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U–Pb geochronology of detrital zircons from a contact metamorphic Brixen Quartzphyllite (South-Tyrol, Italy): evidence for a complex pre-Variscan evolution of the Southalpine basement

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Abstract Laser ablation ICP-MS U–Pb zircon geochronology of detrital zircons from a contact metamorphic sample of the Brixen Quartzphyllite from the innermost part of the contact aureole adjacent to the Brixen granodiorite yielded three different Precambrian concordia ages: zircon cores and an older generation of zircons give a maximum age of 2,023 ± 31 Ma, zircon rims and a younger generation of single grains yield a concordia age of 882 ± 19 Ma. A third generation of single zircon grains yields an age of 638 ± 20 Ma. In contrast to Austroalpine quartzphyllite complexes from the Eastern Alps neither Cambrian/Ordovician (570–450 Ma) nor Carboniferous (360–340 Ma) ages on single zircons have been observed so far in these samples. These ages provide evidence of a complex pre-Variscan evolution of the Southalpine basement since these data suggest a possible affinity of the Southalpine basement to Gondwana-related tectonic elements as well as to a possible Cadomian hinterland. This study shows that dating detrital zircons of the Brixen Quartzphyllites has great potential for providing age constraints on the complex geological evolution of the Southalpine basement.

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Introduction

The Eastern Alps are composed of three different main domains namely the Penninic, Austroalpine and Southalpine units (e.g. Schmid et al. 2004). The Austroalpine and the Southalpine are the uppermost tectonic elements and belong to the Adriatic micro-plate, which represented the upper plate during closure of the Penninic Ocean in the Cretaceous and Tertiary. Both Austroalpine and Southalpine units are separated by the Periadriatic Lineament (PAL) but show many similarities with respect to their pre-Alpine basement evolution, their Paleozoic sequences and their Mesozoic cover series. The eastern Southalpine unit lies to the south of the SAM zone (southern limit of Alpine metamorphism; Hoinkes et al. 1999), and hence was only affected by pre-Alpine metamorphism. However, evidence for a Permo-Triassic thermal event has been documented in the Southalpine and recently also in the Austroalpine domain (Schuster et al. 2001). During the Permian, the Austroalpine and Southalpine units were affected by widespread magmatism, high-*T*/low-*P* metamorphism and extensional tectonics.

The Variscan basement of the Southalpine is confined to the west and north by the Periadriatic (Giudicarie line and Pustertal line) fault system (Schmidt et al. 1989). In the southeast, small basement outcrops within the Cenozoic molasse deposits of the Po Plain occur. Most of the basement is composed of monotonous quartzphyllites, which were pervasively affected by the Variscan metamorphic and tectonic overprint (Ring and Richter 1994; Sassi and Spiess

1993). Due to its now slightly tilted position, the basement shows a metamorphic gradient, which increases from southeast towards northwest (Sassi and Spiess 1993). In the area of Toblach/Dobiacco, the basement contains the mineral assemblage chlorite + muscovite + albite + quartz and represents the lowest peak metamorphic conditions with temperatures of 350–400°C and a pressure of ca. 0.4 GPa. The metamorphic conditions increase towards the northwest and reach maximum *P*–*T* conditions in the area of Brixen/Bressanone. In this area the basement contains the mineral assemblage biotite + chlorite + muscovite + garnet + albite + plagioclase + quartz and calculated *P*–*T* conditions yielded pressures of 0.5–0.65 GPa and temperatures of 450–550°C (Ring and Richter 1994).

In the Southalpine domain, Permian magmatism is represented by both intrusive and extrusive rocks. Plutonic rocks prevail in the western- (Massiccio dei Laghi and Ivrea-Verbano Zone) and eastern Southalpine (Brixen/Bressanone-, Ifinger/Ivigna-, Kreuzberg/M. Croce-, Cima d'Asta plutons), while volcanics prevail in the central Southalpine (Bargossi et al. 1999). Magmatic activity is restricted to the Lower Permian with intrusions and volcanics in the age range of 285–275 Ma (Borsi et al. 1972; Del Moro and Visona 1982; Rottura et al. 1997; Schaltegger and Brack 1999; Marocchi et al. 2008). The Brixen granodiorite was emplaced during the Permian (280 Ma) into the country rocks of the Brixen Quartzphyllites. Only a small part of the basement at the southern rim of the Brixen granodiorite was thermally affected by Permian contact metamorphism (Petraschek 1905; Sander 1906; Scolari and Zipoli 1970; Wyhlidal 2008; Wyhlidal et al. 2008).

Although there are many age data concerning the Variscan and the Permian events in the Brixen Quartzphyllite available, no U–Pb zircon ages of the Permian event exist so far from the contact metamorphic basement. Therefore it was originally planned to investigate a contact metamorphic sample from the innermost contact aureole in order to reconfirm the U–Th–Pb electron microprobe ages of monazites by Thöny (2008) with U–Pb zircon ages. These ages were obtained in the course of the study of Permian contact metamorphism in the Southalpine by Thöny (2008) and Wyhlidal (2008). Therefore the aim of this study was to (1) obtain Permian U–Pb zircon ages and to (2) identify possible older ages in addition to the Permian and Variscan metamorphic ages.

Variscan- and pre-Variscan geochronology of the Southalpine basement

Variscan and older ages have been reported for the Brixen Quartzphyllite by several authors. The oldest age value of 463 ± 18 Ma (Rb–Sr, whole rock–albite–muscovite) has been obtained by Del Moro et al. (1984) from a quartzphyllite outcropping in the area of Bruneck/Brunico, Puster valley. This age was interpreted as the crystallization age of the analyzed minerals, indicating that parts of the Southalpine crystalline basement were affected by Cambrian/Ordoviocian metamorphism. Variscan age constrains indicate a two-stage development of this metamorphic event at 350 and 320 Ma, which was first confirmed by microtextural observations by Sassi and Zipoli (1968). Del Moro et al. (1980) and Cavazzini et al. (1991) dated the Variscan metamorphic event 354 ± 10 Ma (Rb–Sr, whole rock–garnet–muscovite) and 347 ± 17 Ma (Rb–Sr, whole rock isochrone), which can be correlated with the initial flysch deposition at the Tournaisian-Viséan boundary (Frisch and Neubauer 1989). This age of 350 Ma is interpreted as the early regional heating (Meli 2004). Del Moro et al. (1984) also reported Rb–Sr, K–Ar and Ar–Ar ages of white micas around 320 Ma and suggested that this age dates the Variscan thermal climax. These data are also in agreement with Rb–Sr and Ar–Ar ages by Meli (2004). Hammerschmidt and Stöckhert (1987) obtained Ar–Ar ages of 319 ± 6 and 312 ± 6 Ma on muscovite which have been interpreted as cooling ages, consistent with the Rb–Sr mineral ages close to 300 Ma obtained by Del Moro et al. (1984). These ages are also in agreement with the results of Thöny (2008) who obtained a Variscan electron microprobe U–Th–Pb monazite age of 336 ± 19 Ma.

Analytical methods

Zircon $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages were determined using a 193 nm solid-state Nd-YAG laser (NewWave UP193-SS) coupled to a multi-collector ICP-MS (Nu Instruments HR) at the Department of Lithospheric Research at the University of Vienna. Ablation in a He atmosphere was either done in spot- or raster mode according to the cathodoluminescence (CL) zonation pattern of the zircons. Spot analyses were 15–25 µm in diameter whereas line widths for rastering were 10–15 µm with a rastering speed of 5 µm/s. Rastering of standard and unknown was preferred, as it yields more consistent results. Energy densities were 5–8 J/cm^2 with a repetition rate of 10 Hz. The He-carrier gas was mixed with the Ar carrier gas flow prior to the plasma torch. Ablation duration was 60 to 120 s with a 30 s gas and Hg blank count rate measurement preceding ablation. Ablation count rates were corrected accordingly offline. Remaining counts on mass 204 were interpreted as representing ^{204}Pb. Static mass spectrometer analysis was carried out as follows: ^{238}U was measured in a Faraday detector, ^{207}Pb, ^{206}Pb, and

^{204}(Pb + Hg) were measured in ion counter detectors. ^{208}Pb was not analysed. An integration time of 1 s was used for all measurements. The ion counter, Faraday and inter-ion counter gain factors were determined before the analytical session using standard zircons 91500 (Wiedenbeck et al. 1995). The standards reproducibility was 99.5%. Sensitivity for ^{206}Pb on standard zircon 91500 was ca. 30,000 cps/ppm Pb. For ^{238}U the corresponding value was ca. 35,000 cps/ppm U.

Mass and elemental bias and mass spectrometer drift of both U/Pb and Pb/Pb ratios respectively, were corrected using a multi-step approach: a first-order mass bias is corrected using a dried ^{233}U–^{205}Tl–^{203}Tl spike solution which is aspirated continuously in Ar and mixed to the He carrier gas coming from the laser before entering the plasma. This corrects for bias effects stemming from the mass spectrometer. The strongly time-dependent elemental fractionation coming from the ablation process itself is then corrected by using the "intercept method" of Sylvester and Ghaderi (1997). The calculated ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb intercept values are corrected for mass discrimination from analyses of standards 91500 and Plesovice measured during the analytical session using a standard bracketing method. The correction utilizes regression of standard measurements by a quadratic function.

Samples from the quartzphyllites were crushed with a mechanical mill to a powder with an average grain size of 150 μm and zircons were separated using the organic liquid di-iodinemethane. Finally separated zircon grains were embedded into a one inch wide plastic ring, polished and carbon coated for scanning electron microscopy (SEM).

Petrography and textural relations in the contact aureole

Contact metamorphosed metapelites were only found in a small approximately 200 m wide contact aureole at the southern rim of the Brixen granodiorite near the small village of Franzensfeste (Fig. 1). Outside this contact aureole the rocks of the Southalpine basement, the Brixen Quartzphyllite (zone 0), occur. Based upon newly grown mineral assemblages, four different contact metamorphic zones (zone 1–3b) could be discerned by Wyhlidal (2008). The mineral assemblages as a function of distance to the intrusive contact are summarized in Table 1.

Zone 0 In the area of Brixen, the quartzphyllite samples contain the mineral assemblage muscovite + chlorite + biotite (chloritized) + plagioclase + albite + garnet + quartz ± K-feldspar and accessory minerals such as zircon + apatite + ilmenite ± rutile ± monazite ± titanite. Garnet always occurs as porphyroblasts with a diameter of 1 mm up to 2 mm and often contains inclusions of quartz, ilmenite and apatite. The garnets are always continuously zoned. Muscovite and chlorite typically define the dominant Variscan foliation.

Zone 1 occurs in a distance of about 140 m from the intrusive contact (Fig. 1b–c). The rocks from this area are macroscopically similar to basements rocks, which were not affected by contact metamorphism. However in thin sections two texturally different generations of biotite and muscovite were observed. Biotite (1) and muscovite (1) occur as a part of the old Variscan foliation. Biotite (2) and muscovite (2) overgrow the pre-existing foliation. Cordierite is also observed in zone I and is completely

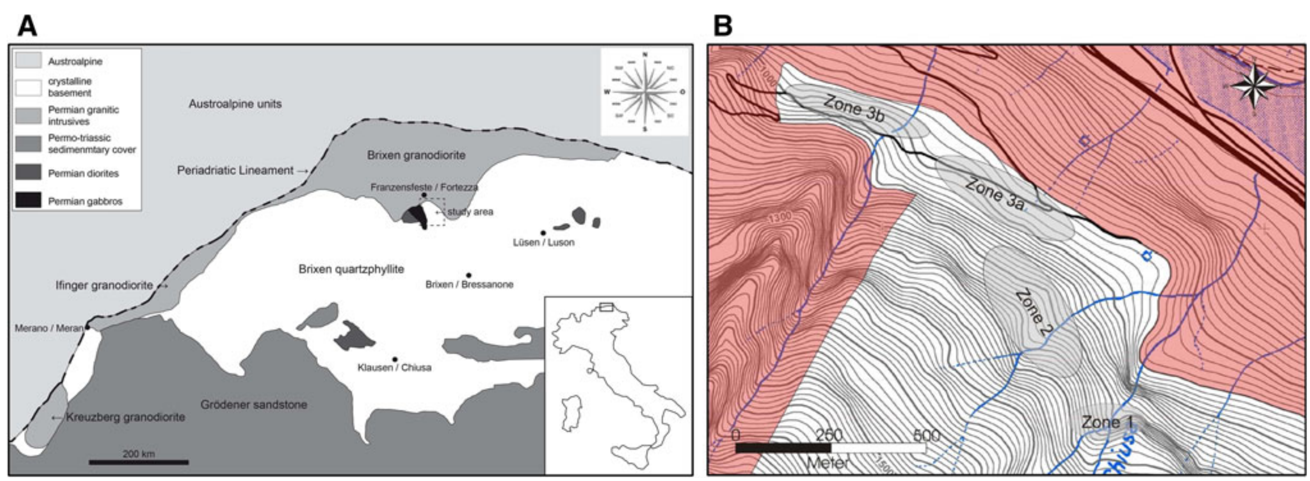


Fig. 1 **a** Simplified geological map of the northern Southalpine crystalline basement in the Eastern Alps after Sassi and Spiess (1993). The stippled line represents the Periadriatic Lineament. **b** Simplified geological map of the contact aureole near Franzensfeste/Fortezza area showing the distribution of the mineral zones 1–3b as described in the text

Table 1 Overview of the mineral assemblages of the contact aureole

Mineral	Zone 0	Zone 1	Zone 2	Zone 3a	Zone 3b
Albite	+	+	+	+	+
Chlorite	+	+	−	−	−
Biotite (1)	+	+	+	−	−
Biotite (2)	−	+	+	+	+
Garnet	+	+	+	−	−
Quartz	+	+	+	+	+
Muscovite (1)	+	+	−	−	−
Muscovite (2)	−	+	+	+	+
Plagioclase	−	−	+	+	+
K-feldspar	+	+	+	+	+
Cordierite	−	+	+	+	+
Andalusite	−	−	−	+	+
Spinel	−	−	−	−	+
Corundum	−	−	−	−	+
Zircon	+	+	+	+	+
Apatite	+	+	+	+	+
Monazite	+	+	+	+	+
Xenozime	−	−	+	+	+
Rutile	+	+	+	+	+
Ilmenite	+	+	+	+	+

+, present; −, absent

altered to pinite (chlorite + muscovite). The mineral assemblage therefore is: biotite (1, 2) + muscovite (1, 2) + cordierite + plagioclase + quartz.

Zone 2 is observed in a distance between 140 and 40 m from the contact and is characterised by the occurrence of cordierite, plagioclase and K-feldspar and by typical pseudomorphs of cordierite + biotite after garnet. Old Variscan garnet porphyroblasts are replaced by cordierite and biotite. Newly formed K-feldspar occurs. The mineral assemblage therefore is: biotite + muscovite + cordierite + K-feldspar + plagioclase + quartz.

Zone 3a occurs in a distance of 40 m away from the contact with the granodiorite and contains the mineral assemblage andalusite + cordierite + K-feldspar + plagioclase + biotite + muscovite + quartz. The old Variscan foliation and mineral assemblage is almost completely obliterated by the contact metamorphic mineral assemblage and the foliated, pelitic country rocks turn into bluish massive hornfelses.

Zone 3b is located in the western part of the investigated area of the contact aureole. In this area the contact metamorphic pelitic rocks are enclosed by the granodiorite intrusion. This zone contains the mineral assemblage andalusite + spinel + cordierite + K-feldspar + plagioclase + biotite + muscovite + quartz. In two samples spinel was found and in one quartz-free sample corundum was observed. The geochronological investigations were performed on a sample (FF3) from this zone in the course of the investigations of Thöny (2008). This sample contains the peak metamorphic assemblage andalusite + cordierite + K-feldspar + plagioclase + biotite + muscovite + ilmenite + quartz (Fig. 2). Andalusite occurs as euhedral prismatic crystals with a length of up to 200 µm and cordierite always occurs as poikiloblasts with inclusions of muscovite, biotite and quartz.

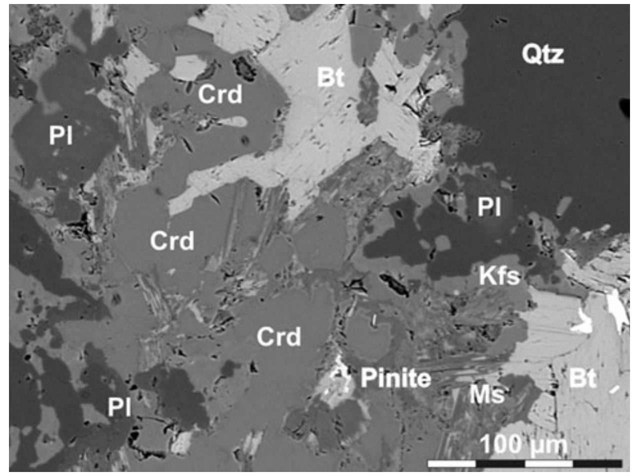


Fig. 2 BSE image of sample FF3 from zone 3b. *Pl* plagioclase, *Crd* cordierite, *Kfs* K-feldspar, *Bt* biotite, *Qtz* quartz, *Pinite* muscovite + chlorite pseudomorph after cordierite

Results of zircon geochronology

Analyses of 12 single zircons from the contact metamorphic Brixen Quartzphyllite sample FF3 yielded three different pre-Variscan concordia ages but no Variscan and Permian ages so far. The data are presented in Table 2. The oldest age group (3 grains) is defined by detrital zircons and zircon cores (Fig. 3a–c) and yields a Proterozoic U–Pb concordia age of 2,023 ± 31 Ma (Fig. 4). A second group (5 grains) of detrital zircons (Fig. 5a–b) and some rims (1 grain) of older zircons yielded concordant U–Pb ages of 882 ± 19 Ma (Fig. 6). The third group (4 grains) represents the youngest detrital zircons (Fig. 7a–c) with a concordant age of 638 ± 20 (Fig. 8).

Discussion

The Southalpine crystalline basement in the eastern Alps is characterized by relatively low-grade Variscan metamorphism (greenschist-facies) and was injected by large magmatic bodies in the Permian such as the Brixen granodiorite. This intrusion lead to widespread contact

Table 2 Geochronological results

$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	ρ	$^{207}Pb/^{206}Pb$	1σ	Single age	Age
0.8733	0.0476	0.1044	0.0044	0.38	0.0601	0.0018	639 ± 21	
0.9060	0.0909	0.0993	0.0099	0.50	0.0651	0.0015	640 ± 45	638 ± 20
0.9320	0.0713	0.0994	0.0072	0.47	0.0645	0.0011	–	
1.4478	0.0594	0.1482	0.0062	0.51	0.0701	0.0008	906 ± 24	
1.3160	0.1761	0.1369	0.0103	0.28	0.0714	0.0033	835 ± 53	
1.2807	0.1238	0.1445	0.0137	0.49	0.0637	0.0007	843 ± 53	882 ± 19
1.3414	0.1433	0.1404	0.0147	0.49	0.0677	0.0008	860 ± 60	
1.2954	0.2836	0.1194	0.0170	0.33	0.0644	0.0048	759 ± 90	
1.5593	0.1260	0.1727	0.0137	0.49	0.0632	0.0010	–	
6.1915	0.3503	0.3539	0.0199	0.50	0.1232	0.0005	2,002 ± 50	
6.1378	0.5703	0.3683	0.0362	0.53	0.1242	0.0014	1,995 ± 81	2023 ± 31
6.5625	0.4473	0.3587	0.0240	0.49	0.1313	0.0009	2,052 ± 60	
6.5236	0.4849	0.3768	0.0277	0.49	0.1240	0.0007	–	

ρ, error correlation value according to Ludwig (1980); –, non-concordant age

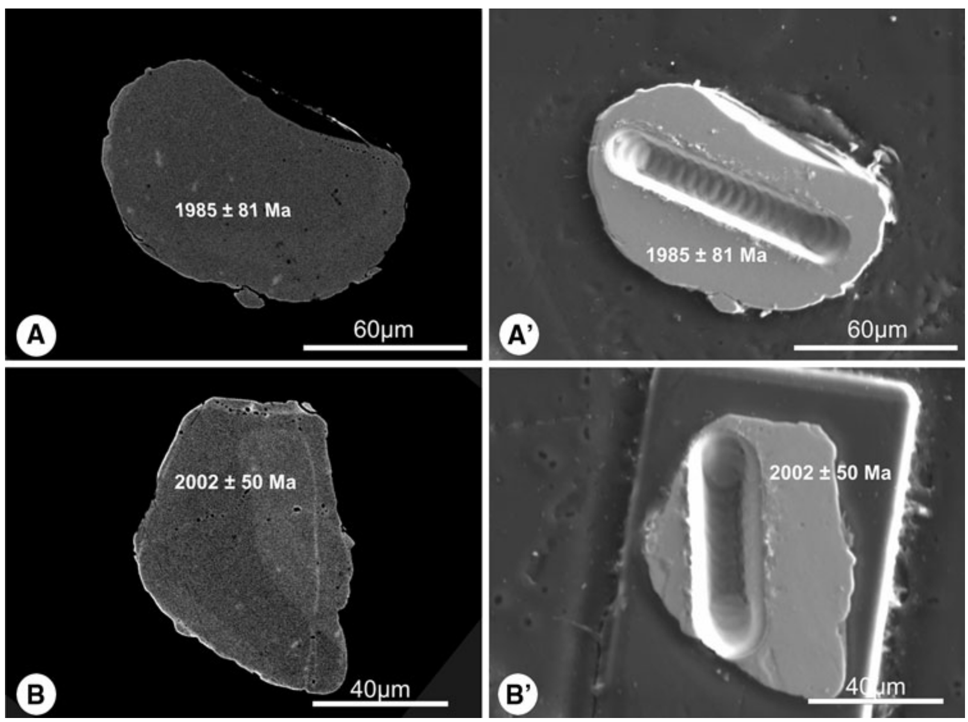


Fig. 3 **a**, **b** BSE images of zircons representing the age group of 2,000 Ma. **a**′, **b**′ SE images of the same zircons showing the typical ablation lines after the measurements. Sample FF3

metamorphism at the southern rim near Franzensfeste, causing a complete replacement of the Variscan mineral assemblage muscovite + chlorite + biotite (chloritized) + plagioclase + albite + garnet + quartz ± K-feldspar. Based on newly grown mineral assemblages Wyhlidal (2008) distinguished four different contact metamorphic zones (zones 1–3b). Geothermometric calculations using Ti-in-biotite and two-feldspar thermometry yielded a temperature increase from ca. 500°C to ca. 620°C from the outer (zone 1) to the innermost (zone 3b) contact aureole (Wyhlidal et al. 2008). Thöny (2008) obtained two populations of electron microprobe U–Th–Pb ages of monazites, a Variscan and a Permian age of 336 ± 19 and 269 ± 18 Ma. However, analyses of single detrital zircons from the contact metamorphic Brixen Quartzphyllite yielded no Permian zircon ages but three different pre-Variscan age groups instead. The temperatures of ca. 620°C reached during contact metamorphism, well below the closure temperature of 900°C for the resetting of zircon U–Pb ages (e.g. Lee et al. 1997), did not affect the older zircon ages.

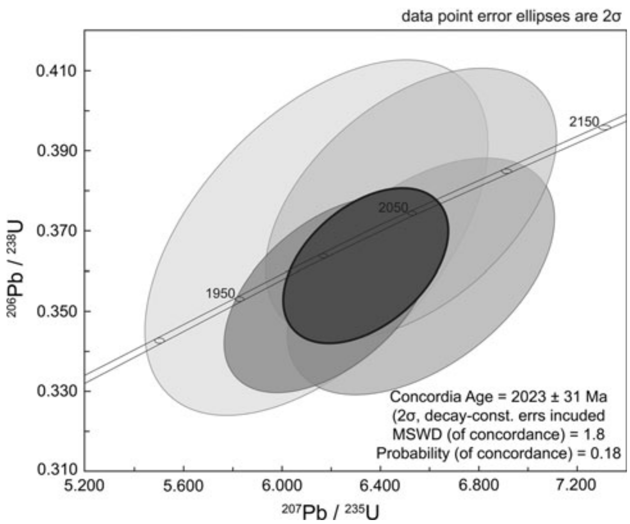


Fig. 4 Concordia plot of detrital zircons from the Brixen Quartz-phyllite with an age of 2,023 ± 31 Ma. *Fine lined ellipses* represent data-point error and the *thick lined ellipse* is the error of the concordia diagram based upon all data of this specific age group. Sample FF3

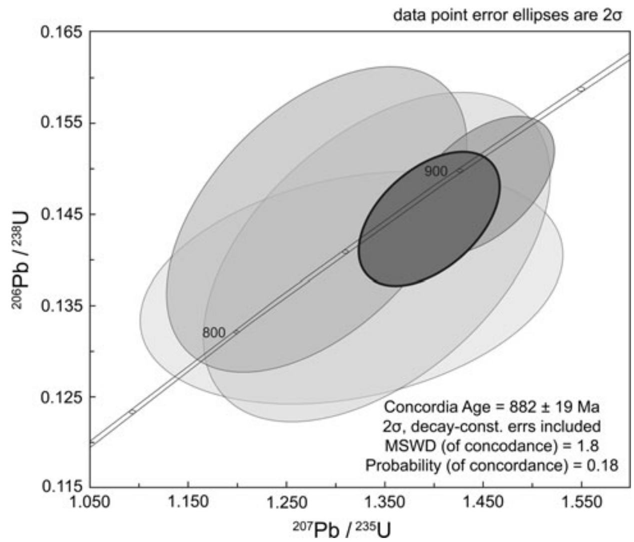
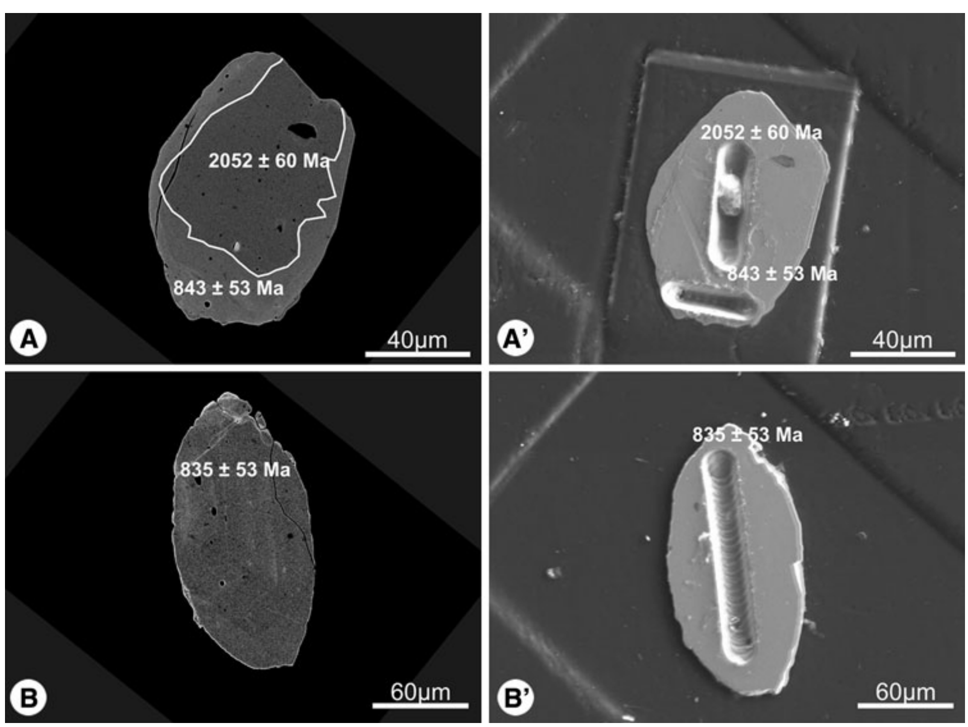


Fig. 6 Concordia plot of detrital zircons illustrating ages in the range of 882 ± 19 Ma. *Fine lined ellipses* represent data-point error and the *thick lined ellipse* is the error of the concordia diagram based upon all data of this specific age group. Sample FF3

The oldest age group of 2,023 ± 31 Ma suggests the existence of a possibly early Proterozoic hinterland as already pointed out by Söllner and Hansen (1987). Similar age constrains in the Southern Alps were reported from basaltic andesites from Waidbruck by Visonà et al. (2007) and from the quartzphyllite complex of Vetriolo by Klötzli (1999). Latter concluded that this age cannot directly be interpreted as a maximum sedimentation age, but represents detrital grains in the Vetriolo phyllite, originally derived from a Proterozoic basement.

The second group showing an U–Pb age of 882 ± 19 Ma has hardly been reported in the Southalpine basement so far and these ages are also very rare in the Alps. Visonà et al. (2007) report a somewhat similar age of

Fig. 5 BSE and SE images of zircons representing the age group of 880 Ma. **a** BSE images of a detrital zircon with an old core (2,000 Ma) and a younger rim (840 Ma). **b** BSE image of a 840 Ma old zircon. **a′**, **b′**: SE images of the same zircons showing typical ablation lines after the measurements. Sample FF3



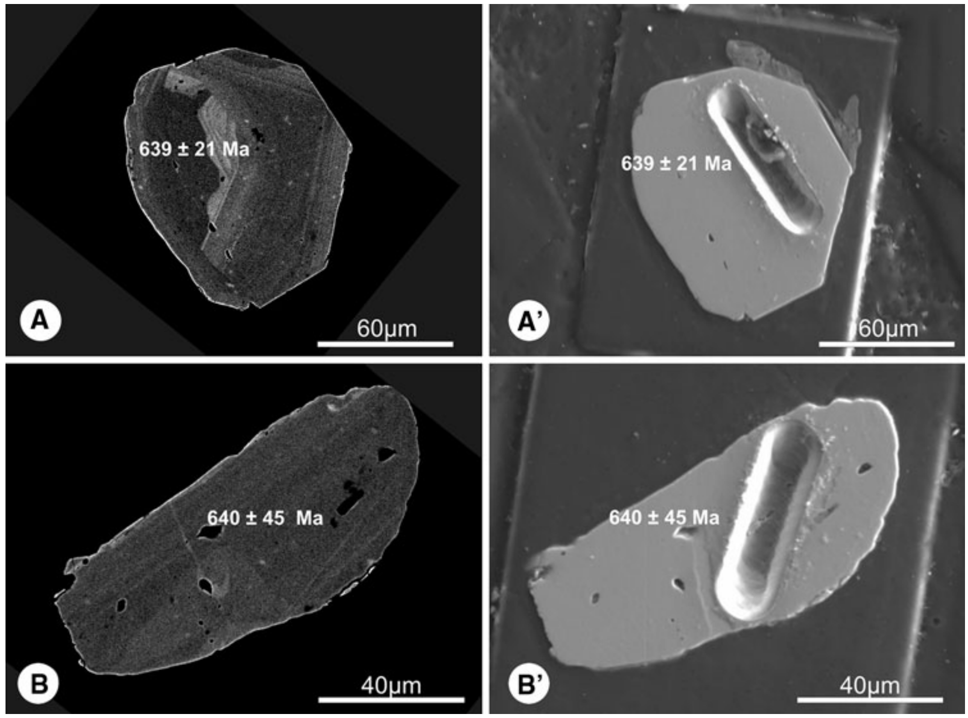


Fig. 7 **a**, **b** BSE images of detrital zircons representing the 640 Ma Cadomian (Pan-African) magmatic or metamorphic event. **a′**, **b′** SE images of the same zircons illustrating typical ablation lines after the measurements. Sample FF3

728.4 ± 9.6 Ma of basaltic andesites from Waidbruck and interpreted this age as reworked Gondwana crust. Gebauer et al. (1988) determined a SHRIMP U–Pb age in the range of 870 Ma from eclogitic zircons of the Gotthard Massif and interpreted it as the intrusion age of late Precambrian mafic and ultramafic igneous rocks.

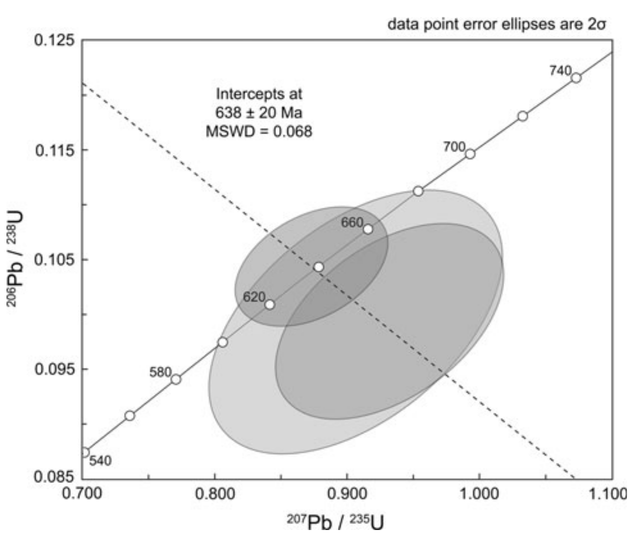


Fig. 8 Concordia plot of detrital zircons illustrating the ages in the range of 638 ± 20 Ma. *Fine lined ellipses* represent data-point error and the *thick lined ellipse* is the error of the concordia diagram based upon all data of this specific age group. Sample FF3. The *stipled line* represents the intercept

The youngest detrital zircons with an age of 638 ± 20 Ma can be interpreted to be maximum sedimentation ages. These are typical Cadomian (Pan-African) ages and occur widespread throughout the European Variscides. Similar ages were reported by Gebauer et al. (1988) from metasediments of the Gotthard and Aar massifs and from the Penninic basement unit in the Habach Complex (von Quadt 1992). In the Southalpine basement this age group is also well established from the Himmelberg Sandstone (640 ± 6 Ma, Dallmeyer and Neubauer 1994).

All three ages groups can be directly compared with ages of detrital zircons from the late Ordovician Uggwa Formation of the Carnic Alps (Southern Alps) reported by Neubauer (2002). His study interpreted the inherited age of the detrital zircons between 2,000 and 2,100 Ma as a possible affinity to Proterozoic Gondwana tectonic elements although the inherited age of 880 Ma is also consistent with an affinity to Baltic tectonic elements. His study also yielded ages of 650 ± 12 Ma interpreted as a magmatic event and concluded that all ages together indicate a close relationship between the Alpine basement and a possible Cadomian hinterland.

Finally, it is interesting to point out that (1) although these three ages are known from the Eastern Alps, they have never been observed in one sample and (2) in contrast to Austroalpine quartzphyllite complexes from the Eastern Alps, neither Cambrian/Ordovician (570–450 Ma) nor Carboniferous (360–340 Ma) ages on single zircons have been observed so far in the Southalpine units. These results show that a careful evaluation of detrital zircons from the Brixen Quartzphyllites has great potential for providing age constraints on the complex geological evolution of the Southalpine basement.

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