the early Svecofennian stratigraphy.

Acknowledgements. The description of the rocks is based upon investigations made for a Master of Science thesis (Wasström 1990), prepared in connection with the bedrock mapping of the Geological Survey of Sweden. The account of the age determination is based on a report written by Dr. Matti Vaasjoki, Unit for Isotope Geology, Geological Survey of Finland. The author would also like to thank Leif Björk, Leif Kero (geophysics) and Prof. Thomas Lundqvist at SGU and Prof. Carl Ehlers at Åbo Akademi. A more detailed investigation of the Knaften granitoid is planned.

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U-Pb ages of Småland granites and a Småland volcanite from the Växjö region, southern Sweden

By

Hugo Wikman

The Transscandinavian Granite-Porphyry Belt (TSB, also called Transscandinavian Igneous Belt = TIB) separates the Southwest Swedish Gneiss Region from the Svecokarelian Orogenic Belt. The main part of the TSB is built up of Småland-Värmland granitoids and associated volcanic rocks, mainly porphyries. These rocks were previously considered postorogenic relative to the Svecokarelian orogeny and U-Pb datings have given ages of c. 1810–1650 Ma. Recently Larson & Berglund (1992) have proposed a threefold division of the TIB rocks in the Värmland, Småland and Blekinge regions based on new age determinations. According to this division the oldest TIB 1-rocks are found in the east and the youngest, TIB 3-rocks in the west.

New age and field data point to a greater complexity within the belt than previously believed. The TSB may also extend to the west of the Protogine zone, which is the major deformation zone between the crustal domains of the TSB in the east and the Southwest Swedish Gneiss Region in the west. The belt might as well also extend to the south into the Blekinge region (cf. Kornfält, this volume). In order to get a better understanding of the TSB-rocks within the Växjö region, where regional mapping is carried out, three samples have been collected in an area close to the Protogine zone.

REDDISH GREY GRANITE, HW 90002

SAMPLE AND ZIRCON DESCRIPTION

This sample was collected in a quarry 8 km to the west of Växjö center, map-sheet 5E Växjö SO, coordinates 630725/143115. The granite is coarse medium-grained, reddish grey with scattered megacrysts of potash feldspar. It shows no signs of deformation and is cut by dykes and minor massifs of fine-grained granite. It is also cut by two dykes of completely altered, fine-grained greenstone.

Radiometric work on this and the following samples was done at the Unit for Isotope Geology, Geological Survey of Finland, under supervision of Dr. Matti Vaasjoki. Four zircon fractions of three different densities were analyzed from the rock, one analysis being from an air abrasion of the heaviest density fraction. The habit of the zircons is generally short-prismatic (L/B from 1.5 to 3). Most of the crystals terminate in simple tetragonal pyramids, but both prismatic and pyramidal faces with higher-order indices are frequent. The crystals are generally turbid, which handicaps the observation of

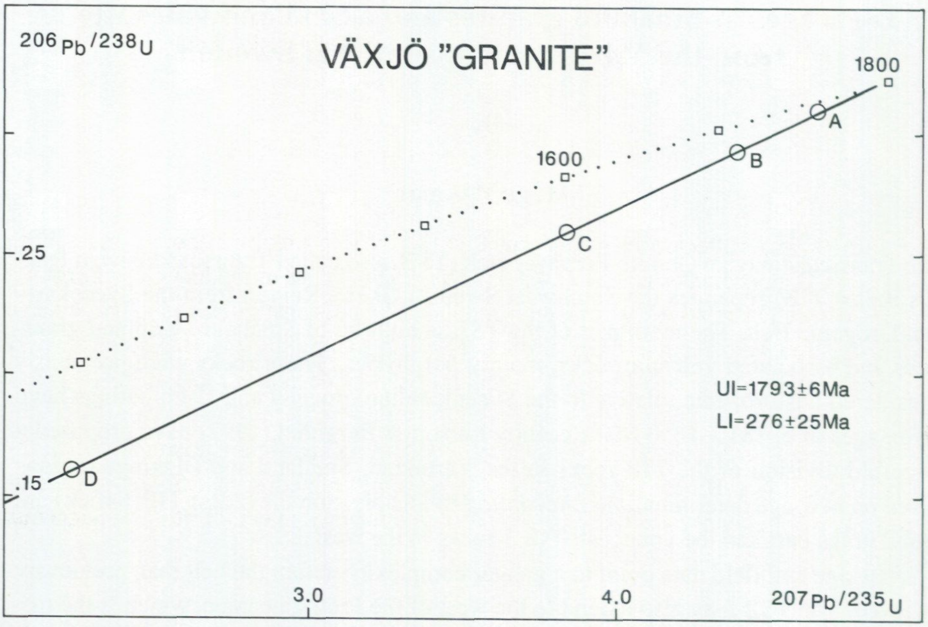

Fig. 1. U-Pb concordia diagram for zircons from sample HW 90002, reddish grey granite.

both inclusions and zonation under air. Under oil immersion, numerous inclusions and growth zonation could be detected. No cores were found in the analyzed fractions.

RESULT

The analytical results are summarized in Table 1. Following the pattern common to most igneous rocks, the uranium contents increase as the density decreases. For fractions A, B and D the common lead contents are relatively high as demonstrated by the fairly low $^{206}Pb/^{204}Pb$ ratios. These are, however, still sufficiently high so that the choice of common lead correction does not significantly affect the result.

Table 2 presents the calculated isotopic ratios and the apparent ages derived from them. It is evident that the analyzed fractions follow a normal discordancy pattern, i.e. the discordancy increases as the uranium contents increase and the density decreases. As usual in igneous rocks, the abraded heavy fraction is the most concordant one of the sample population.

Figure 1 summarizes the results on a concordia diagram. The analyzed fractions define a well-correlated linear trend with an upper intersect at 1793±6 Ma and a lower intersect at 276±25 Ma. As the most concordant data point is 96.2 % concordant, the upper intersect age is to be considered reliable and most probably represents the time of intrusion of the granite. The lower intersect age is probably geologically meaningless.

RED, FOLIATED GRANITE, HW 990003

SAMPLE AND ZIRCON DESCRIPTION

The sample was collected in a road cut 850 m NNE of Lekaryd church, map-sheet 5E Växjö SO, coordinates 631245/142605. The granite is red to reddish grey, medium-grained and shows relatively strong deformation. This deformation is due to movements along the Protogine zone. Similar granites are found along the zone to the north, and the granite is very similar to that at Hagshult which has been dated to 1664±9 Ma (Jarl 1992).

The zircons in the sample are generally rounded with high-index prismatic and pyramidal faces. The L/B ratio varies from 1.2 to 2.5 with a median at 1.5. Under immersion, only a faint zonation could be detected. These features may indicate a non-igneous history for the zircons analyzed.

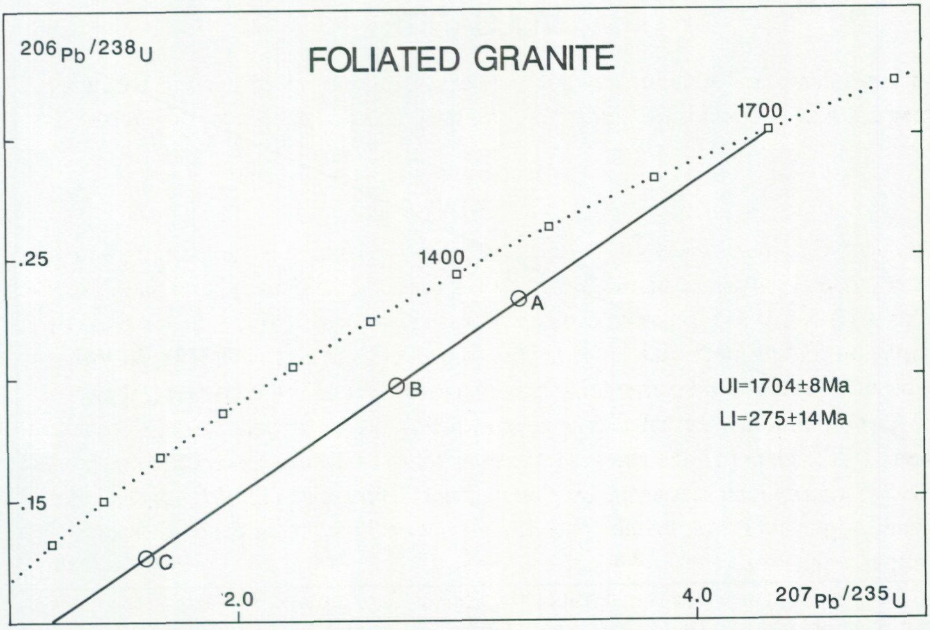

Fig. 2. U-Pb discordia diagram for zircons from sample HW 90003, red foliated granite.

RESULT

The analytical data (cf. Tables 1 and 2) of the three zircon fractions which could be successfully separated show a normal discordancy pattern, but all analyses are relatively discordant. The concordancy degree of the heaviest fraction (A) is 72.6%. The three fractions define a relatively good discordia line, which intersects the concordia at 1704±8 and 275±14 (Fig. 2).

GREY, FINE-GRAINED VOLCANITE, HW 90004

SAMPLE AND ZIRCON DESCRIPTION

HW 90004 was sampled in a road cut 2.9 km ESE of Öja church, map-sheet 5E Växjö SO, coordinates 630235/143015. The volcanite is grey, fine-grained and sparsely porphyritic. It differs from the usually more reddish or brownish porphyries normally found together with the Småland-Värmland granites. It can be traced further to the south towards the Blekinge region. In some places the rock seems to be sub-volcanic and partly looks like a fine-grained granite.

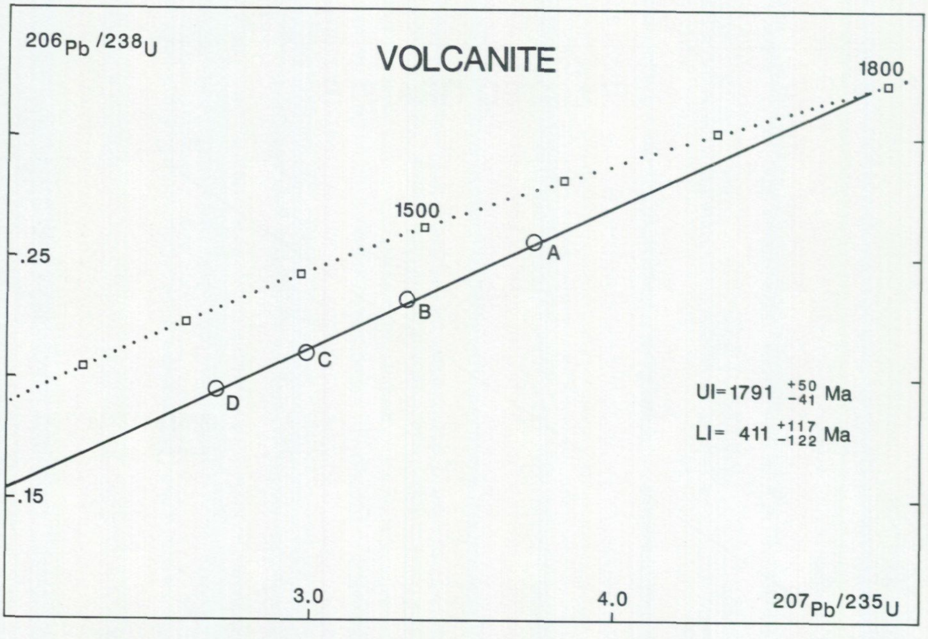

Fig. 3 U-Pb discordia diagram for zircons from sample HW 90004, grey, fine-grained volcanite.

The zircon fractions consist of two morphological types, dark brown stubby crystals with high-index crystal faces and a L/B ratio of 2–4 with a median at 3. Rather surprisingly, the prismatic crystals are more abundant in the light fraction 4.2–4.3, while the heavier fractions are dominated by the dark, stubby variety.

RESULT

The analyzed samples (cf. Tables 1 and 2) are rather discordant, the concordancy degree of fraction A being 76.8 %. Unfortunately, the small amount of the heavy fraction precluded the preparation of an air abraded fraction, but an air abrasion was performed on the 4.3–4.5 fraction (analysis B). The results also exhibit a considerable scatter in excess of analytical error (Fig. 3), suggesting inhomogeneity of the zircon fractions and resulting in large error estimates. Also, the common lead contents are fairly high, which is a feature atypical of unaltered volcanic rocks.

The upper intersect age for all four fractions is 1791 +50/-41 Ma, while the lower intersect lies at 411 +117/-122 Ma. If fraction B is excluded from the calculation, the result becomes 1796 +66/-51 Ma for the upper intersect. Correspondingly, by exclud-

TABLE 1. U-Pb analyses of zircons from samples HW90002-4.

Sample	Fraction	Concentrations			Lead ratios, 206=100		
		^{238}U	Pb(tot)	$^{206}Pb/^{204}Pb$	^{204}Pb	^{207}Pb	^{208}Pb
HW90002							
A	>4.5/abr	196.40	72.46	970	0.1031	12.31	22.60
B	>4.5	227.05	77.91	1009	0.0991	12.25	20.80
C	4.3-4.5	346.63	100.44	3302	0.0303	11.18	17.37
D	4.2-4.3	971.95	184.53	1178	0.0849	11.22	22.96
HW90003							
A	>4.5	238.68	65.72	1027	0.0974	11.50	23.45
B	4.3-4.5/>150	548.53	128.62	754	0.1327	11.81	22.75
C	4.2-4.3/>150	1463.88	217.56	772	0.1295	11.01	21.63
HW90004							
A	>4.5	242.06	69.63	1580	0.0633	11.46	16.91
B	4.3-4.5/abr	632.38	169.47	752	0.1329	12.20	17.82
C	4.3-4.5	676.94	161.79	903	0.1108	11.83	16.81
D	4.2-4.3	1072.97	267.15	350	0.2856	13.96	26.11

Concentrations in µg/g; corrected for blank; abr = abraded.

ing fractions C and D, upper intersects of 1791 +19/-17 and 1773 +65/-47 Ma are arrived at. The three latter results are somewhat artificial as, in view of the heterogeneous zircon population, there really is no reason to exclude any of the fractions from the calculation.

DISCUSSION

Jarl & Johansson (1988) have published a U-Pb dating on zircons from a Växjö granite about 25 km east of the present sampling site. This granite is somewhat more reddish and corresponds to the granite type which is called "red Växjö". The latter, however, is richer in quartz than the dated granite in this report. Jarl & Johansson's age, 1769 ±6 Ma, seems to be significantly younger than that from the present sample. This is well in accordance with what might be expected if we have a continuous fractionation during the formation of the TSB-granitoids. However, it should be pointed out that the data of the "red Växjö" are rather discordant and thus somewhat less reliable.

TABLE 2. U/Pb ratios and apparent radiometric ages for zircons from samples HW90002-4.

Sample	Atomic ratios			Apparent ages (Ma)		
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	T (6/8)	T (7/5)	T (7/6)
HW90002						
A	0.3101	4.658	0.1090	1741	1759	1782
B	0.2927	4.396	0.1089	1654	1711	1781
C	0.2588	3.840	0.1076	1483	1601	1759
D	0.1609	2.229	0.1005	961	1190	1632
HW90003						
A	0.2315	3.243	0.1016	1342	1467	1653
B	0.1966	2.705	0.0998	1157	1329	1620
C	0.1265	1.605	0.0920	767	972	1467
HW90004						
A	0.2559	3.735	0.1059	1468	1578	1729
B	0.2326	3.324	0.1037	1348	1486	1690
C	0.2105	2.989	0.1030	1231	1404	1678
D	0.1954	2.697	0.1001	1150	1327	1626

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

Jarl & Johansson (1988) also report ages in the range 1799±5 to 1841±12 for a "Växjö granite" west of Linköping, considerably north of the site of the present sample. An interesting feature in this data set is that the most concordant data point has a $^{207}Pb/^{206}Pb$ age of 1780 Ma, and if one deviating result (fraction 2) is omitted, the result becomes 1808±20 Ma. In summary, the analyses on sample HW 90002 suggest an age of 1793±6 Ma for the intrusion of this rock.

The result of sample HW 90003 differs significantly from the estimated intrusion age of the granite HW 90002. The deformation of the rock is thought to be due to movements along the Protogine zone. It should be noted in this context that although zircon generally preserves its original age information even under high grade conditions (Vaasjoki & Sakko 1988), cases are known when zircon is reset already at relatively mild conditions (Gebauer & Grunenfelder 1976). If the deformation was accompanied by a flux of hydrous fluids along the shear zone, it is possible that an almost total resetting of the zircons in sample HW 90003 could have occurred during a phase of tectonic activity. Considering the location of the analyses on the concordia diagram, the resetting would have been almost total and thus the upper intersect age would date this event. If the original material was a Växjö type granite, no effect of a younger event, e.g. of Sveconorwegian age, can be inferred.

It can not be excluded that the sample HW 90004 is a volcanic sediment (tuffite), with a variable provenance (cf. Vaasjoki & Sakko 1988). Thus, the $^{207}Pb/^{206}Pb$ age of the most concordant fraction, 1729±11 Ma, sets an absolute minimum age for the provenance of this rock. However, in view of the relatively large discordancy of the analyzed fractions, the source areas could well be older than 1791 Ma.

An alternative is that the age may reflect a partial influence from a later tectonic process, as outlined for sample HW 90003. Even in this case movements along the Protogine zone might be responsible for the resetting, as the sample is collected in an area very close to that zone. In favour of an interpretation not involving sedimentary processes is also the fact that the rock according to field observation is homogeneous and shows no signs of sedimentary structures (bedding etc.). A genetic relationship between this rock and the granite represented by sample HW 90002 seems so far to be very plausible.

CONCLUSIONS

In summary the three rocks seem to belong to the Småland–Värmland granitoids and associated volcanic rocks. It is interesting to notice that sample HW 90002 is older than the red Växjö granite further to the east (Jarl & Johansson 1988). Also interesting is the relatively low age of the deformed granite HW 90003. Whether this value is due to some sort of resetting, or supports the theory that the youngest rocks within the TIB are found in the west, is still an open question. The zircons of the analyzed volcanite give indications that older material may form part of the rock. Nevertheless, the age points to a connection between this rock and the Småland-Värmland granitoids.

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U-Pb dating of the Stormandebo rhyolite in the Västervik area, southeastern Sweden

By
Anders Wikström

BACKGROUND

Gavelin (1984) described an area some 20 km west of the town Västervik with a sequence of well-preserved volcanic rocks, conformably overlying the Västervik metasediments. The sequence was mapped in detail by Jonuks (1984). A stratigraphy was established by him consisting of, from the bottom: acid volcanites–volcanic and epiclastic sedimentary rocks–andesitic volcanites–acid, in part ignimbritic volcanites. In the older Geological Survey (SGU) map of the area (Svenonius 1905) this sequence was considered to belong to the Småland porphyries, but Gavelin (1984) regarded it to be Svecofennian. The main reason for this was that the sequence was slightly folded, conformably with the underlying quartzites, in a synformal structure. In the somewhat later SGU map (Lundegårdh *et al.* 1985) the sequence was once again classified to belong to the Småland porphyries. The argument was the petrological similarities, at least of the acid volcanites, with the Småland porphyries and that late folding events had been recognized in marginal zones to the Småland–Värmland granitoids in some other areas (Wikström 1984). In order to get more information on this subject a sample of the acid volcanites from Jonuks' uppermost formation was collected for radiometric analysis. The sample was collected in a road cut close to the small hut Västantorp (map-sheet 7G Västervik SO, National Grid coordinates: 640230/152960) and consists of a red, very fine-grained, almost flint-like porphyry with some scattered, tiny phenocrysts of feldspar. The sample was analyzed at the Unit for Isotope Geology, Geological Survey of Finland.

ISOTOPE ANALYSES

The zircons in the sample are euhedral, slightly turbid pale brown crystals with simple prismatic and pyramidal faces. Their grain size is relatively fine, 90 % of the crystals being less than 100 µm in length. The length/breadth ratio generally varies from 1.5 to 3.

The discordancy pattern of the analyzed zircons is normal, i.e. the density decreases while the uranium contents and the degree of discordancy increase. The common lead contents of the samples are relatively high as can be seen from the low $^{206}Pb/^{204}Pb$ ratios. The content of radiogenic lead is, however, high enough to facilitate a reliable age determination. Cf Tables 1 and 2.

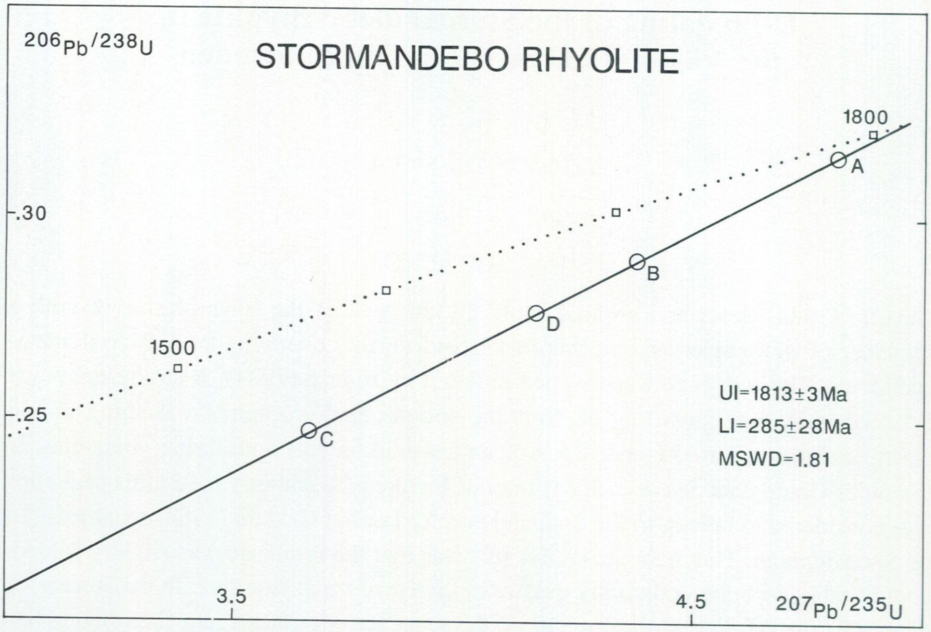

Fig. 1. U-Pb concordia-discordia diagram for zircons from the Stormandebo rhyolite.

The four analyzed fractions define a discordia line with an upper intersect at 1813 ±3 Ma and a lower intersect at 285±28 Ma (Fig. 1). The MSWD for the fit is 1.81, indicating that a small part of the scatter is due to other factors than analytical uncertainty. On the other hand, because of the high degree of concordancy of the abraded fraction (96.8%), the upper intersect age is regarded as a reliable estimate for the extrusion of the Stormandebo rhyolite.

CONCLUSIONS

The results of the zircon determinations indicate that the analyzed rock is not associated with the main Svecofennian volcanic events as rocks belonging to this group in Sweden and Finland have been mostly dated to be 1880–1910 Ma old. (Welin 1987, Kähkönen *et al.* 1989; Vaasjoki & Lahti 1991). Somewhat younger ages around 1850 Ma from central Bergslagen have also been reported by Beunk *et al.* (1985). So far the only published zircon age determination of the Småland porphyries has been made by Åberg & Persson (1984) with a result of 1834 +46/-29 Ma. A dating by Skiöld (1988) of the Dobblon porphyry in northern Sweden gives 1803 Ma. Wikman (this volume) reports an age of 1791 +50/-41 Ma from central Småland and Persson & Lundqvist (this volume) an age of 1787 +35/-24 Ma from northern Dalarna. These values roughly

TABLE 1. U-Pb analyses of zircons.

Sample	Fraction	Concentrations			Lead ratios, 206=100		
		^{238}U	Pb(tot)	$^{206}Pb/^{204}Pb$	^{204}Pb	^{207}Pb	^{208}Pb
A	>4.5/abr	220.9	86.30	596	0.1677	13.33	25.44
B	4.5	255.8	90.19	725	0.1379	12.80	23.89
C	4.0-4.2	419.7	128.50	525	0.1902	13.39	25.24
D	4.3-4.5	310.0	105.81	612	0.1632	13.15	25.44

Concentrations in µg/g; corrected for blank; abr = abraded.

TABLE 2. U/Pb ratios and apparent radiometric ages for zircons.

Sample	Atomic ratios			Apparent ages (Ma)		
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	T (6/8)	T (7/5)	T (7/6)
A	0.3156	4.813	0.1106	1768	1787	1809
B	0.2900	4.380	0.1091	1642	1709	1784
C	0.2468	3.669	0.1078	1451	1564	1763
D	0.2762	4.161	0.1092	1573	1666	1785

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

coincide with the majority of datings of the Småland-Värmland granitoids. The highest age of the Småland granitoids so far is from the Askersund granite (1849 Ma, Persson & Wikström, in prep.), where the granitoid has been emplaced in a vaning compressive regime. Apparently the granitoid and volcanic magmatism in the Transscandinavian Igneous Belt has an extended history. The Stormandebo volcanic rocks fit within this development. The age determination also demonstrates that a minor folding event in the area is younger than 1813 Ma.

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