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U-Pb SHRIMP data on the crystallization age of the Gran Paradiso augengneiss, Italian Western Alps: Further evidence for Permian magmatic activity in the Alps during break-up of Pangea

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Key words: U-Pb dating, SHRIMP, zircon, Permian magmatism, Gran Paradiso Massif, Italian Western Alps

ABSTRACT

New U-Pb Sensitive High Resolution Ion MicroProbe (SHRIMP) ages from two augengneiss samples of the Gran Paradiso Massif in the Italian Western Alps yielded well-defined Late Permian crystallization ages of 269.0±6.5 Ma and 270.2±5.0 Ma. The ages provide further evidence that the Gran Paradiso augengneiss is not Variscan basement but reflects post-Variscan magmatic activity related to the break-up of Pangea after the Variscan orogeny eventually leading to the formation of Neo-Tethys. The Gran Paradiso Massif belongs to the so-called internal massifs, which are marked by extension-related bimodal magmatism during the Permian and Mesozoic. Furthermore, the Late Permian ages suggest that the Gran Paradiso Massif did not belong to the same pre-Alpine tectonic domain as the External massifs (as part of the European plate margin), which are characterized by Variscan basement.

ZUSAMMENFASSUNG

Neue SHRIMP U-Pb Zirkonalter von zwei Augengneis-Proben des Gran Paradiso Massivs in den italienischen Westalpen ergeben gut definierte spätpermische Kristallisationsalter von 269.0±6.5 Ma und 270.2±5.0 Ma. Diese Alter bestätigen das die Augengneise des Gran Paradiso Massivs nicht Variskisches Grundgebirge darstellen, sondern vielmehr mit der post-variskischen, magmatischen Aktivität im Zuge des Auseinanderbrechens Pangäas nach der Variskischen Orogenese verbunden sind, die letztlich zur Bildung der Neo-Tethys führte. Das Gran Paradiso Massiv gehört zu den sogenannten Internmassiven der Alpen, welche durch extensionsgebundenen, bimodalen Magmatismus im Perm und im Mesozoikum gekennzeichnet sind. Insgesamt lassen die permischen Intrusionsalter der Augengneise vermuten, dass das Gran Paradiso Massiv nicht zu der gleichen präalpinen tektonischen Einheit wie die Externmassive gehörte. Die Externmassive, als Teil der Europäischen Platte, sind durch varikisches Grundgebirge charakterisiert.

Introduction

Because of the severe Alpine overprint, aspects of pre-Alpine tectonics and pre-Alpine paleogeography of the Alps will always be a controversial issue (Ring & Richter 1994; von Raumer 1998; Desmons et al. 1999). Important data for constraining pre-Alpine paleogeography and tectonics in more detail would be to have precise information on the age of the various pre-Mesozoic basement units of the Alps (Schaltegger & Gebauer 1999; Thöni 1999; Rubatto & Gebauer 1999). Bertrand et al. (1996, 2000) stressed the importance of Permian magmatic activity in the internal Western Alps using Secondary Ion Mass Spectrometry (SIMS) and Thermal Ionisation Mass Spectrometry (TIMS) U-Pb zircon data. Bertrand et al. (2000) and von Raumer (1998) showed the Gondwana affinity of the Alpine terranes and placed them along the northern margin of Gondwana in the Late Precambrian through Ordovician.

In this article we supply more evidence for Permian magmatic activity in the Gran Paradiso Massif of the internal Western Alps. Following cathodoluminescence work on zonation patterns in zircon, we dated small zones of 16 individual zircon grains from two augengneiss samples by SIMS U-Th-Pb dating using the Sensitive High Resolution Ion MicroProbe (SHRIMP).

Geological Setting

The major lithotectonic units of the Western Alps are from top to bottom: (1) the Austroalpine units, (2) the partly oceanic Pennine domain, and (3) the Helvetic nappes (Fig. 1). The continental Austroalpine units can be separated into the Dent Blanche Nappe and the Sesia Zone (Ballèvre et al. 1986). The heterogeneous Combin Zone marks the boundary between the Austroalpine units and the underlying Pennine nappes (Bearth

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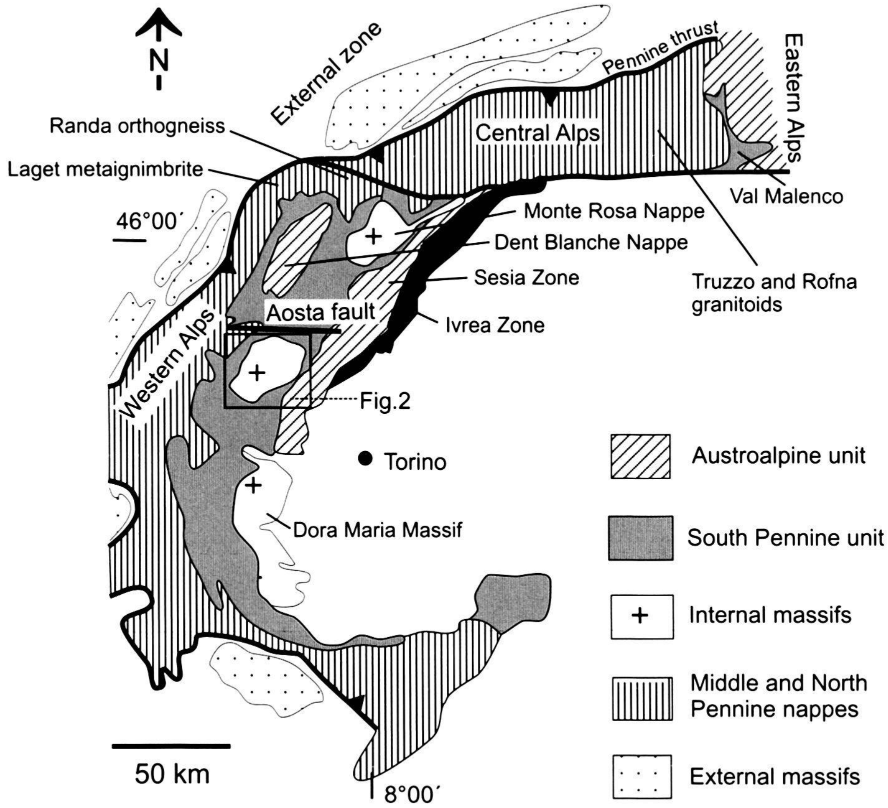

Fig. 1. Tectonic sketch map of the Western and Central Alps (box shows location of Fig. 2) with localities of other Permian magmatic rocks.

1956, 1976; Ring & Merle 1992; Reddy et al. 1999; Fig. 2). The Combin Zone is separated from the underlying Zermatt-Saas Zone by the Combin Fault (Ballèvre & Merle 1993; Ring 1995; Reddy et al. 2003). The Zermatt-Saas Zone is a South Pennine oceanic unit made up of serpentinite, metagabbro, metabasalt, metachert and Bündnerschiefer (Bearth 1976). The continental basement of the Gran Paradiso Massif occurs below the Zermatt-Saas Zone. It has the same Middle Pennine tectonic position as the Monte Rosa Nappe, the Dora Maira Massif and the Grand St. Bernard Nappe (Ballèvre et al. 1986; Pawlig & Baumgartner 2001). Because the Gran Paradiso Massif, the Monte Rosa Nappe and the Dora Maira Massif form windows within the South Pennine oceanic units, they are regarded as internal massifs. In the Tertiary Apine nappe stacking in the internal Western Alps proceeded during high- and ultrahigh-pressure metamorphism (e.g. Tilton et al. 1991; Borgi et al. 1994; Rubatto & Gebauer 1999; Meffan-Main et al. 2004). The North and Middle Pennine units were thrust over the Helvetic nappes along the Pennine thrust (Bertrand et al. 1996; Bucher et al. 2004).

In this article we focus on the Gran Paradiso Massif (Fig. 2a), which consists of two subunits (Compagnoni & Lombardo 1974). The first subunit is the Gran Paradiso Unit at the top of the Gran Paradiso Massif. It is made up of pre-Permian metasediments, into which the granitic precursor of widespread augengneiss was intruded, and also remnants of a Permo-Mesozoic cover. The metasediments form a thin blanket at the top of the Gran Paradiso Unit. It seems that the contact between augengneiss and metasediments represents a strong mechanical anisotropy along which the basal thrust of the Zermatt-Saas Zone developed (Kassem & Ring 2004). The second subunit is the tectonically lower Erfaulet Unit that comprises metaconglomerate, metapelite and metagranite/augengneiss (Borghi et al. 1996). The Erfault Unit is usually correlated with the Sanfront-Pinerolo Unit of the Dora Maira Massif (Sandrone & Borghi 1992). In the southwestern part of the Gran Paradiso Massif, the Bonneval Gneiss crops out above the augengneiss of the Gran Paradiso Unit (Vearncombe 1985). This banded gneiss is commonly mylonitic, is derived from Permian volcanics and sediments (Bertrand 1968), and is part of the Permo-Mesozoic cover of the Gran Paradiso Unit. The Bonneval Gneiss is separated from the augengneiss by a fault zone in which dolomite, cargneule, anhydrite and calcschist occur (Bois & Fabre 1956). The penetrative foliation in the Gran Paradiso Massif is generally flat-lying and forms a broad structural arch (Fig. 2b).

Relationships between pre-Alpine intrusions and pre-Alpine metamorphism

Compagnoni & Prato (1969), Callegari et al. (1969), Vearncombe (1985), Borghi et al. (1994, 1996) and Borghi & Sandrone (1996) showed that the pre-Permian metasediments of the Gran Paradiso Unit were first metamorphosed and de-

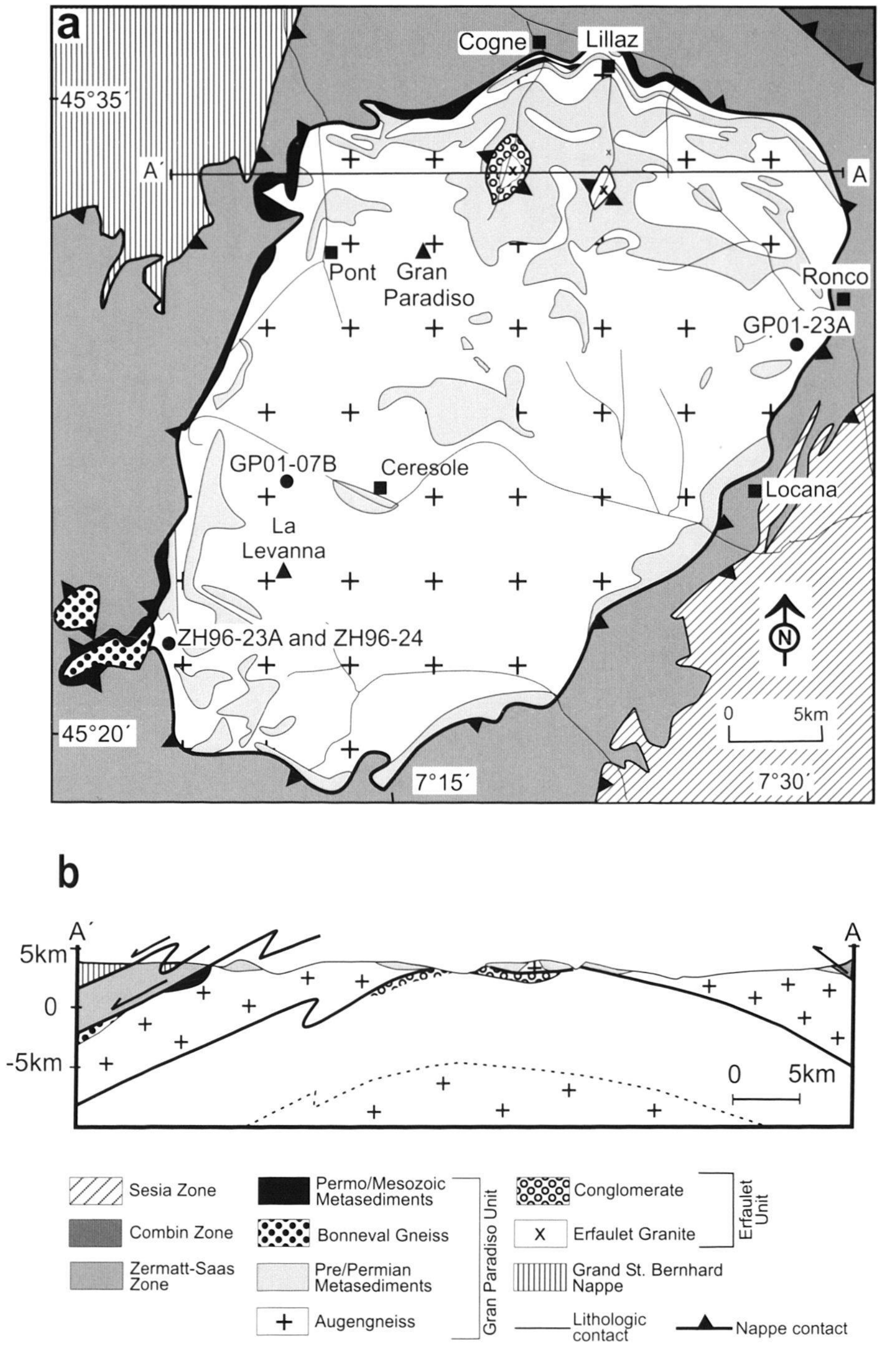

Fig. 2. (a) Tectonic map of the Gran Paradiso Massif (modified from Kassem & Ring 2004). Cross section A-A' and major streams (thin black lines) are indicated. The localities of samples GP01-7B and GP01-23A and also the sample locality of samples ZH96-23A and ZH96-24 of Bertrand et al. (2000) are indicated. (b) Cross section A-A' showing broad domal structure, the Erfaulet Unit forms the base of the exposed section and crops out in major valleys.

formed during the Variscan orogeny. Variscan metamorphic relics include sillimanite, plagioclase, biotite, and garnet. The augengneiss of the Gran Paradiso Unit is usually considered to be of Variscan age (Chessex et al. 1964; Callegari et al. 1982). Intrusive relationships of the precursor of the augengneiss into the metasediments occur in various places (Callegari et al. 1969; Compagnoni & Prato 1969). Desmons et al. (1999) reported biotite, sillimanite, andalusite and cordierite pseudomorphs forming contact metamorphic aureoles around the granitoids of the Gran Paradiso Massif. The intrusive relationships and the hornfelses, as well as the fact that the augengneiss does not shown any relics of the Variscan high-temperature metamorphism indicates that the intrusion of the augengneiss precursor must postdate the main Variscan metamorphic event.

The rocks of the Erfaulet Unit also do not show any evidence for the Variscan high-temperature metamorphism.

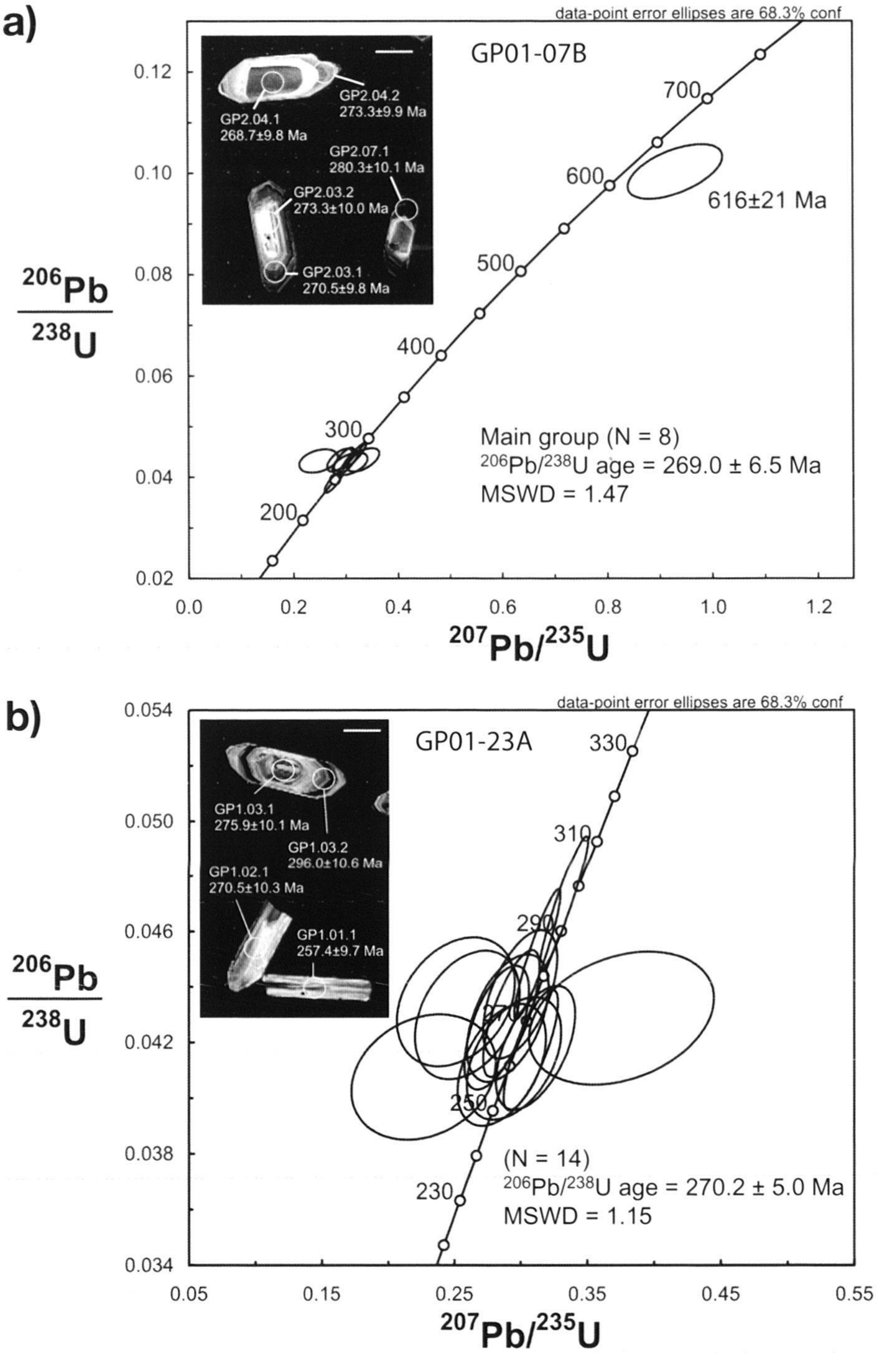

Fig. 3. (a) Cathodoluminescence images of grains from sample GP01-07B displaying irregularly zoned cores rimmed with oscillatory-zoned zircon. Both cores and rims yielded ages of about 270 Ma. (b) Oscillatory zoned zircons without distinct cores from sample GP01-23A providing ages of 257-296 Ma; the mean age is indistinguishable from the mean age of sample GP01-07B. Errors for individual analyses are quoted at the 1σ level and weighted mean ages are quoted at the 2σ level.

Compagnoni et al. (1974) suggested a Late Carboniferous and/or Permian age for the conglomerate. Le Bayon & Ballèvre (2004) confirmed this inference by showing that the Late Carboniferous-Permian Erfault metagranite/augengneiss has an intrusive relationship into the Erfaulet metasediments and caused a contact metamorphic aureole in the metasediments. Further indirect support for a late- to post-Variscan age of the rocks of the Erfaulet Unit comes from metagranites of the correlative Sanfront-Pinerolo unit, which yielded U-Pb zircon ages of 290–270 Ma (Bussy & Cadoppi 1996).

Previous zircon ages from the Gran Paradiso augengneiss

Chessex et al. (1964) suggested a Variscan age for the augengneiss precursor. Bertrand et al. (2000) analyzed two au-

Table 1. U-Th-Pb isotopic data and calculated ages from SIMS zircon analyses from augengneiss of the Gran Paradiso Massif (GP 01-07B, GP 01-23A) using the SHRIMP II). Common Pb derived from measured ^{204}Pb assuming Broken Hill Pb isotopic ratio; data processed using programs SQUID and ISOPLOT. Errors include error in mean of 2.63% quadratically added to individual analysis errors. Abbreviations: conc. = concentration; com. = common ^{206}Pb; disconc. = % discordance; [1]radiogenic Pb only; [2]all errors are absolute 1σ errors; R = rim, C = core analysis.

		Conc. (ppm)										Ages						
Spot		U	Th	^{232}Th/ ^{238}U	%com. ^{206}Pb	^{206}Pb[1]/ ^{238}U	±[2]	^{207}Pb[1]/ ^{235}U	±[2]	^{207}Pb[1]/ ^{206}Pb	±[2]	^{206}Pb[1]/ ^{238}U	±[2]	^{207}Pb[1]/ ^{235}U	±[2]	^{207}Pb[1]/ ^{206}Pb	±[2]	% disconc.
GPOL.23A																		
GP1.01.1		216	147	0,70	2,25	0,0407	0,0016	0,2249	0,0363	0,0400	0,0063	257,4	9,7	205,9	29,6	-349	404	336
GP1.02.1		144	57	0,41	1,38	0,0429	0,0017	0,3745	0,0462	0,0634	0,0074	270,5	10,3	323,0	33,6	721	248	-67
GP1.03.1	C	401	189	0,49	0,85	0,0437	0,0016	0,2982	0,0188	0,0495	0,0025	275,9	10,1	265,0	14,6	170	118	138
GP1.03.2	R	3994	412	0,11	0,19	0,0470	0,0017	0,3310	0,0129	0,0511	0,0006	296,0	10,6	290,3	9,8	245	29	117
GP1.04.1	C	345	68	0,20	0,76	0,0429	0,0016	0,2887	0,0208	0,0489	0,0030	270,5	9,9	257,6	16,3	141	145	148
GP1.04.2	R	308	81	0,27	0,68	0,0418	0,0016	0,3099	0,0203	0,0538	0,0029	263,9	9,7	274,1	15,7	362	121	63
GP1.05.1	R	336	117	0,36	1,53	0,0414	0,0016	0,2936	0,0241	0,0514	0,0037	261,6	9,6	261,4	18,7	260	167	101
GP1.05.2	C	1328	666	0,52	0,23	0,0417	0,0015	0,3063	0,0140	0,0532	0,0014	263,5	9,5	271,3	10,8	339	61	71
GP1.06.1	R	298	140	0,48	1,64	0,0430	0,0016	0,2581	0,0264	0,0436	0,0041	271,2	10,0	233,1	21,1	-136	235	250
GP1.06.2	C	746	720	1,00	0,76	0,0425	0,0016	0,2804	0,0167	0,0478	0,0022	268,4	9,7	251,0	13,1	91	110	166
GP1.07.1		429	193	0,46	0,91	0,0412	0,0015	0,2843	0,0225	0,0501	0,0035	260,2	9,5	254,1	17,7	198	162	124
GP1.08.1	C	3212	2010	0,65	0,27	0,0452	0,0017	0,3115	0,0123	0,0500	0,0007	284,8	10,2	275,4	9,5	196	34	131
GP1.08.2	R	1502	87	0,06	0,42	0,0430	0,0016	0,2916	0,0144	0,0492	0,0016	271,5	9,9	259,8	11,3	155	76	143
GP1.09.1		519	117	0,23	2,10	0,0434	0,0016	0,2495	0,0297	0,0417	0,0047	274,2	10,1	226,2	23,9	-248	286	290
GPOL.07B																		
GP2.01.1		1837	1013	0,57	0,22	0,0388	3,6804	0,2718	4,3584	0,0507	2,3348	245,7	8,9	244,1	9,4	229	54	107
GP2.02.1		139	107	0,80	0,82	0,1003	3,8018	0,9287	6,5324	0,0672	5,3121	616,0	22,3	666,9	31,4	843	111	63
GP2.03.1	R	1627	105	0,07	0,01	0,0429	3,6831	0,3027	4,0895	0,0512	1,7772	270,5	9,8	268,5	9,6	251	41	107
GP2.03.2	C	382	164	0,44	0,40	0,0433	3,7405	0,3291	6,4086	0,0551	5,2038	273,3	10,0	288,9	16,0	416	116	48
GP2.04.1	C	446	256	0,59	1,05	0,0426	3,7450	0,3038	7,3682	0,0518	6,3454	268,7	9,8	269,4	17,3	276	145	97
GP2.04.2	R	715	53	0,08	1,00	0,0433	3,7034	0,2833	5,8571	0,0475	4,5377	273,3	9,9	253,3	13,0	72	108	174
GP2.05.1		1647	44	0,03	0,62	0,0435	3,7171	0,2914	4,5830	0,0486	2,6808	274,3	10,0	259,7	10,4	130	63	153
GP2.06.1		340	173	0,53	1,84	0,0431	3,7569	0,2431	10,1265	0,0409	9,4038	272,2	10,0	221,0	19,9	-294	240	308
GP2.07.1		2680	134	0,05	0,12	0,0444	3,6760	0,3162	4,0597	0,0516	1,7229	280,3	10,1	279,0	9,9	268	40	104

gengneiss samples from the southwestern Gran Paradiso Massif (Fig. 2a). Sample ZH96-23A is a porphyritic augengneiss, which is the most common rock type in the Gran Paradiso Massif. Chemical data suggest a sub-alkaline character of the porphyritic granite (Bonin et al. 1993). The second sample (ZH96-24) is from a dark, metre-sized enclave in the augengneiss. Both samples yielded euhedral zircons with numerous inclusions and obvious cores.

SHRIMP analyses of the porphyritic augengneiss mainly yielded concordant points with ages between 280–250 Ma. The weighted mean of 13 points provided a $^{206}Pb/^{238}U$ age of 269±6 Ma (Bertrand et al. 2000). Old xenocrysts gave ages of up to 1893±4 Ma ($^{207}Pb/^{206}Pb$ age). The dark enclave yielded a distinctly older weighted mean $^{206}Pb/^{238}U$ age of 597±18 Ma. However, there are also younger ages found in zircons from the dark enclave. Although the observed age pattern is ambiguous, a poorly defined intrusion age of 270 Ma has been discussed (Bertrand et al. 2000).

In summary, the previous dating by Bertrand et al. (2000) suggests an age of about 270 Ma for the Gran Paradiso augengneiss. However, because the results from the dark enclave (ZH96-24) are ambiguous, the conclusion of Bertrand et al. (2000) basically hinges on one single sample.

SIMS U–Th–Pb zircon dating

Heavy minerals were separated from augengneiss samples GP01-07B and GP01-23A from the Gran Paradiso Unit (Fig. 2a). Sample GP01-07B is from a road cut west of Ceresole. It is a mylonitically deformed platy gneiss in which the feldspar grains are extremely smeared out with aspect ratios >25 in XZ sections (Kassem & Ring 2004). Sample GP01-23A is from the Val di Forzo southwest of Ronco. It is a modestly deformed augengneiss with a distinct augen structure. The main minerals in both samples are potassium feldspar, plagioclase, white mica, quartz, ilmenite and magnetite.

Zircons were hand picked, mounted, polished, cleaned and gold coated. Cathodoluminescence (CL) imaging was carried out to characterize the zircon and identify analysis spot sites (Fig. 3). The zircons predominantly form elongate prisms with aspect ratios of >3:1. Under CL these crystals have irregularly zoned elongate cores and are surrounded by finely oscillatory zoned rims with common sector zonation (Fig. 3). A couple of more equant grains were seen that in CL have sub-circular cores again rimmed with oscillatory zoned zircon.

Zircon U-Th-Pb isotopic data was collected using the Sensitive High Resolution Ion Microprobe Mass Spectrometer

(SHRIMP II) based in the John de Laeter Centre of Mass Spectrometry, Perth, Western Australia. The sensitivity for Pb isotopes in zircon using SHRIMP II was ~18 cps/ppm/nA, the primary beam current was 2.5–3.0 nA and mass resolution was ~5000. Correction of measured isotopic ratios for common Pb was based on the measured ^{204}Pb in each sample and often represented a <1% correction to the ^{206}Pb counts (see % common ^{206}Pb in Table 1). Any common Pb component in the standard was interpreted as surface contaminant and modelled on the composition of Broken Hill ore Pb, common Pb in the unknowns was modelled on the approximate age of the grain using the Pb isotope evolution model of Stacey & Kramers (1975) using the program SQUID 1.02 (Ludwig 2001).

Pb/U isotopic ratios were corrected for instrumental inter-element discrimination using the observed covariation between Pb^+/U^+ and UO^+/U^+ (Hinthorne et al. 1979; Compston et al. 1984) determined from interspersed analyses of the Perth standard zircon CZ3. CZ3 is a single zircon megacryst from Sri Lanka with an age of 564 Ma and a ^{206}Pb/^{238}U=0.0914 (Nelson 1997). The mean error of the standard was quadratically added to the unknown data and is included in all quoted ages.

From sample GP01-07B of the western Gran Paradiso Massif (Fig. 2a) two distinct cores and rims were analyzed along with five grains without distinct cores and rims. A weighted mean of all but one of the ^{206}Pb/^{238}U ages yielded a Permian age of 269.0±6.5 Ma (MSWD=1.5, Fig. 3a) (note that single analyses errors are quoted at the 1σ level, mean ages are quoted at 2σ). One single core yielded an age of 616±21 Ma (Table 1, Fig. 3a). We interpret this core to be xenocrystic.

Sample GP01-23A from the eastern part of the massif (Fig. 2a) yielded similar results. All 14 analyzed cores and rims yielded Permian ^{206}Pb/^{238}U ages of between 296±11 Ma and 257±10 Ma (Table 1). The 14 analyses yielded a weighted mean ^{206}Pb/^{238}U age of 270.2±5.0 Ma (MSWD=1.2, Fig. 3b), which is identical to the age of sample GP01-07B.

The pristine oscillatory zoned nature of all analyzed zircons indicates that the zircons crystallized from a granitic magma, the ages from both samples are therefore interpreted as the crystallization age of the precursor of the augengneiss.

Discussion

Our new SIMS zircon ages of 269.0±6.5 Ma and 270.2±5.0 Ma are similar to the recently reported zircon age of 269±6 Ma from augengneiss sample ZH 96-23 (Bertrand et al. 2000) and thus provide further evidence that the augengneiss unit of the Gran Paradiso Massif is of Permian age. Similar Permian zircon ages were also reported from augengneiss in the Monte Rosa Nappe (Köppel & Grünenfelder 1975; Pawlig & Baumgartner 2001) and the Dora Maira Massif (Bertrand et al. 2000). Other Permian intrusive ages are known from the Middle Pennine nappes in the northern Western Alps (Randa orthogneiss; Bussy et al. 1996) and in the eastern Central Alps (Truzzo and Roffna granitoids; Marquer et al. 1998). Bussy et al. (1996) also reported a 280-270 Ma age for the Laget metaignimbrite from the Middle Pennine Siviez-Mischabel nappe. All these ages demonstrate that the Middle Pennine nappes underwent a common Permian evolution.

In addition to the granitic Permian intrusions, mantle derived mafic magmas of Permian age have been reported from the Ivrea Zone (Schaltegger & Gebauer 1999; Mayer et al. 2000). The gabbroic rocks of the Ivrea Zone are thought to reflect mantle upwelling during Permian rifting in the Alps (Desmons & Hunziker 1988; Brodie et al. 1989). The intrusion of the mafic complex caused the main, extension-related metamorphism in the Ivrea Zone, which reached 850±100°C and 8–9 kbar (Colombo & Tunesi 1999). Radiometric ages constrain this main regional metamorphism at about 290-270 Ma (Brodie et al. 1989; Bürgi & Klötzli 1990; Vavra et al. 1996). Other major extension-related Permian mafic intrusions have been reported from the Val Malenco in the eastern Central Alps by Hansmann et al. (2001).

According to Schaltegger & Gebauer (1999) and Thöni (1999), Middle Pennine basement nappes and parts of the Austroalpine show widespread bimodal magmatic activity during Permian through Mesozoic times. The bimodal Permian volcanics, the mantle-derived gabbroic intrusions and the widespread granitic rocks point to the occurrence of a major extensional event in the internal Alps in the Permian. Large-scale considerations suggest a major plate-tectonic reoganization giving rise to a tensional regime in the Permian and Mesozoic (Ziegler 1993). The widespread Permian ages (290-260 Ma) from the Middle Penninic domain are most probably related to plate divergence and are younger than ages of >290 Ma from the External massifs (Bussy & von Raumer 1994; Schaltegger 1994), which are usually interpreted to date distinct stages of the Variscan orogeny in the Alps.

This brief summary of Late Paleozoic intrusion ages has some implications for pre-Alpine paleogeography in the Alps and shows that the Middle Pennine units in the internal Western Alps (Monte Rosa Nappe, Gran Paradiso and Dora Maira massifs) were a distinct paleogeographic domain during the Permian that was differed from the External massifs (as part of the European plate margin), a hypothesis already stressed by Bertrand et al. (2000) and Pawlig & Baumgartner (2001). Since bimodal, extension related magmatism occurred in the Middle Pennine units and in the Austroalpine domain but has so far not been reported from the former European margin, it appears as if the Middle Pennine and Austroalpine domains had a different Permian and Mesozoic geologic history than the European margin. This finding does not support the recent hypothesis of Froitzheim (2001) that the Monte Rosa nappe is not part of the Middle Pennine unit but rather belongs to the European margin.

We did not find any evidence for Alpine zircon rims as reported from the two other internal Penninic massifs, the Monte Rosa Nappe (Rubatto & Gebauer 1999) and the Dora Maira Massif (Tilton et al. 1991; Gebauer et al. 1997). Rubatto & Gebauer (1999) found zircon rims only in mica schists from the Monte Rosa nappe but the augengneiss did not contain any metamorphic zircon (D. Rubatto, writt. comm. 2005). Gebauer et al. (1997) derived Oligocene zircon ages from quartzite. An orthogneiss sample yielded Permian ages as well as partially reset ages, the youngest of which yielded an apparent age of 92±2 Ma. Therefore, the lack of any metamorphic zircon rims in our augengneiss samples is not surprising, although poorly understood. Precipitation of metamorphic zircon can results from solid-state reactions involving breakdown of metamorphic and magmatic Zr-bearing phases. Garnet, amphibole, pyroxene and ilmenite can contain significant amounts of Zr, which can be made available during metamorphism and lead to zircon precipitation (Bingen et al. 2001). The dated augengneisses from the Gran Paradiso Massif contain abundant ilmenite; however, we never observed any reactions textures between ilmenite and zircon, which might explain the lack of any metamorphic zircon in our samples.

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