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U-Pb zircon ages of metatuffites and Older Granite from the Tunaberg area, SE Bergslagen, Sweden

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Abstract

Two U-Pb zircon datings of metatuffites from the lower and upper unit of the metavolcanosedimentary sequence in the Tunaberg area, SE Bergslagen, Sweden, yield an age of 1871 ± 7 Ma for the metatuffite in the lower unit and an age of 1836 ± 9 Ma for the metatuffite in the upper unit. An Older Granite in a folded, composite granite-basite sheet that is intrusive in the upper metavolcanosedimentary unit contains zircons with cores that are apparently inherited from older crust; the U-Pb zircon age of 1912 ± 29 Ma obtained for this Older Granite must be discarded as the intrusion age of this granite. The maximum age of intrusion of the pre-main folding composite sheet of Older Granite and metabasite is constrained by the 1836 ± 9 Ma age of the upper volcanosedimentary unit. The deposition of the southern Bergslagen metavolcanosedimentary sequence in the Tunaberg area occurred in the period 1.88–1.83 Ga, i.e. a somewhat later and much longer period than the deposition period of the 1.89–1.88 Ga western Bergslagen volcanosedimentary sequence.

Introduction

The bedrock in the central-Swedish Bergslagen region is dominated by Early Proterozoic, Svecofennian (1.9–1.8 Ga) volcanosedimentary and plutonic rocks. West Bergslagen is occupied by the greenschist- to low-amphibolite-facies, mainly volcanic and ore-rich, SW–NE trending western volcanosedimentary belt. South and southeast Bergslagen are occupied by the amphibolite-facies, mainly sedimentary, E–W trending, southern volcanosedimentary belt. Central, north and northeast Bergslagen are predominated by large batholiths of Svecofennian Older Granite with isolated septa of volcanosedimentary rocks. Figure 1 depicts the subdivision of Bergslagen in, roughly, the western and southern volcanosedimentary belts and the northeastern granite region.

Multigrain U-Pb zircon ages of 1.89–1.88 Ga Svecofennian acid metavolcanics and 1.89–1.85 Ga Svecofennian Older Granites have been reported from the western volcanosedimentary belt and the northeastern granite region, north of the line Filipstad-Uppsala (Fig. 1). Zircon ages of Svecofennian acid metavolcanics and Older Granites in the southern volcanosedimentary belt have not been provided before, but it is generally assumed that the metavolcanics and Older Granites in the western and southern volcanosedimentary belts are of similar age. To verify this assumption and to check the lithostratigraphic relationships in the southern volcanosedimentary belt, three conventional multigrain U-Pb zircon datings have been performed on two acid metatuffites and one Older Granite from the Tunaberg area, which is located in the east of the southern belt, 100 km SW of Stockholm at longitude 16°55′ E and latitude 58°39′ N.

Geological setting

Field work by Dobbe (1994a) indicates that the volcanosedimentary sequence in the Tunaberg area consists of a lower unit, discordantly overlain by an upper unit. The lower unit comprises the migmatized Frankhyttan meta-arkose and Skeppsvik meta-

Fig. 1. Geological sketch map of Bergslagen (De Groot 1993, adapted from Lundström 1988). Radiometric U-Pb zircon ages (in Ma) of *metavolcanites*: **1900 ± 19** (Åberg et al. 1984), **1882 ± 24, 1892 ± 6, 1891 ± 10** (Welin 1987), and **1871 ± 7, 1836 ± 9** (this paper); and *Older Granites*: **1886** (Welin et al. 1980, diffusion age), **1850** (Åberg et al. 1983), **1873** (Åberg et al. 1984), **1869** (Åberg & Strömberg 1984), **1854 ± 5** (Welin & Stålhös 1986, 1st generation pegmatite related to Older Granite), and **1890 ± 3** (Persson 1993).

greywacke formations, which show lateral transition. The ENE–WSW striking Frankhyttan meta-arkose formation forms the north-limb and the E–W striking Skeppsvik metagreywacke formation the south-limb of a large ENE-plunging open synclinorium (Fig. 2). The Skeppsvik metagreywacke formation contains intercalations of andesitic (biotite – hornblende-rich) and rhyolitic or acid metatuffites. The most extensive and thickest (up to 200 m) acid metatuffite horizon in the Skeppsvik metagreywacke formation is the Fe-Mn-mineralized Prästängen acid metatuffite horizon. The upper unit of the volcanosedimentary series consists of the Cu-Co-Zn-Pb-mineralized Syrtorp metatuffite formation, which comprises, from bottom to top, an acid metatuffite, a marble, and a metagreywacke member. The Syrtorp formation discordantly overlies the Frankhyttan and Skeppsvik formations, and is disharmoniously infolded in the core of the ENE-plunging synclinorium. The Syrtorp formation is intruded by a composite intrusive sheet of Older Granite and metabasite that is affected by the same folding phases as the ENE-plunging synclinorium. The Older Granites and associated metabasites are broadly contemporaneous with or slightly younger than the volcanosedimentary series and they intruded before or during folding and metamorphism. The metavolcanosedimentary sequence is further intruded by undeformed Younger Granites and Jotnian dolerites. U-Pb zircon datings have been performed on three samples: BRL-503, acid metatuffite from the Prästängen acid metatuffite horizon in the lower volcanosedimentary unit; BRL-500, acid metatuffite from the acid metatuffite member of

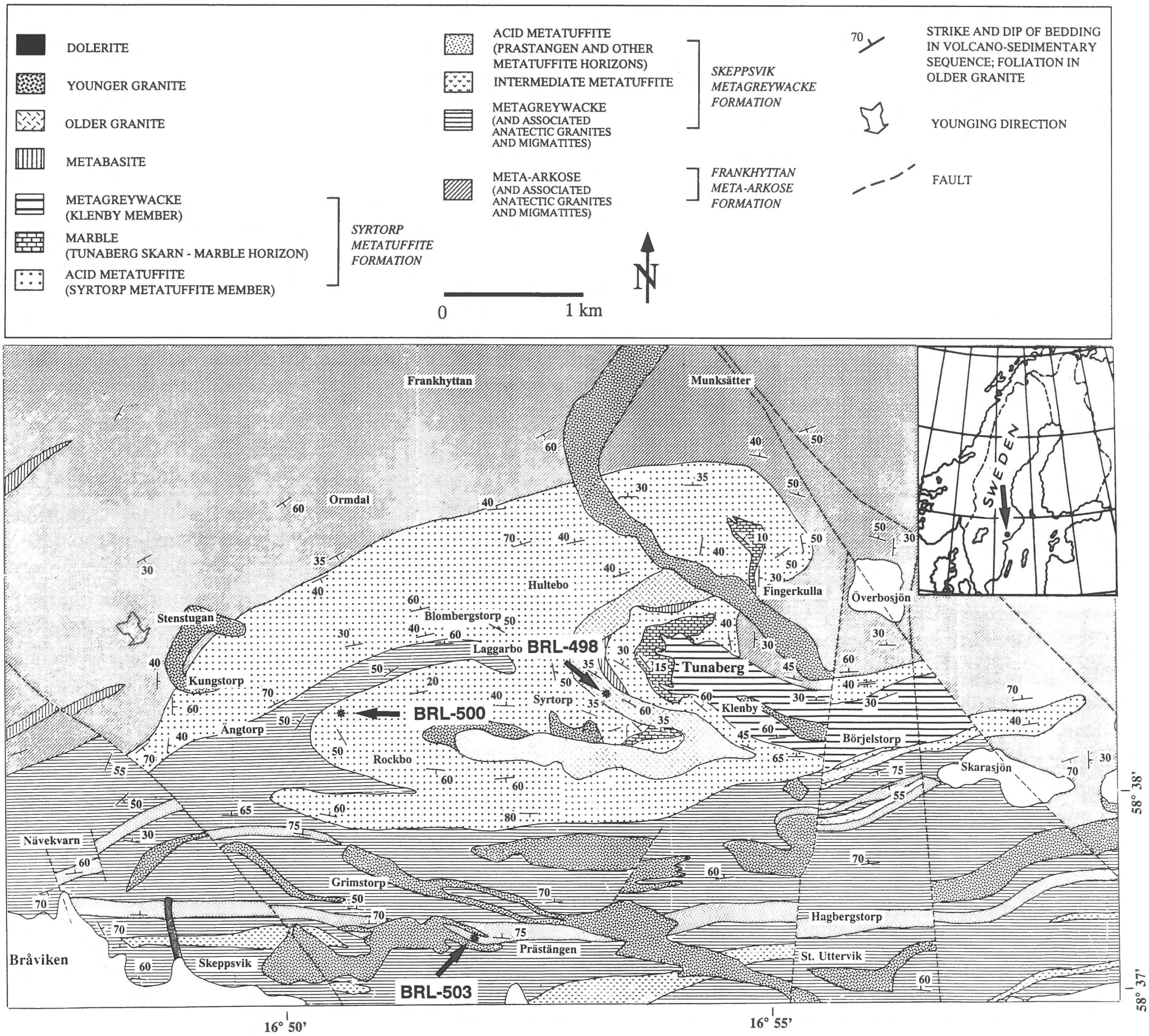

Fig. 2. Geological map of the Tunaberg area (modified after Lundström 1974). Sample sites are indicated.

the Syrtorp formation in the upper volcanosedimentary unit; BRL-498, Older Granite from a composite intrusive sheet in the upper volcanosedimentary unit. Sample localities are indicated on Fig. 2.

Petrography

The acid metatuffites of the Prästängen horizon are massive non-layered, but often biotite-foliated, alkali-intermediate to potassic-acid metatuffitic gneisses containing some concordant pegmatitic lenses and veins; most common are microcline-rich potassic-acid metatuffites. At sample locality BRL-503 (Fig. 2, Swedish national grid coordinates 650030/156154) the metatuffite is a fine- to medium-grained, grano- to xenoblastic, alkali-intermediate, grey metatuffite gneiss, consisting of quartz (57 vol. %), oligoclase (25 vol. %), microcline (15 vol. %) and biotite (3 vol. %), with zircon, apatite and opaque minerals as accessories. The Prästängen acid metatuffites are associated with intercalated migmatized greywackes, plagioclase–hornblende amphibolites, hornblende rocks, marbles, and exhalative-sedimentary Mn-rich silicate and Fe-oxide deposits with related Mg-rich cordierite–anthophyllite alteration zones (Dobbe 1994b).

The Syrtorp acid metatuffite member of the Syrtorp formation consists of fine-grained, well-banded and laminated quartz–microcline–biotite metatuffites, showing an alternation of 5–20 cm thick, biotite-poor light grey and biotite-richer grey bands. At sample locality BRL-500 (Fig. 2, coordinates 650227/156025) the rock is a biotite-foliated, xenoblastic potassic-acid grey metatuffite consisting of quartz (45 vol. %), microcline (51 vol. %) and biotite (4 vol. %), with zircon, apatite, clinozoisite, colourless mica, garnet, carbonate, chlorite, amphibole and opaque minerals as accessories. The Syrtorp acid metatuffite member contains intercalations of sillimanite–muscovite-rich microcline–quartz rocks, calcite- and calcsilicate-bearing quartz–microcline–biotite metatuffites, meta-greywackes, graphitic slates with Zn-Pb-sulphide deposits, and marble–skarn horizons with siliceous and oxidic iron formations and Cu-Co- and Zn-Pb-sulphide deposits (Dobbe & Oen 1993, 1994).

The Older Granite in the composite sheet of granite and metabasite in the Syrtorp formation shows a patchy development of equigranular fine- to medium-grained, foliated granodiorites and coarser grained gneissic migmatitic rocks displaying platy quartz–feldspar aggregates. At sample locality BRL-498 (Fig. 2, coordinates 650268/156273) the Older Granite is a strongly gneissose granodiorite with xenoblastic texture, composed of quartz (35 vol. %), oligoclase (60 vol. %), microcline perthite (1 vol. %) and biotite (4 vol. %), with zircon, apatite and opaque minerals as accessories. Secondary alteration products are microcline, sericite, calcite and chlorite.

U-Pb zircon analytical methods

Zircon separation and isotopic analyses were done at the Laboratory of Isotope Geology (CIGO), Vrije Universiteit, Amsterdam. The zircons were recovered from ground samples by, successively, density separation using bromoform, di-iodomethane and Clerici solution in a laboratory overflow centrifuge (IJlst 1973), and magnetic separation with a modified Frantz isodynamic separator (Verschure & IJlst 1966). Size fractions of crystals of similar width were prepared using sieves with oblong splits. Final purification occurred by hand-picking under the microscope. The > 90 μm and 60–90 μm fractions ($d < 4.2$) of BRL-503 were air-abraded using a technique adopted from Krogh (1982). The weight of the zircon fractions ranged between 0.1–1.2 mg. Chemical decomposition of zircons and separation of lead and uranium were essentially done according to a laboratory procedure adopted from Krogh (1973). After washing with 7 M HNO_3, samples were dissolved in PTFE® micro-capsules (0.4 ml) with HF and HNO_3. The capsules were placed into a large PTFE® beaker (125 ml) with 5 ml HF and HNO_3. The beaker was mounted into a metal Parr® bomb, and subsequently heated to 205 °C during 5 days. A mixed spike $^{208}Pb/^{235}U$ was used for isotope dilution. After evaporation, the natural and spiked aliquots were redissolved in HCl, and U and Pb were separated by anion exchange chromatography (Bio-Rad AG® 1 × 8 200–400 mesh, 0.1 ml). The isotopic composition of Pb was determined on a FINNIGAN MAT-261® thermal ionization mass spectrometer using a fixed nine-Faraday-cup collector system. The samples were dissolved in 2 μl H_3PO_4 and loaded into undiluted silicagel on a single zone-refined Re filament. Loading blanks were 5–10 pg. Usual procedural Pb blanks for this analytical work were between 50–100 pg. The mass discrimination factor, quantified after repeated measurements at 1350 °C on the NBS981 standard (100 ng), is 0.131 ± 0.009 amu^{-1} (N = 26). The isotopic composition of U was also determined on the FINNIGAN MAT-261® mass-spectrometer, using a multiplier. Samples of 100 ng were dissolved in H_3PO_4 and analysed with a double Re filament set up at 1950 °C. Total procedural blanks were below 25 pg. The mass discrimination factor on U-500 is 0.233 $\pm$ 0.010 amu^{-1} (N = 15). Calculations are based upon the I.U.G.S.-recommended constants. Decay constants are $^{238}U = 1.55125 \times 10^{-10}$ a^{-1} and $^{235}U = 9.8485 \times 10^{-10}$ a^{-1} (Steiger & Jäger 1977). Non-radiogenic lead correction has been applied according to the model: Pb non-radiogenic = Pb procedure blanc (AML, average modern lead) + Pb initial (two-stage lead model of Stacey & Kramers (1975); backward extrapolation from AML to the upper intercept age). Realistic measurement errors, statistical as well as systematic, have been substituted; i.e. the statistical uncertainty in the mass spectrometric ratio measurements, the uncertainty in fractionation correction, and the uncertainty in the isotopic composition used in correcting for common lead. All errors were applied on an individual basis, i.e. per fraction. The uncertainty in the spike calibration has been included in the concordia plot. Only the uncertainty in the decay constants has not

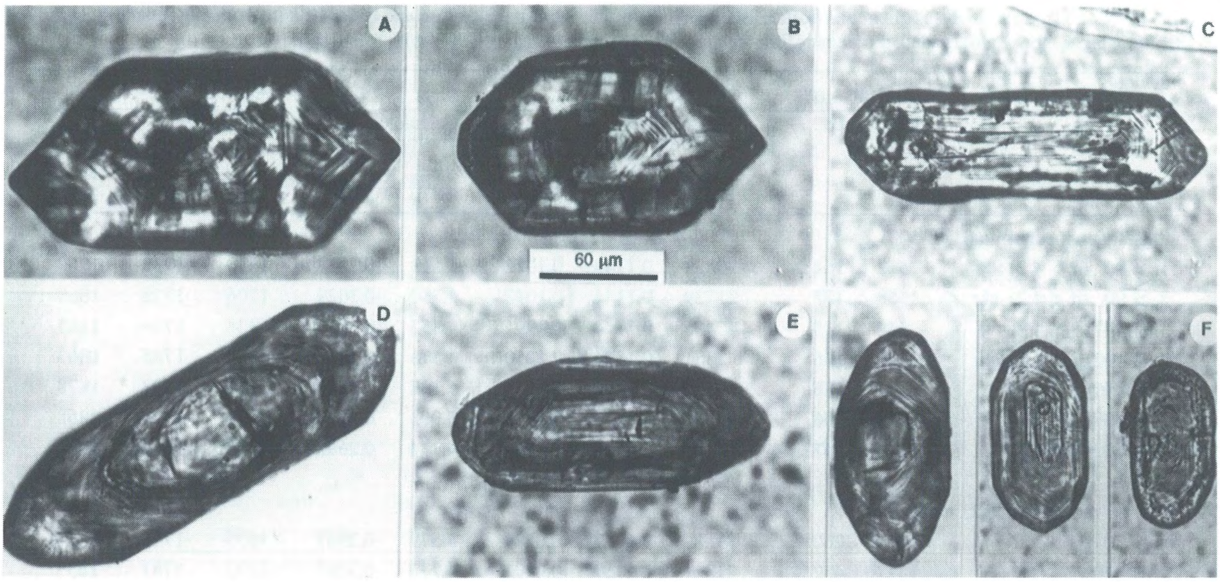

Fig. 3. A, B, C: Euhedral zircons from the Prästängen metatuffite show magmatic, euhedral zonation and rare secondary zircon growth. D, E, F: Zircons from the Older Granite show magmatic zonation around distinct round (D) to euhedral (E, F) cores; secondary zircon overgrowth is shown in F, in the crystal on the right.

been incorporated. All analytical errors are given at the 95% confidence level.

Zircon description

The zircon contents of the three samples can be evaluated from the Zr-contents obtained by X-ray fluorescence (XRF) analysis, which are 258 ppm for sample BRL-503, 217 ppm for sample BRL-500, and 143 ppm for sample BRL-498. Most zircons from the three samples are severely metamict and fractured. The handpicked zircons selected (< 10%) for isotopic analysis consist of translucent to transparent crystals with sparse cracks.

Analysed zircons of the sample from the Prästängen acid metatuffite horizon (BRL-503) are mostly short-prismatic, colourless, euhedral zircons with well-developed prism and pyramid faces and sharp edges (Fig. 3A–C). Smaller zircons are short to long-prismatic with rounded edges. The occasional inclusion-bearing zircons show magmatic, euhedral zonation. Secondary zircon growth is very rarely observed.

Analysed zircons of the sample from the acid metatuffite member of the Syrtorp formation (BRL-500) are oval to short-prismatic, sub- to euhedral, pale yellow to pale brown zircons. Long-prismatic crystals and colourless and brown zircons are rare. The occasional inclusion-bearing zircons generally show magmatic, euhedral zonation. Secondary zircon growth is somewhat more conspicuous than in BRL-503, but is always below 5–10 vol. %.

Analysed zircons of the sample of Older Granite (BRL-498) are long-prismatic, rounded to subhedral brown zircons (Fig. 3D–F). The finer grained zircon fractions consist of rounded short to long-prismatic, colourless to brown zircons. The zircons show magmatic euhedral zonation around round (Fig. 3D) to euhedral (Fig. 3E, F), inclusion-bearing metamict cores. Secondary zircon overgrowths also occur (Fig. 3F).

Analytical results

Results of the zircon U-Pb isotopic analyses of the three samples are shown in Table 1 and in concordia diagrams in Fig. 4.

The zircons of the acid metatuffite from the Prästängen horizon show a constant content of U and Pb, except for the U-Pb-rich zircons of the clearly discordant fraction 7. The two air-abraded fractions 2 and 4 represent the uppermost data points close to concor-

Table 1. U-Pb isotopic analyses of zircons from Prästängen metatuffite, Syrtorp metatuffite and Older Granite from the Tunaberg region, SE Bergslagen. abr. = air-abraded, d = density, R = fraction further separated using sieves with round splits.

Zircon fractions (μm)	Contents (μg/g)		Isotope ratios					Ages, in Ma		
	U	Pb	Measured			Calculated				
			$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$
Prästängen metatuffite (BRL-503)										
1. > 90 (d > 4.2)	542	164	20833	0.1144	0.1072	4.513	0.2878	1630	1733	1860
2. > 90 (d < 4.2), abr.	558	177	21739	0.1144	0.1042	4.750	0.3029	1706	1776	1860
3. 60–90 (d > 4.2)	544	175	45455	0.1144	0.0994	4.852	0.3086	1734	1794	1865
4. 60–90 (d < 4.2), abr.	560	176	2381	0.1196	0.1250	4.578	0.2915	1649	1745	1863
5. 40–60 (d > 4.2)	531	186	12195	0.1160	0.1351	5.142	0.3246	1812	1843	1878
6. < 40 (d > 4.2)	614	206	25000	0.1148	0.1115	5.003	0.3177	1778	1820	1868
7. < 40 (d < 4.2)	1246	347	14706	0.1116	0.0870	4.114	0.2695	1538	1657	1811
Syrtorp metatuffite (BRL-500)										
1. > 70	864	260	3968	0.1153	0.0587	4.579	0.2967	1675	1745	1831
2. 50–70	1477	457	4132	0.1157	0.0477	4.778	0.3082	1732	1781	1839
3. 40–50 / < 60R	939	283	4167	0.1150	0.0457	4.640	0.3010	1696	1756	1829
4. 40–50 / > 60R	936	285	2070	0.1184	0.0564	4.608	0.2987	1685	1751	1830
5. 30–50 / brown	1592	447	3704	0.1156	0.0403	4.346	0.2815	1599	1702	1832
6. 30–40	1053	316	1789	0.1192	0.0589	4.517	0.2934	1659	1734	1826
Older Granite (BRL-498)										
1. > 90	3073	489	1482	0.1230	0.0564	2.439	0.1552	930	1254	1863
2. 70–90	4455	653	2132	0.1196	0.0457	2.269	0.1453	874	1203	1852
3. 50–70	4147	478	1931	0.1197	0.0497	1.766	0.1136	694	1033	1843
4. 40–50	3947	494	3774	0.1160	0.0400	1.942	0.1253	761	1096	1838

dia (Fig. 4A). All seven fractions produce a discordia line with an upper intercept age of 1886 ± 8 Ma, a lower intercept age of 350 ± 51 Ma, and a very high MSWD value of 74. If fraction 7 is omitted from the regression calculations, a discordia line with an upper intercept age of 1871 ± 7 Ma, a lower intercept age of 127 ± 48 Ma, and a much lower MSWD value of 4.7 is obtained.

The zircons of the acid metatuffite from the Syrtorp formation show higher contents of U and Pb than the zircons of the Prästängen metatuffite. The six zircon fractions are slightly discordant and yield upper and lower intercept ages of 1836 ± 9 Ma and 82 ± 123 Ma (Fig. 4B). The MSWD is 7.0.

The zircons of the Older Granite are very rich in U and Pb compared to those of the two metatuffite samples. The data points of the four zircon fractions are strongly discordant (Fig. 4C). The MSWD is 3.4. The upper and lower intercept ages are 1912 ± 29 Ma and 82 ± 34 Ma.

Discussion

The 1871 ± 7 Ma age of the acid metatuffite of the Prästängen horizon is obtained from euhedral, primary magmatic zircon crystals without relict cores and with only minor secondary overgrowth. Moreover, the two abraded fractions plot on the same discordia as the four other fractions, suggesting an age homogeneity of all zircon fractions. The obtained age of 1871 ± 7 Ma is considered to represent the time since the crystallization of the zircons in the erupting magmas that provided the material for the formation of the Prästängen acid metatuffite horizon. Lundström (1987) has suggested that the lack of synvolcanic alterations and ore deposits in thin volcanic beds within the volcanosedimentary

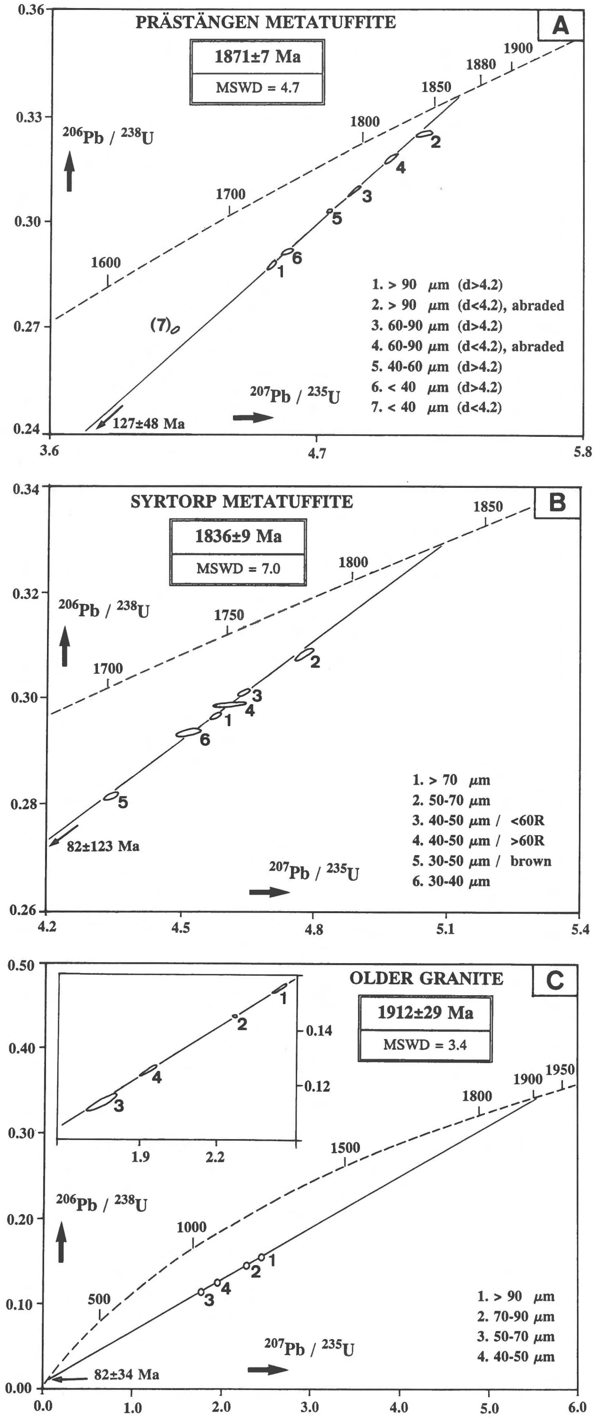

Fig. 4. Concordia plots of zircon U-Pb analyses. Errors are at the 95 % confidence level. Numbering of zircon fractions refers to Table 1. MSWD = mean standard weighted deviation. A. Acid metatuffite from the Prästängen horizon. Fraction 7 is not included in the age calculation. B. Acid metatuffite from the Syrtorp acid metatuffite member. C. Older Granite.

sequence of eastern Bergslagen may indicate that these volcanics are largely distal deposits derived from western volcanic centres. However, the acid metatuffites in the Tunaberg area are closely related to local mineralizations and alterations (Dobbe 1994a), demonstrating a proximal relationship to local volcanic and ore-forming activities. Within the limits of error the age of the Prästängen metatuffite may overlap that of the short period of volcanism between 1.89 and 1.88 Ga in western Bergslagen (Welin 1992), but in general the age obtained for the Prästängen metatuffite indicates that the lower volcanosedimentary unit of the southern Bergslagen volcanosedimentary belt in the Tunaberg region is slightly younger than the volcanosedimentary units in the western Bergslagen volcanosedimentary belt and in the central and northeastern Bergslagen granite region.

The 1836 ± 9 Ma age of the acid metatuffite from the Syrtorp formation is obtained from somewhat rounded, but in general homogeneous grains of magmatic zircons with only minor overgrowth; this suggests that the obtained age also represents the crystallization age of zircon in the volcanic rock. The about 35 Ma age difference between the Prästängen acid metatuffite horizon in the lower unit and the Syrtorp acid metatuffite formation in the upper unit of the volcanosedimentary sequence indicates a later and longer period of deposition, roughly 1.88–1.83 Ga, of the rocks of the southern Bergslagen volcano-sedimentary belt as compared to the earlier, short period of deposition, roughly 1.89–1.88 Ga, of the rocks of the western Bergslagen volcanosedimentary belt (Oen 1987).

The age of the Older Granite, which is intrusive in the Syrtorp formation, is constrained by the 1836 ± 9 Ma age of the Syrtorp metatuffite. The much older age of 1912 ± 29 Ma for the Older Granite at Tunaberg is obtained from heterogeneous zircons containing distinct round to euhedral cores, probably inherited from older, pre-1.9 Ga crust. Ion-microprobe (SHRIMP)-analysed zircons from Svecofennian metasediments (including Norberg in Bergslagen) show a mixture of 30% Archaean (3.0–2.6 Ga) and 70% Proterozoic (2.1–1.9 Ga) components, implying that the formation of Palaeoproterozoic crust commenced as much as 200 Ma earlier than the exposed 1.90–1.86 Ga old Svecofennian crust (Claesson et al. 1993). The obtained age of 1912 ± 29 Ma should therefore be discarded as the intrusion age of the Older Granites in the Tunaberg area; the latter Older Granites must have intruded somewhat later than about 1836 Ma.

Lithostratigraphic correlation of the volcanosedimentary sequences in the western and southern Bergslagen volcanosedimentary belts has been impeded by the lack of radiometric age data in the southern belt. Baker et al. (1988) correlated the predominantly volcanic rocks of the western Bergslagen volcanosedimentary belt with the predominantly volcanic upper unit of the volcanosedimentary sequence in the southern Bergslagen belt. They suggested that in the southern belt deposition of the mainly sedimentary lower unit already occurred before the formation of the rift-related West Bergslagen iron formation basin and the associated volcanism and ore deposition. On the contrary, the present study shows that the 1.88–1.83 Ga-old metavolcanosedimentary sequence in the Tunaberg area (lower and upper units) in SE Bergslagen is apparently somewhat younger than the 1.89–1.88 Ga-old mainly metavolcanic sequence in western Bergslagen.

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