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Evidence for Lower Paleozoic magmatism in the Eastern Southalpine basement: zircon geochronology from Comelico porphyroids

by *Sandro Meli*[1] and *Urs S. Klötzli*[2]

Abstract

Multigrain conventional U/Pb and single grain $^{207}Pb^*/^{206}Pb^*$ evaporation data on zircons are presented for two samples of acidic metavolcanic rocks from the Eastern Southalpine basement (Comelico, North-Eastern Italy). Three zircon populations have been distinguished in each sample, reflecting different contributions in the metavolcanics. Clear, colourless, elongated crystals are thought to be single stage magmatic products, whilst zircons belonging to other populations contain inherited cores mantled by magmatic overgrowths. Elongated crystals yielded concordant U/Pb ages (479 ± 8 and 485 ± 8 Ma), whereas other zircon populations were discordant; the inherited components have poorly constrained Archean apparent ages. Evaporation measurements performed on a core-bearing crystal yielded ages ranging from 646 to 715 Ma, which are interpreted as discordant ages of the core; Th/U zoning also points to a magmatic signature of the inherited cores. The conventional U/Pb data represent the first radiometric age determinations of the pre-Variscan acidic volcanism in the Southalpine domain, and the concordant ages constrain the acidic volcanic activity in the Eastern Southalpine basement within the Arenig. The new isotopic ages are consistent with the biostratigraphy and lithostratigraphy of a nearby basement outcrop (Agordo), which has been correlated to Comelico. Moreover, it is also possible to correlate the Southalpine Ordovician volcanism with a volcanic event in the Austroalpine domain (Eisenerz), for which a comparable age has been inferred by means of biostratigraphy.

Keywords: porphyroids, acidic metavolcanics, U/Pb geochronology, Southalpine basement, Ordovician.

1. Introduction

In the Eastern Alps (Fig. 1), the occurrence of metavolcanic layers ("porphyroids") both in the Austroalpine (HEINISCH, 1981) and in the Southalpine (BELLIENI and SASSI, 1981) domains document the existence of a widespread pre-Variscan acidic magmatic activity, possibly connected to an orogenic event. An Upper Ordovician age was assigned to the protoliths of the Southalpine porphyroids on a lithostratigraphic basis, at the Caradocian–Ashgillian boundary (SASSI et al., 1979); the assessment was based upon a long distance correlation between the rock sequence in which the Comelico porphyroids occur and that described by FLAJS and SCHÖNLAUB (1976) in the Northern Greywacke Zone (Austria). The hypothesis was strengthened by some palynologic data from the Agordo phyllites (Col di Foglia Fm.), which point to an Upper Cambrian sedimentation age for the pelitic protoliths underlying the nearby porphyroids (KALVACHEVA et al., 1986): the sedimentation age represents a maximum age for Agordo porphyroids. However, radiometric dating on the metavolcanics was lacking, and the eruption age was loosely constrained. There has been much debate about the geodynamic setting (e.g., HEINISCH and SCHMIDT, 1976; BÖGEL et al., 1979; SASSI and SCHMIDT, 1982; SASSI et al., 1987; HEINISCH, 1988; LOESCHKE, 1989; MELI, 1998) and the major orogenic cycles to which the volcanics can be genetically linked (Caledonian *vs.* Cadomian). The existence of a "Caledonian" event was maintained by BORSI et al. (1975), SASSI and SCHMIDT (1982), EBNER et al. (1987), on the basis of: (i) the occurrence of an Upper Cambrian–

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Lower Ordovician metamorphic event in some Austroalpine and Southalpine complexes (BORSI et al., 1973, DEL MORO et al., 1984); (ii) the occurrence of Late Ordovician peraluminous granitoids (BORSI et al., 1973); (iii) the possible occurrence of basal conglomerates overlying the Ordovician crystalline rocks (SASSI and ZANFERRARI, 1972); (iv) the occurrence of intra-Ordovician volcanic activity; this latter was not dated by means of radiometric geochronology. The existence of a "Cadomian" event was maintained, among others, by VAI (1975), and HANDLER et al., (1997), on the basis of (i) geochronological discrepancies of the above mentioned metamorphic and magmatic events with Caledonides *s.s.*; (ii) $^{40}Ar/^{39}Ar$ ages on detrital white micas; (iii) chronostratigraphic arguments about the Ordovician molasse in the Carnic Alps. The tectonic significance of both events is still under debate.

Several attempts have been made to date the emplacement of the porphyroid protoliths, but the Variscan overprint prevented any primary age estimate, either with Rb/Sr or K/Ar methods. In this contribution new U/Pb and $^{207}Pb^*/^{206}Pb^*$ (* = radiogenic) data are presented, to solve the uncertainty on the age of this widespread magmatic activity.

2. Geologic outline

The Eastern Southalpine Basement outcrops in three different areas (Fig. 1): a belt oriented WNW–ESE, close to the Periadriatic Line, a narrow belt between Trento and Agordo, and a small area close to Recoaro. The metamorphic basement is separated from the overlying Upper Paleozoic clastic sediments ("Verrucano" conglomerates and Val Gardena Sandstones) by an unconformity (SASSI and SPIESS, 1993). Acidic metavolcanics and metavolcanoclastics occur as thick layers interbedded with phyllites (SASSI and ZIRPOLI, 1989); the metavolcanic layers are widespread throughout the whole basement outcrops, with the only exception of Recoaro area (SASSI and ZIRPOLI, 1968).

SASSI and ZIRPOLI (1989) divided the Southalpine metamorphic basement into three units by means of lithostratigraphic criteria: (1) a Lower Pelitic-Psammitic Complex (LPC); (2) a Volcano-Sedimentary Complex (VSC); (3) an Upper Pelitic-Psammitic Complex (UPC). LPC and UPC are very similar, consisting both of quartzphyllites; their distinction is possible only on the basis of the relative stratigraphic position with respect to the VSC, which has been considered as a guide level (SASSI et al.,1974). This latter consists of a metapelitic-psammitic sequence, interlayered by (i) thick layers of acidic metavolcanics (porphyroids); (ii) a thin, discontinuous level of mafic metavolcanics; (iii) carbonate-bearing phyllites and carbonate schists (SASSI and ZIRPOLI, 1989). At present, no detailed mapping of the three complexes is available.

The Southalpine basement escaped Alpine metamorphism, and only gentle folding and brittle deformations of Alpine age occur (SASSI and SPIESS, 1993); the features of the Variscan metamorphism, which developed in two stages at about 345 and 320 Ma (DEL MORO et al., 1980, 1984; MELI, 1994), are therefore preserved. The P-T conditions recorded in the outcropping rocks range within the greenschist facies (see NEUBAUER et al., 1999, for a review), and a slight increase of the metamorphic grade is recognizable northwards and westwards, from the chlorite-zone (Comelico) to the almandine-zone (Val Sarentino) (CARDIN et al., 1985; MAZZOLI and SASSI, 1988). Microstructural and petrological studies demonstrated that the whole Southalpine crystalline basement shared the same metamorphic history during Paleozoic (SASSI and ZIRPOLI, 1989).

Petrographic and geochemical features of the acidic metavolcanics are consistent with an anatectic origin of the magmas, generated by partial melting of metapelites; the discriminant diagrams for acidic rocks indicate a late- to post-orogenic geodynamic setting at the time of emplacement (MELI, 1998). BELLIENI and SASSI (1981) included the pre-Variscan eruptives in the "Upper Ordovician Granite-Rhyolite Association", which also comprises coeval granitoids occurring in the Austroalpine domain. MAZZOLI and SASSI (1992) pointed out the geochemical similarities between porphyroids and granitoids, and referred the Ordovician plutonism and volcanism to a unique cycle of magma generation. The sporadic mafic metavolcanics occurring in the upper part of the Volcano-Sedimentary Complex (SASSI and ZIRPOLI, 1989) probably have a within-plate alkaline affinity (VISONÀ and ZANFERRARI, 1985), but their primary age is loosely constrained.

In this work, we focus our attention on the Comelico area, where the degree of recrystallization of the protoliths is lower than that observed in other sectors of the basement (SASSI et al., 1979); moreover, the stratigraphy is better defined and comparable with that of other sites, for which biostratigraphic data are available (ZANFERRARI, 1985; KALVACHEVA et al., 1986). In Comelico, the porphyroids outcrop in two localities: M. Elmo (ME), and M. Cavallino (MC) (Fig. 2); field work demonstrated that ME and MC por-

phyroids are distinct lithologic units (MELI, 1994), being separated by a thick metasedimentary body. Samples ME37 and MC63 were collected from ME and MC, respectively.

3. Petrography

Comelico porphyroids are characterized by a marked grain size bimodality: large crystals, interpreted as relics of magmatic phenocrysts, occur in a very fine grained matrix, which represents a recrystallyzed volcanic microcrystalline and/or glassy groundmass. The pre-metamorphic mineralogical association consists of quartz, K-feldspar, plagioclase, ilmenite, biotite, apatite and zircon. The present feldspar compositions do not reflect their pristine chemistry, as plagioclase has been transformed into albite + epidote ± sericite or albite + calcite + sericite, and alkali mobilization caused the growth of both chess-board albite upon pre-existing K-feldspar (CALLEGARI and DE PIERI, 1966) and microcline overgrowth on plagioclase. Quartz porphyroclasts preserve a typ-

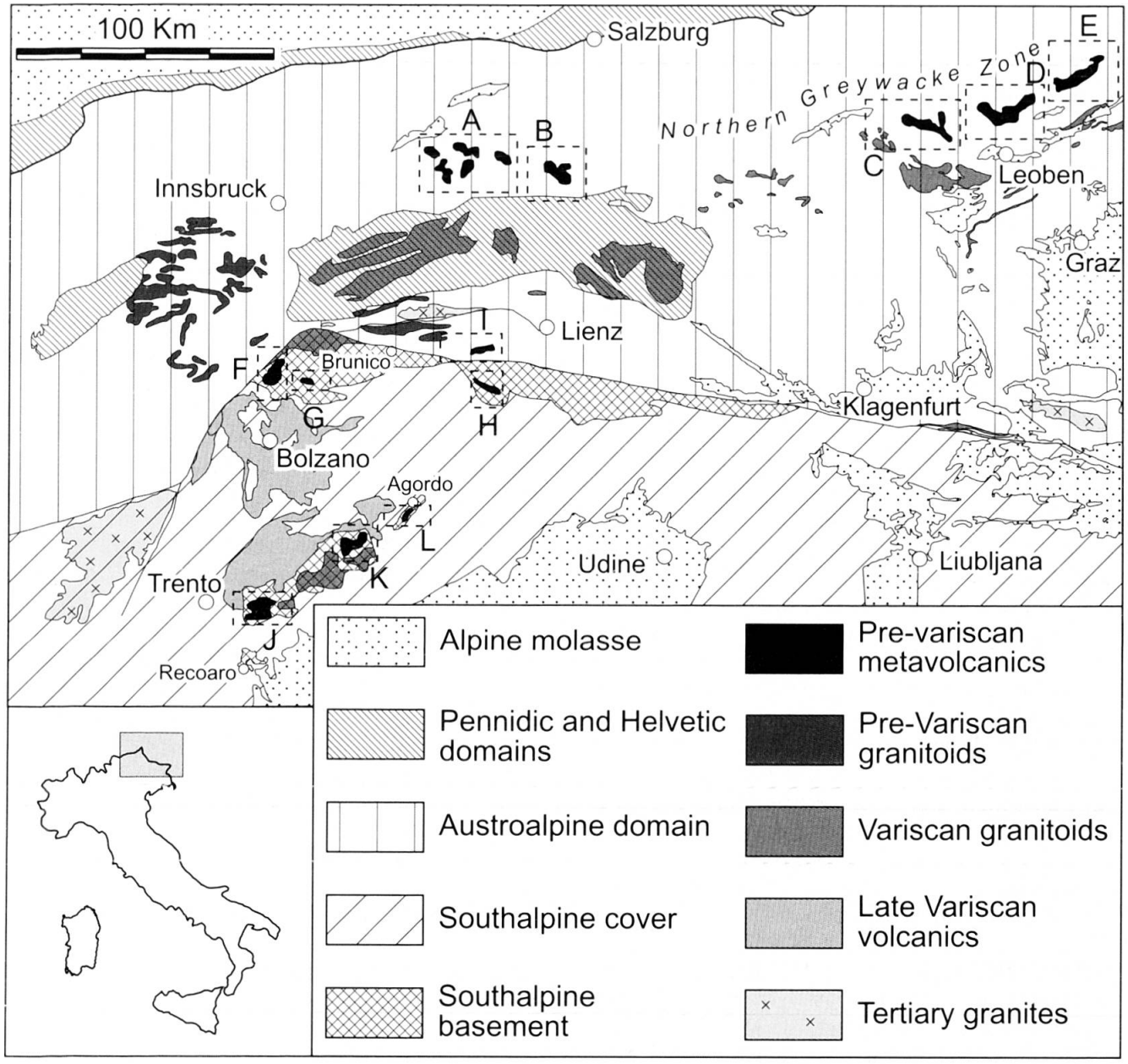

Fig. 1 Geological sketch map of the Eastern Alps (simplified from: HEINISCH, 1981; SASSI et al., 1985; BARTH et al., 1994; HANDLER et al., 1997; FREY et al., 1999). The letters refer to porphyroid outcrops: (A) Kitzbühel; (B) Zeller Furche–Dienten; (C) Radmer, Blasseneck and Ratschengraben; (D) Eisenerz; (E) Hohe Veitsch; (F) Bressanone–Val Sarentino; (G) Val di Funes; (H) Comelico; (I) Thurntaler; (J) Val Sugana; (K) Cima d'Arzon–Cima d'Asta; (L) Agordo.

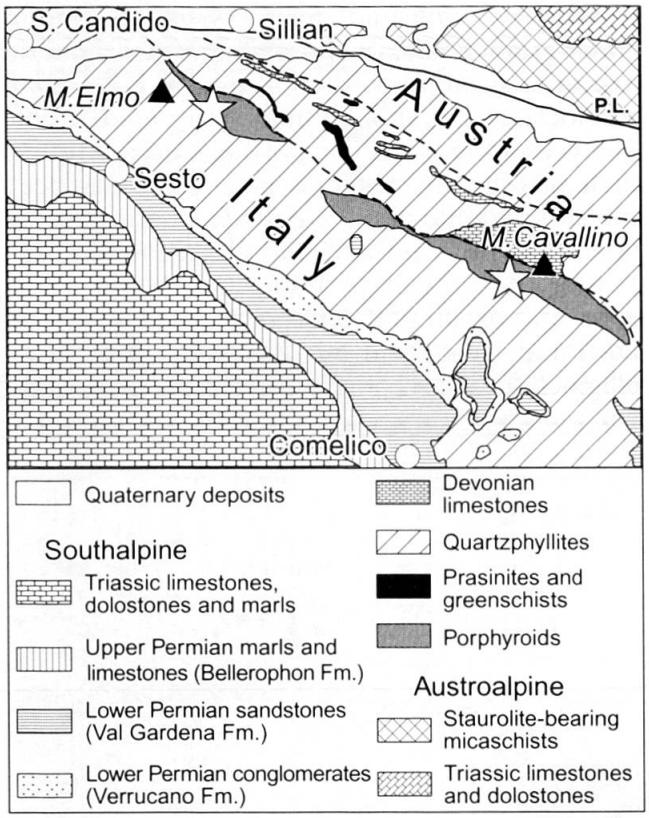

Fig. 2 Geological sketch map of the Comelico area (simplified from: BIANCHI et al., 1930; CASTIGLIONI et al., 1940; CANTELLI et al., 1971; MELI, 1994; HEINISCH et al., 2000). Sampling areas represented by stars: Monte Elmo (ME), N 46°43'08", E 12°24'27"; Monte Cavallino (MC), N 46°40'06", E 12°31'12". P. L. = Periadriatic Line.

ically magmatic embayment. Chlorite + Fe-Ti oxide pseudomorphs point to the occurrence of biotite phenocrysts in the volcanic assemblage. Garnet relics, which are thought to be restitic (MELI, 1998), are often present in MC, while their occurrence has not been detected in ME.

The metamorphic assemblage of Comelico porphyroids is consistent with the Variscan zoneography described by MAZZOLI and SASSI (1988): only chlorite is present as index mineral; other metamorphic minerals are quartz, albite, K-feldspar, muscovite and ilmenite.

4. Zircon typology

Zircon concentrates were obtained using standard techniques; the typology characterization was done following the classification scheme of PUPIN (1980). Accordingly, three populations have been recognized in both samples, as shown in figure 3.

Population 37A: clear and colourless crystals, long prismatic, containing few inclusions; no visible cores. The typology distribution clusters around subtype S1.

Population 37B: clear and colourless crystals, short prismatic, with few inclusions; visible cores. The typology distribution clusters around subtype S7.

Population 37C: clear to slightly turbid, pale pink crystals, short prismatic, with few inclusions; visible cores. The typology distribution clusters around subtype S12.

Population 63A: clear and colourless crystals, long prismatic, containing few inclusions; no visible cores. The typology distribution clusters around subtype S1.

Population 63B: clear to turbid, pale pink crystals, short prismatic, with few inclusions; visible cores. The typology distribution clusters around subtype S12.

Population 63C: rounded, slightly elongated crystals, turbid; strongly metamictic. They cannot be classified typologically.

Internal features like cores and inclusions refer to observations from optical microscopy. A cathodoluminescence image performed on a crystal from population 63B confirmed the occurrence of cores in the less elongated crystals (Fig. 4).

Populations 37A and 63A are thought to represent true magmatic products, owing to the elongation, the clearness, the absence of appreciable inclusions and the S1 clustering (PUPIN, 1980). Core-bearing populations 37B, 37C and 63B represent mixtures of inherited crystals and magmatic overgrowths. HUBICH and LOESCHKE (1993) in an extensive cathodoluminescence study of zircons coming from the same area, showed that cores are always present in crystals of the same shape. Population 63C is rounded and strongly metamictic: zircons belonging to this group are thought to be detrital crystals which have been incorporated either into the source or into the melt from wallrocks. Due to their presumably high lattice damages, they have not been analyzed.

5. $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$, and $^{207}Pb^*/^{206}Pb^*$ data

5.1. ANALYTICAL TECHNIQUES

Single grain evaporation Pb–Pb analyses and multigrain conventional U–Pb zircon dating were performed on a Finnigan MAT 262 multicollector mass spectrometer; in both conventional and evaporation runs we employed a secondary electron multiplier (SEM)-ion counter detection system. Pb fractionation for the SEM-ion counter is in the range of 0.200 ± 0.087% per mass unit.

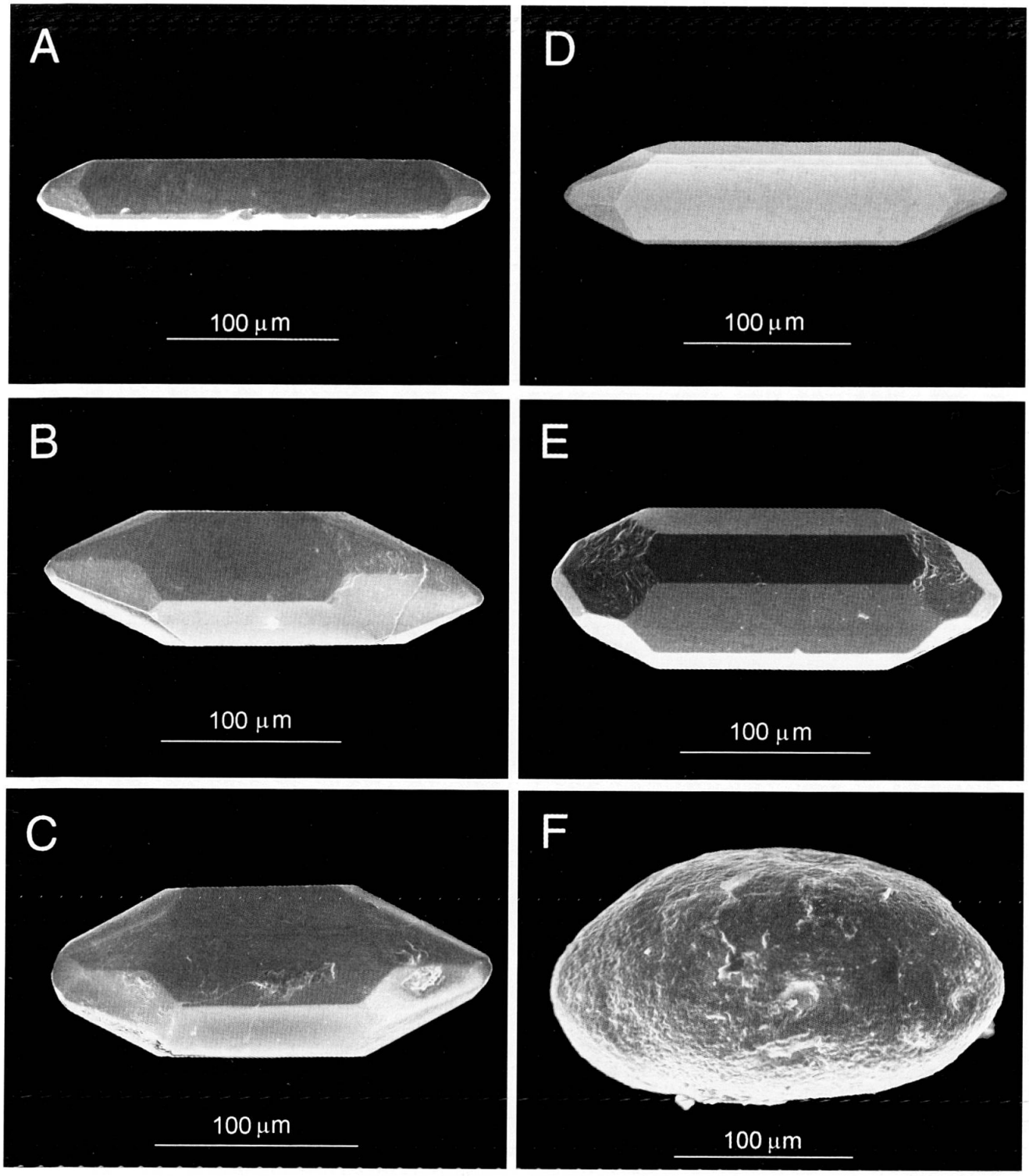

Fig. 3 SEM photomicrographs of representative zircon crystals form the populations found in samples ME37 and MC63: A = 37A; B = 37B; C = 37C; D = 63A; E = 63B; F = 63C. A, B, C, E, F are SE images; D is a BSE image.

The U-Pb multigrain analyses followed the procedures described by KROGH (1973) and PARRISH et al. (1987). All zircon populations were mechanically abraded employing an air abrasion technique (KROGH, 1982). Elemental ratios were determined using a mixed ^{205}Pb–^{233}U–^{235}U spike; U and Pb concentrations were not determined by ID as sample weighing was not possible; a rough estimate of U concentrations is given in table 1. Pb fractionation was corrected using NBS 981 and NBS 982 standard measurements (0.1070 ± 0.046% per mass unit). The total procedural blank for all fractions was 12 pg for Pb and 0.1 pg for U.

Single zircon evaporation dating followed modified procedures originally described by KOBER (1987); full details about the applied tech-

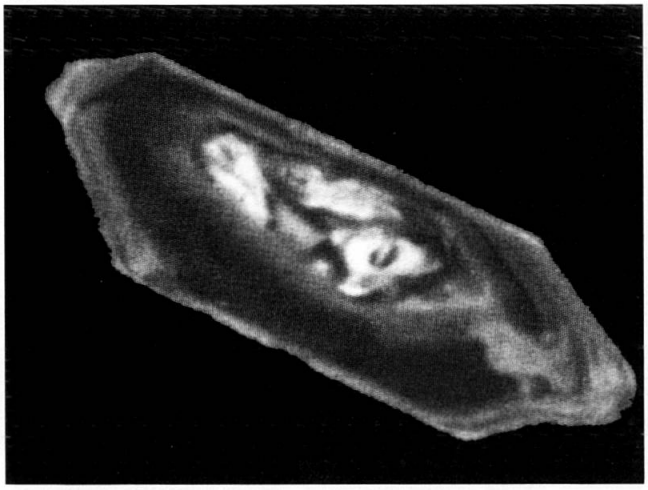

Fig. 4 CL image of a core-bearing zircon crystal belonging to population 63B; field of view: 180×120 μm.

nique are summarized by KLÖTZLI (1997). $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios were corrected by factors derived from NBS SRM 982 standard measurements. Only high temperature steps (> 1350 °C) with $^{206}Pb/^{204}Pb$ > 5000 were used for age calculations, and no common lead correction has been applied.

Age calculation and error statistics were made using a modified version of "ROCKAGE 3" from the Geological Survey of Canada and "ISOPLOT" of LUDWIG (1992); decay constants are those recommended by STEIGER and JÄGER (1977).

5.2. RESULTS

The conventional U/Pb method has been applied to few crystals belonging to populations 37A, 37B, 37C, 63A, 63B: the results are reported in table 1 and in figure 5. The error ellipses of 37A and 63A overlap the concordia line; the weighted average of $^{207}Pb/^{206}Pb$, $^{207}Pb/^{235}U$, and $^{206}Pb/^{238}U$ ages is 479 ± 8 and 485 ± 8 Ma for ME63 and ME37, respectively. Other populations are discordant; 37B and 37C are undistinguishable within the error limits, and 63B shows a significant departure from the rest of the data points.

Evaporation technique was not suitable for lead measurements on elongated zircons 37A and 63A. As the crystals were of the highest quality, a missing silica gel effect is postulated, due to a shift of silica evaporation towards higher temperatures (KLÖTZLI-CHOWANETZ et al., 1997). Therefore, this technique has been applied only to one core-bearing crystal from population 37B; data are summarized in table 2 and reported in the frequency histogram of figure 6. The high T steps yield measurements which cluster around an age of 681 ± 7 Ma; no age zoning can be detected within the crystal. Fig. 7 shows spatial variations of $^{208}Pb^*/^{206}Pb^*$ towards the crystal interior, not accompanied by a similar variation of $^{207}Pb^*/^{206}Pb^*$. As $^{208}Pb^*$ solely descends from the decay of ^{232}Th, such features are thought to reveal changing Th/U ratios in different zircon domains, probed at different evaporation temperatures.

Tab. 1 U–Pb data on zircon populations from Comelico porphyroids.

Pop.	Isotopic ratios				
	^{206}Pb [a] / ^{204}Pb	^{207}Pb [b] / ^{235}U	^{206}Pb [b] / ^{238}U	^{207}Pb [b] / ^{206}Pb	^{208}Pb [b] / ^{206}Pb
37A	889	0.61308 ± 1.42%	0.07799 ± 1.40%	0.05701 ± .60%	0.3116
37B	896	0.68779 ± 1.28%	0.08072 ± 1.40%	0.06179 ± .58%	0.2884
37C	903	0.69057 ± 1.58%	0.08079 ± 1.64%	0.06199 ± .64%	0.2773
63A	831	0.60517 ± 0.90%	0.07704 ± 0.52%	0.05696 ± .35%	0.3998
63B	722	1.51320 ± 0.76%	0.09950 ± 0.84%	0.11026 ± .26%	0.4771

Pop.	N° of crystals	U ppm [c]	Th/U today	Apparent ages		
				^{207}Pb / ^{235}U	^{206}Pb / ^{238}U	^{207}Pb / ^{206}Pb
37A	5	1500	1.00	485.5 ± 5.4	484.1 ± 6.6	491.9 ± 13.1
37B	7	5000	0.93	531.5 ± 5.4	500.5 ± 6.8	666.9 ± 12.3
37C	7	5000	0.89	533.1 ± 6.6	500.9 ± 7.8	673.7 ± 13.7
63A	5	2000	1.28	480.5 ± 3.4	478.5 ± 2.4	490.3 ± 7.8
63B	4	8000	1.64	935.7 ± 4.6	611.6 ± 4.8	1803.8 ± 8.4

Errors on isotopic ratios are 2σ of the mean in %; apparent age errors are 2σ of the mean in Ma.
[a] measured ratios.
[b] ratios corrected for the common lead, assuming that its isotopic composition is predicted by the two-stage model of STACEY and KRAMERS (1975).
[c] approximate values.

6. Discussion

6.1. INTERPRETATION OF U–Pb AND Pb–Pb AGES

Zircon crystals which are thought to bear inherited cores are discordant. HUBICH and LOESCHKE (1993) demonstrated the existence of older cores in the interior of the S7 (S12) clustering populations, without any evidence of multiple recycling of the grains. Therefore, a discordance produced by mixing of two components could be a realistic hypothesis; however, applying the integrating conventional U/Pb method, it is not possible to ascertain whether the core component is concordant by itself.

Elongated crystals are concordant; nevertheless, the age sequence $^{207}Pb/^{206}Pb > {}^{207}Pb/^{235}U > {}^{206}Pb/^{238}U$ is found. This could be due to an underestimation of the $^{207}Pb/^{204}Pb$ in the common Pb correction, performed employing the Pb evolutionary curve proposed by STACEY and KRAMERS (1975). As the contribution of older crust is demonstrated by the core-bearing populations 37B, 37C and 63B, the inheritance of small amounts of lead with anomalously high $^{207}Pb/^{204}Pb$ seems probable; unfortunately, the Variscan metamorphic reequilibration of suitable phases prevented more precise common Pb correction.

The upper intercepts give ages of 2628 ± 760 and 3280 ± 51 Ma, but their interpretation is not straightforward, as the data do not allow us to establish whether they represent a discordia generated by a mixing of two concordant ages, or the inherited component is discordant by itself, causing a multiple discordance. In the latter case, upper intercepts do not represent any geological event; however, the $^{207}Pb/^{206}Pb$ datum (Tab. 1) constrains the minimum age of the oldest basement rocks in the region at about 1800 Ma.

Tab. 2 Evaporation data of a zircon crystal belonging to the population 37B.

T (°C)	$^{207}Pb/^{206}Pb$	age	$^{208}Pb/^{206}Pb$	Th/U
1377	0.06223 ± 45	681.4 ± 15.1	0.12545 ± 67	0.40
1399	0.06321 ± 25	715.1 ± 8.6	0.13029 ± 55	0.42
1420	0.06124 ± 36	646.6 ± 12.9	0.12066 ± 57	0.39
1441	0.06228 ± 42	682.5 ± 14.4	0.13033 ± 57	0.42
Total	0.06224 ± 21	681 ± 7	0.12685 ± 57	0.41

Reported ages are propagated weighted mean values calculated from at least 20 measured $^{207}Pb/^{206}Pb$ ratios. Errors on isotopic ratios and ages are 2σ of the mean.

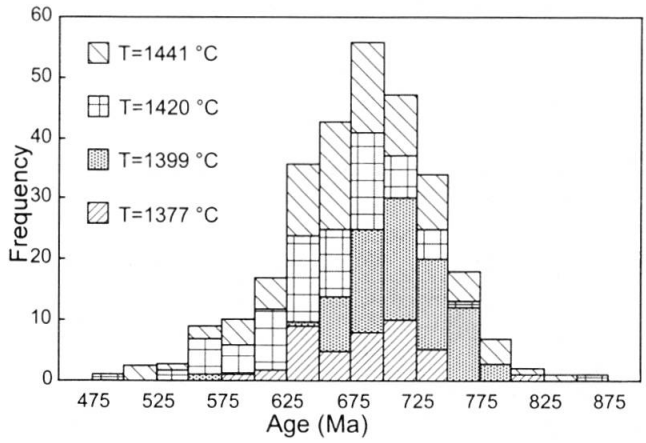

Fig. 6 $^{207}Pb^*/^{206}Pb^*$ age distribution from 37B single grain evaporation measurement.

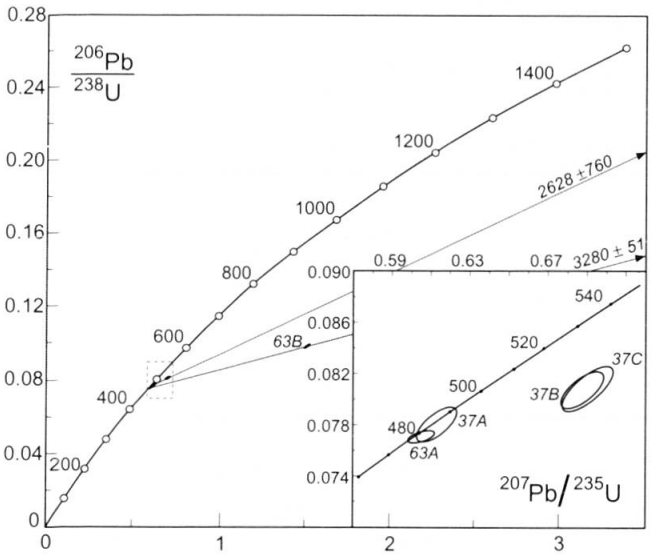

Fig. 5 Concordia diagram of U–Pb zircon data from the Comelico porphyroids.

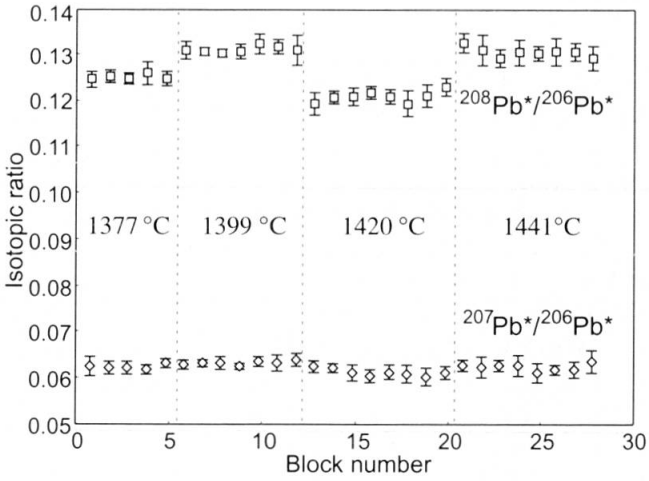

Fig. 7 Plot of block number versus $^{207}Pb^*/^{206}Pb^*$ and $^{208}Pb^*/^{206}Pb^*$. Block number gives progress of evaporation with steps of increasing T. Each block represent the mean of 20 mass scans. Assigned errors of averaged ratios are 2σ of the mean.

In the light of U–Pb data, the $^{207}Pb^*/^{206}Pb^*$ age obtained on a single zircon from population 37B does not match with concordant ages of 37A and 63A populations. The lack of ages around 480–490 Ma in the low T steps are probably related again to a missing silica gel effect in the outer part of the zircon, as happened for 37A and 63A. The evaporation spectrum reveals also a Th/U zoning of the inherited core (Fig. 7), which points towards a magmatic signature of this domain. Therefore, a partial reworking of igneous material by the anatectic melts is suggested.

6.2. REGIONAL IMPLICATIONS

As demonstrated by zircon populations, some differences between ME37 and MC63 are evident: in the former, rounded metamictic zircons are absent, and the inherited cores show different isotopic compositions. Moreover, several restitic garnets have been observed only in the latter, pointing to a medium-scale heterogeneity in the crustal source of the Ordovician volcanics.

The concordant ages of both 37A and 63A constrain the Comelico volcanism within the Arenig (HARLAND et al., 1989). Thus, the new radiometric ages are not contradictory with the Caledonian hypothesis held by BORSI et al. (1975) and EBNER et al. (1987), as the metamorphic event they found in the Eastern Alps is slightly older than the emplacement of acidic volcanics. Moreover, a time resemblance with the Caledonides *s.s.* is testified by the occurrence of igneous products aged 463–475 Ma in the Connemara region, Ireland (FRIEDRICH et al., 1999a; KINNY et al., 1999). In particular, a set of anatectic products, which include migmatites and granitic pegmatites, has been dated at 467–468 Ma (FRIEDRICH et al., 1999b). However, the attribution of the Ordovician volcanism to the Caledonian event *s.s.* is still problematic, as other geologic elements are still lacking.

The extensional tectonic setting hypopthesized on geochemical and petrological grounds (MELI, 1998) fits that described for the Upper Cambrian–Lower Ordovician time span in Central-Western Europe (PIN, 1991). The occurrence of an Early–Middle Ordovician extensional tectonic setting was proposed also for the French Central Massif (PLOQUIN and STUSSI, 1994) and the Armorican Massif (LE CORRE, 1994), where a metavolcanic body interlayered with syn-sedimentary beds has been dated by means of U/Pb methods at 466 ± 1 Ma (BONJOUR et al., 1988). Therefore, the porphyroids can represent episodes of crustal anatexis and widespread acidic, peraluminous volcanism, which developed in a thinned continental crust characterized by increased basal heat flow.

The long distance correlations between Austroalpine and Southalpine volcanic events (SASSI and ZIRPOLI, 1989) can be reviewed in the light of the new U/Pb data on Comelico porphyroids. In the Eisenerz metamorphic succession ("D" in Fig. 1), two different porphyroid bodies have been identified (NEUBAUER and SASSI, 1993): the age of the older layer is Lower Ordovician, whereas the younger one is located in the Upper Ordovician, probably being a part of the main pre-Variscan Austroalpine acidic volcanic episode, named "Blasseneck event" from the type locality ("C" in Fig. 1). This latter is younger than Lower Caradocian (FLAJS and SCHÖNLAUB 1976); therefore a long distance chronostratigraphic correlation with Comelico porphyroids does not hold, as a time gap of at least 35 Ma exists (PALMER, 1983; ODIN, 1986; HARLAND et al., 1989; GRADSTEIN and OGG, 1996). Comelico metavolcanics are better correlated with the lower porphyroid level, which underlies the Blasseneck ignimbrites and whose age has been referred to Lower Ordovician. The new radiometric ages suggest that the space-time distribution of the pre-Variscan volcanics is more complex than previously believed, and that pre-Variscan volcanism cannot be considered synchronous throughout the Southalpine and Austroalpine domains. However, within the Southalpine basement, Comelico radiometric ages fit the chronobiostratigraphy of Agordo zone ("L" in Fig. 1), whose metamorphic succession has been correlated with the Comelico units (ZANFERRARI, 1985): the acritarch dated Col di Foglia Fm., which underlies the porphyroids, is older than Arenig (KALVACHEVA et al., 1986). Therefore, at least within the easternmost part of the Southalpine basement, the acidic metavolcanic layers occurring in the Volcano-Sedimentary Complex should have been formed within the same time span. Fig. 8 summarizes the timing of the magmatic and metamorphic events occurred during Paleozoic in the Eastern Southalpine basement, taking into account also these new geochronological data.

7. Conclusions

The U/Pb ages presented in this contribution represent the first geochronologic data of an Ordovician magmatic event in the Southalpine to the east of the Giudicarie Line: other Ordovician (450–480 Ma) magmatic bodies (tonalitic and granitic orthogneisses) are known only in the West-

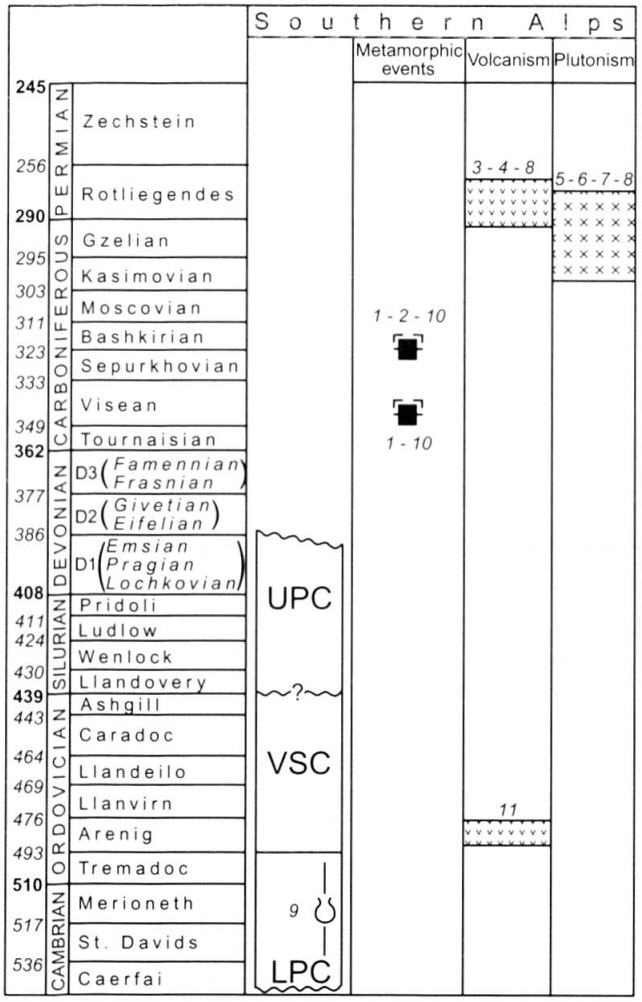

Fig. 8 Sketch of the timing of Paleozoic magmatic and metamorphic events in the Southalpine domain to the east of the Giudicarie Line (modified after SASSI and ZIRPOLI, 1989). Sources of geochronological and biostratigraphic data: 1 = DEL MORO et al., 1980 (Val di Funes); 2 = DEL MORO et al., 1984 (Brunico); 3 = BRONDI et al., 1970 (Bolzano); 4 = D'AMICO et al., 1980 (Bolzano); 5 = BORSI et al., 1972 (Bressanone); 6 = BORSI et al., 1974 (Cima d'Asta); 7 = DEL MORO and VISONÀ, 1982 (Bressanone); 8 = BARTH et al., 1994 (Bolzano and Cima d'Asta); 9 = KALVACHEVA et al., 1986 (Agordo); 10 = MELI, 1994 (Val Sarentino and Val Sugana); 11 = this work. Geologic time scale taken from HARLAND et al. (1989). Abbreviations as in section 2.

ern Southalpine, within the "Scisti dei Laghi" metamorphic unit (SCHALTEGGER and GEBAUER, 1999, and references therein). The age of volcanism in Comelico is constrained within the Lower Ordovician: concordant ages of 479 ± 8 and 485 ± 8 Ma result for MC and ME, respectively. Thus, the "Caledonian" hypothesis is now more substantiated than the alternative "Cadomian" hypothesis. The pre-Variscan volcanism developed earlier than Caradocian–Ashgillian, as previously believed: its correct chronostratigraphic position is within the Arenig. At the present state of knowledge, no geological event can be reasonably attributed to the upper intercept ages; however, a minimum age of 1800 Ma is inferred for the oldest component of the source material of the anatectic melts. The differences in isotopic composition between M. Elmo and M. Cavallino zircon populations could be due to a medium-scale heterogeneity within the crustal source of the volcanics, testified also by some petrographic features of ME and MC samples.

Within the easternmost part of the Southalpine basement, the Ordovician volcanism can be considered synchronous, as the new U/Pb ages of Comelico porphyroids agree with the ages inferred for Agordo metavolcanics on biostratigraphic grounds. The Southalpine porphyroids were also correlated with Austroalpine metavolcanics outcropping in the Northern Greywacke Zone; however, the more complex stratigraphy of Austroalpine successions does not allow simple correlations with the Southalpine domain: the main Austroalpine ignimbritic eruption ("Blassenecк event") is younger than Comelico volcanism, whereas an older metavolcanic layer occurring in the Eisenerz area is approximately coeval. Therefore, these new data do not rule out the possibility of considering Southalpine and Austroalpine metavolcanics as being part of a unique cycle of magma generation; however, more detailed geochronology is needed to correctly describe the Ordovician volcanic activity in the Eastern Alps, as sporadic data tend to oversimplify the picture.

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