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Laser ablation U/Pb age patterns of detrital zircons in the Schlieren Flysch (Central Switzerland): new evidence on the detrital sources

Endrio Bütler · Wilfried Winkler · Marcel Guillong

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Abstract The palaeogeographic attribution of the Schlieren Flysch and its counterparts in the Gurnigel Nappe is still a matter of debate. These Late Alpine deep-sea trench deposits show a variable tectonic thrust relationship with other nappes inferring either an Ultrahelvetic or South Penninic origin of the elongated trench basin. An improved knowledge of the supplying source terranes of the Schlieren Flysch basin may add to the palaeogeographic ascription. Detrital zircons from seven representative samples have been dated by laser ablation ICP-MS analysis methods. The obtained age patterns are compared with standard provenance analysis methods including modal grain and heavy mineral statistics of the sandstones. The detrital zircons show two major populations of Pan-African (ca. 650–450 Ma) and Variscan (ca. 360–320 Ma) ages. A low abundance of Devonian detrital zircons separates the two main age populations. The Th/U signature of the zircons implies that igneous rocks of these two orogenic cycles directly, or indirectly (by multicyclic reworking of zircons) have strongly contributed to the clastic input. The earlier described bimodal turbiditic supply to the Schlieren Flysch basin is matched by the geochronologic data. With regard to the other petrographic signatures of the sandstones, it becomes evident that the granitic-rhyolitic source terrane derived (K-feldspar bearing) sandstones show a higher abundance of Pan-African zircons and a higher abundance of tourmaline in the heavy mineral fractions. In contrast, the exclusively plagioclase-bearing sandstones from the tonalitic–andesitic source contain a majority of Variscan zircons and higher contents of apatite. In addition, we observe a third minor population comprising Triassic–Early Jurassic detrital zircons. The correlation of the obtained detrital zircon ages with pre-Cretaceous igneous, metamorphic and geodynamic events, which affected the basement of the northern and southern margins of the Alpine Tethys reveals a major difference by the presence of Triassic magmatic products and volcaniclastics in South Alpine and Austroalpine units. The discovery of the minor Triassic–Early Jurassic population in both sandstone types of the Schlieren Flysch would argue for the derivation of the clastic material from the southern Alpine Tethys or Adriatic–Apulian margin.

Keywords Flysch · Detrital zircons · Laser ablation U/Pb ages · Sandstone petrology · Provenance · Palaeogeography

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1 Introduction

The Late Maastrichtian–Early Eocene Schlieren Flysch is a component of the Gurnigel Nappe, which extends along the Alpine front from the French and Swiss Préalpes Romandes to Central Switzerland (Fig. 1). Whereas in the Prealpine sections in western Switzerland, the Gurnigel Nappe is overthrust by the Middle Penninic nappes derived from the Briançonnais domain (i.e., Préalpes médianes plastiques), in Central Switzerland (including the Sörenberg, Grosse Schliere and Wägital areas) it tectonically overlies external units of the Helvetic nappes (Fig. 1). Because of the variable tectonic relationship of the Gurnigel Nappe with the Middle Penninic and Helvetic units, the palaeogeographic position of the Late Maastrichtian–Early Eocene basinal series still is a matter of debate (Trümpy 2006). For many decades an Ultrahelvetic origin (i.e., from the southern edge of the Southhelvetic realm) was assumed (see overview in Trümpy 1980). However, Caron et al. (1980) proposed a vague "ultrabriançonnais" palaeogeographic origin based on the close chronostratigraphic, lithologic and petrographic affinity of the Gurnigel Flysch with the basal Reidigen series of the Upper Prealpine Nappe on top of the Middle Penninic Prealps (Fig. 1). The Upper Prealpine Nappe (also called Simme Nappe s.l.) with an age-inverted stack of various flysch and mélange formations shows typical features of a Late Cretaceous-Palaeogene accretionary prism (Gasinski et al. 1997). The Gurnigel Flysch and Reidigen series presumably represented the final trench basin deposits, which were tectonically expelled together with the accretionary prism during collision of the northern and southern Alpine margins. Later out-of-sequence thrusting may have triggered the thrusting of the Middle Penninic nappes over the originally South Penninic Gurnigel Flysch (Gasinski et al. 1997). This opinion is shared by a number of Alpine researchers and found acceptance in the newest tectonic map of Switzerland (Bundesamt für Wasser und Geologie 2005).

In the seventies and eighties of the last century, different sectors of the Gurnigel Nappe were subject of monographs including biostratigraphic dating by nannofossils, sedimentology and source areas by heavy minerals and sandstone modal composition (van Stuijvenberg 1979; Morel 1978; Winkler 1983; Winkler et al. 1985b). In a summary paper Winkler (1984) documented a constant chronostratigraphic pattern of the flysch series along strike from Lake Geneva to Central Switzerland including: (1) Late Maastrichtian and Early Palaeocene (Danian) generally thin-bedded turbidite facies (with occasional conglomerates in the latest Cretaceous), (2) massive, thick-bedded supra-fan facies in the Late Palaeocene (Selandian–Thanetian), (3) an abyssal plain facies rich in hemipelagic deposits at the Palaeocene–Eocene transition followed upsection again by (4) prograding, massive supra-fan turbidite systems, and finally (5) by base-of-slope deposits

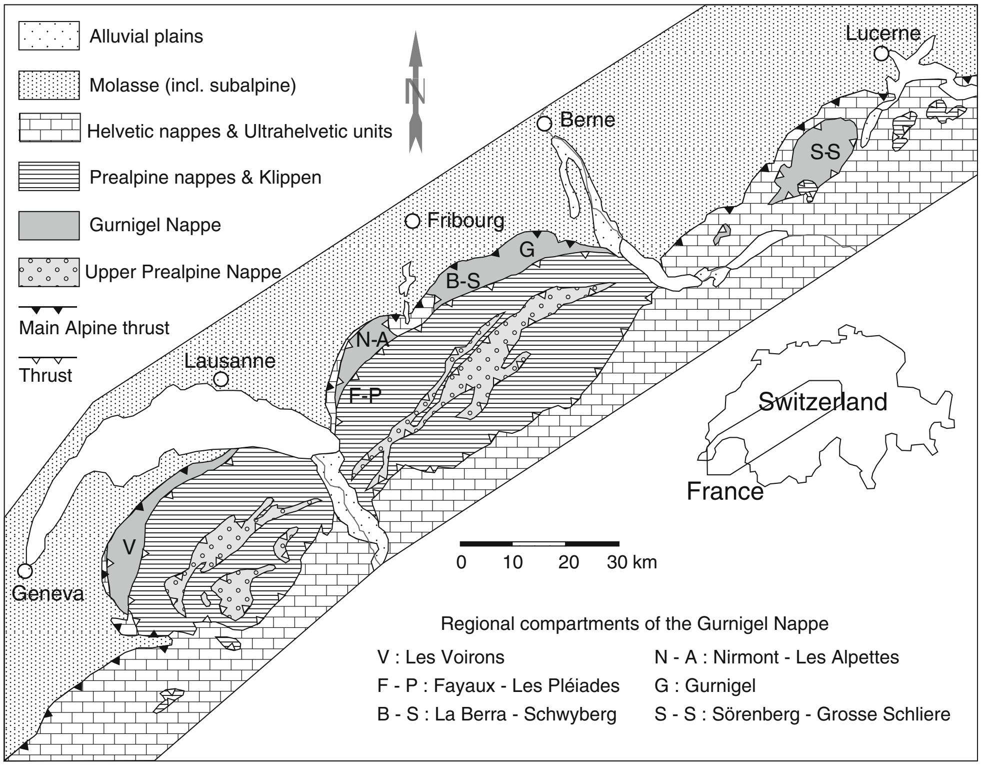


Fig. 1 Simplified geological map of the Alpine front between Geneva and Lucerne depicting the different parts of the Gurnigel Nappe (after Winkler 1984; Bundesamt für Wasser und Geologie 2005)

rich in mud turbidites. In the Voirons segment in the west, the youngest conglomerate-rich facies has a Middle to earliest Late Eocene age (van Stuivenberg 1980). The combination of systematic palaeocurrent measurements and sandstone modal composition data suggests that the individual turbidite fans were deposited in an elongated, deep basin with a bathymetry around the local CCD. They were supplied by multiple point sources along its southern basin margin with a general flow deviation parallel to the basin axis and towards the east (in present-day coordinates) (Winkler 1984). A common heavy mineral association including garnet and the ultrastable grains zircon, tourmaline and rutile distinguishes the sandstones clearly from contemporaneous ones supplied from the northern (European) Alpine Tethys margin (Wildi 1985), which generally do not contain garnet.

The present paper investigates the detrital zircons in the Sörenberg-Grosse Schliere sector (Fig. 1) by ICP-MS laser ablation U/Pb dating of single grains. The study is aimed at revealing the geochronologic age pattern of the magmatic and metamorphic basement rocks in the source terranes of the Schlieren Flysch Group (cf. Winkler 1983, 1984). This methodological approach is expected to provide further details on the nature and composition of the sediment sources of the turbidites. We also discuss wether the geochronology of detrital zircons can be used to allocate the sources of the Schlieren Flysch sediments to the northern or southern Alpine Tethys margin, which may have existed due to different geological histories. The data presented here were obtained during the elaboration of the unpublished Master thesis of Endrio Bütler (2009).

2 Lithostratigraphy and sedimentology of the Schlieren Flysch

The Schlieren Flysch Group is mildly folded into two roughly W-E running synforms overlying a basal mélange or "wildflysch" package (Sörenberg Mélange, Bayer 1982). The type section is located in the Grosse Schliere valley where its formations were described and dated by nummulites (Schaub 1951) and nannofossils (Winkler 1983). Winkler (1983, 1984) distinguished a northern and southern facies belt defined by the diachronous upper boundary of the two Tonsteinschichten intervals and clastic contents (Fig. 2). The Schlieren Group is approx. 1,500 m thick; small-scale tectonic folding is conspicuous in the basal formations above the thrust separating it from the mélange. In the Basal Schlieren Flysch, a thin-bedded turbidite facies prevails showing a faint thickening/coarsening-upward trend. In the Late Maastrichtian interval, debris flows/grain flow conglomerates and calcareous turbidites ("Alberese" limestones) occasionally occur.

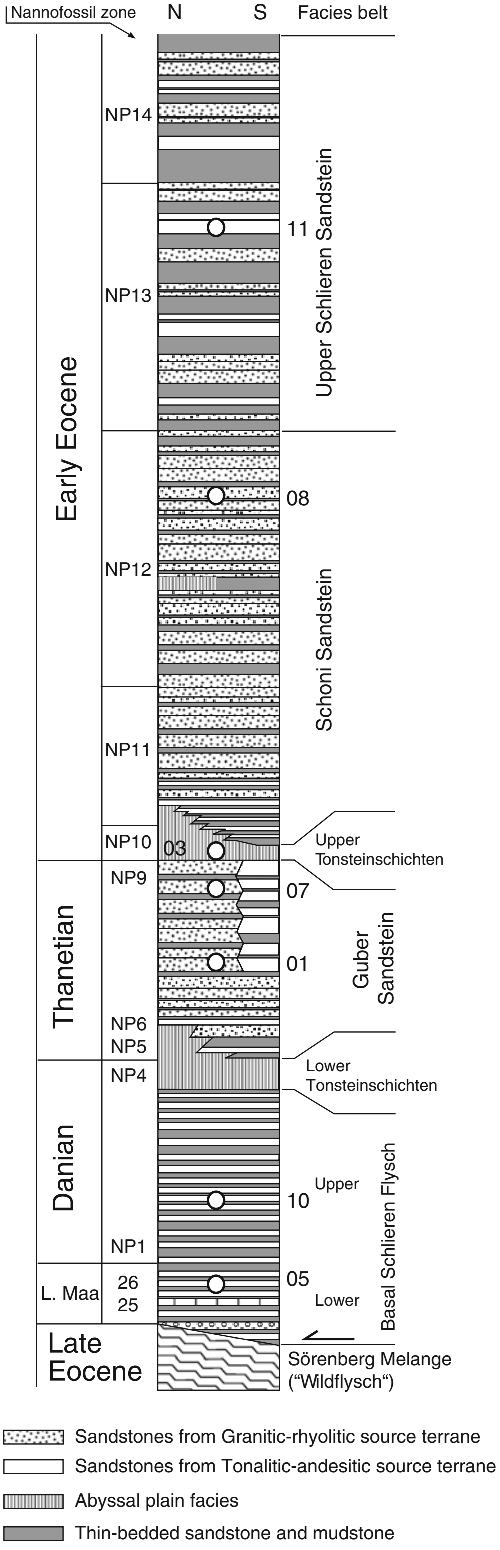


Fig. 2 Composite lithostratigraphic profile of the Schlieren Flysch Group (simplified from Winkler 1983). Biostratigraphic correlations with nannofossil zones and lithologic variations between northern and southern facies belts are indicated. Samples analyzed in this study are shown by open circles and the first digits of the sample numbers (e.g., 07 indicated sample number 07EB07, etc.)

This formation passes into a thin-bedded turbidite sequence containing cm-dm thick hemipelagic/interturbidite layers between the rapidly deposited Bouma-cycles, which progressively grades into the massive sandstone facies of the (locally quarried) Guber Sandstein Formation. The overlying hemipelagic-rich Upper Tonsteinschichten Formation has a biostratigraphically well-constrained diachronous upper boundary (Winkler 1983). The Lower and Upper Tonsteinschichten facies are thought to represent the distal northern transition to the abyssal plain of the elongated trench basin. The diachronous upper boundaries reflect S–N oriented synsedimentary compression and bulging of the outer northern basin floor, which later was onlapped by the main trench basin-fill fans from south to north (Guber and Schoni Sandstein formations).

In a similar way as the Guber Sandstein, also the Schoni Sandstein Formation progrades on top of the Upper Tonsteinschichten and develops upwards into massive supra-fan deposits (well exposed in the famous Sörenberg landslide scar, Winkler 1983), occasionally showing Tonsteinschichten facies intervals along the northern facies belt. The overlying Upper Schlieren Sandstein is characterized by bundles of coarse turbidite layers often depicting either fining- or coarsening-upward cycles, which are embedded in meter- to decametre-thick shaley intervals, composed of several pelite-rich turbidite beds. An inner fan and base-of-slope environment is suggested for this uppermost portion of the basin fill (Winkler 1983, 1993).

The Schlieren Flysch basin was supplied from two distinct terrigeneous source terranes. The detrital input varied in space and time (Fig. 2). They are recognized by the different feldspar mineralogy of the sandstones and different palaeocurrent directions: (1) the granitic-rhyolitic source terrane provided K-feldspar and plagioclase-bearing sands to the basin by flow parallel to the basin axis from west to east (in modern co-ordinates), and in contrast (2) the exclusively plagioclase-bearing turbidites from the tonalitic–andesitic source terrane, which entered the basin from the south and were deviated to the east, along basin axes. This distinction is also matched by the related conglomerate composition: no granitic–rhyoltic pebbles occur in the deposits derived from the tonalitic–andesitic source (Winkler 1983). Similar provenance analyses in the entire Gurnigel Nappe suggest that both source terranes were located on the southern margin of the Schlieren Flysch basin (Winkler 1984). The type of basement of the basin is not known because of Alpine nappe thrusting. Presumably, the basin represented a remnant of the South Penninic ocean, which existed prior to the collision of the southern Alpine Tethys margin with the Middle Penninic (Briançonnais) terrane (Gasinski et al. 1997; Stampfli et al. 2002).

Generally, the deep, presumably remnant, oceanic Schlieren Flysch basin shows a sedimentary evolution forced by tectonic shortening and deepening intervals, and a climatically controlled availability of clastic material, as depicted by systematic clay mineral analyses (Winkler 1993). Tectonic and climatic (humid vs. cool) parameters must have influenced the frequency of turbidity currents; a rough estimate suggests that the currents occurred at intervals of 3,000–15,000 years depending on these variables (Winkler 1993).

3 Samples and methods

Seven medium to coarse-grained turbiditic sandstones were analysed out of a greater number of samples from the all formations. Lithostratigraphic positions, geographic locations and some details on the samples with reference to Winkler (1983) are given in Table 1 (see Fig. 2 for the stratigraphic positions of the samples).

Table 1 Location of the investigated Schlieren Flysch samples and details

Sample	Formation/member	Locality	Altitude (m)	Swiss topographic grid (1:25,000)	Remarks
11EB07	Upper Schlieren Sandstein	Blattligraben	1,270	647.200/189.740	Bed Wi 1026 in section XXIII (Winkler 1983)
08EB07	Schoni Sandstein	Grosse Schliere river	1,060	658.200/197.760	Bed Wi 247 in section XXI (Winkler 1983)
03EB07	Upper Tonsteinschichten	Chistenwald above Guber quarry	1,030	660.180/197.740	Bed Wi 737 in section XV (Winkler 1983)
07EB07	Guber Sandstein	Grosse Schliere valley, dust road to Alpe Schoni	1,060	659.120/198.500	Bed Wi 40 in section X in Winkler (1983)
01EB07	Guber Sandstein	Upper Guber quarry	960	660.150/197.950	Mudchip-bearing sandstone below channel-fill (level c on Fig. 21 in Winkler 1983)
10EB07	Upper Basal Schlieren Flysch	Grosse Schliere river	800	659.900/198.150	
05EB07	Lower Basal Schlieren Flysch	Grosse Schliere river	570	661.870/198.250	

Modal grain quantification of the sandstones was performed on thin sections stained for feldspar and carbonate by statistical (mid-point ribbon) counting of at least 300 grains per sample. Monomineralic grains (quartz, feldspars) and aphanitic lithoclasts were distinguished (e.g., Dickinson 1970; Dickinson and Suczek 1979). For obtaining the heavy mineral fraction, the sandstone samples were crushed, and the bulk carbonate (cement, bioclasts and lithoclasts) in the fraction 1–2 mm was dissolved in warm, 10% acetic acid. The 0.063–0.4 mm residue was used for subsequent heavy liquid (bromoform, D = 2.89) separation and mounting of the heavy minerals in piperine (Martens 1932) between glass slabs and cover. Statistical counting of 100–200 single grains was performed under the petrographic microscope (Mange and Maurer 1992).

Isotopic and geochemical investigations on single detrital zircon grains have turned out to be a powerful tool in provenance studies (e.g., Košler et al. 2002; Yuan et al. 2008; Lemieux et al. 2007; Kelty et al. 2008; Martin-Gombojav and Winkler 2008). In particular, laser ablation U/Pb dating of detrital zircons, combined with modal sandstone and heavy mineral analysis, contributes significantly to the knowledge of the chronostratigraphic age framework of the basin hinterland.

Laser ablation ICP-MS analyses of single detrital zircons were carried out at the Institute of Geochemistry and Petrology, ETH Zurich, on an Elan 6100 DRC instrument coupled to an 193 ArF Excimer laser. Ablation in He gas occurred with a pulse rate of 10 Hz at an energy density of 5 J/cm^2. The homogenized, focused laser beam diameter was fixed at 40 µm. The accuracy and reproducibility of U–Pb zircon dating with NIST SRM 610 as external standard reference material is not as good as with matrix matched zircon as reference material (Kuhn et al. 2010). Therefore, we monitored the accuracy and reproducibility within each run of analysis by analysing zircon reference materials, e.g., BR266 with 206 Pb/238 U and 207 Pb/206 Pb ages between 559.0 ± 0.3 and 562.2 Ma (Stern 2001), to be able to correct the age of the samples. Data reduction was performed using the MATLAB-based code SILLS (Guillong et al. 2008) to calculate the isotopic ratios and errors. The ages where then calculated by isoplot (Ludwig 2009). Prior to laser ablation ICP-MS analysis, all zircon grains were inspected by back scattered and cathode luminescence under the electron microscope (e.g., Kempe et al. 2000). This is aimed at identifying old cores and inclusions within the grains for fixing accurately the appropriate laser ablation shots. Old cores were not dated. An average number of 88 dated detrital zircons per sample (within a spread of 50–127) were obtained. For statistical application, Dodson et al. (1988) proposed a minimum dating of 60 zircons in single sandstone samples. However, Vermeesch (2004) showed that this number may be too low, because the maximum probability of missing at least one fraction greater than 5% is 64%. A higher number of around 117 is recommended by the latter author because this provides 95% confidence that no fraction smaller than 5% was missed. In our data set two samples with 127 and 109 dated zircons are in the optimal range, suboptimal are two samples with 92–93 zircon ages. With regard to our whole data set we observe that with lower numbers of zircon ages (82, 67 and 50) the main populations are still well represented. In addition, small populations with percentages of 5–1% zircons of the total zircons like the Triasic–Liassic ones are also signalled. However, a lower number of dated grains than 117 becomes critical in provenance studies when the absence of age fractions is used as a discrimination argument (Vermeesch 2004). In the present work, however, our arguments rest fully on the presence of age populations.

4 Results

Based on the percentages of monocrystalline quartz, feldspar and aphanitic rock fragments, the investigated sandstones of the Schlieren Flysch Group are classed as quartz-rich arkoses and lithic arkoses (Folk 1974). In the ternary Qm-F-Lt plot, revealing the larger scale tectonic position and type of basement in the source areas (Dickinson 1985), a main derivation of the siliciclastic material

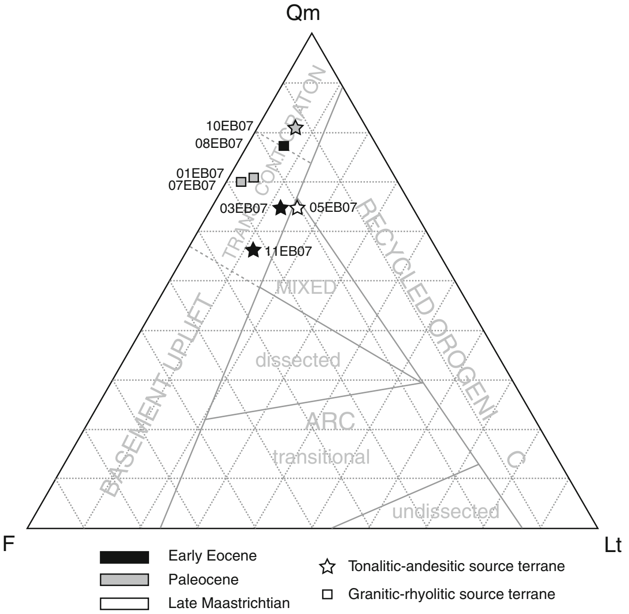


Fig. 3 Sandstone modal compositions of investigated samples according to chronostratigraphic age and clastic source terrane. After Dickinson (1985). Key: monocrystalline quartz, Qm; feldspar, F; total aphanitic lithoclasts, Lt

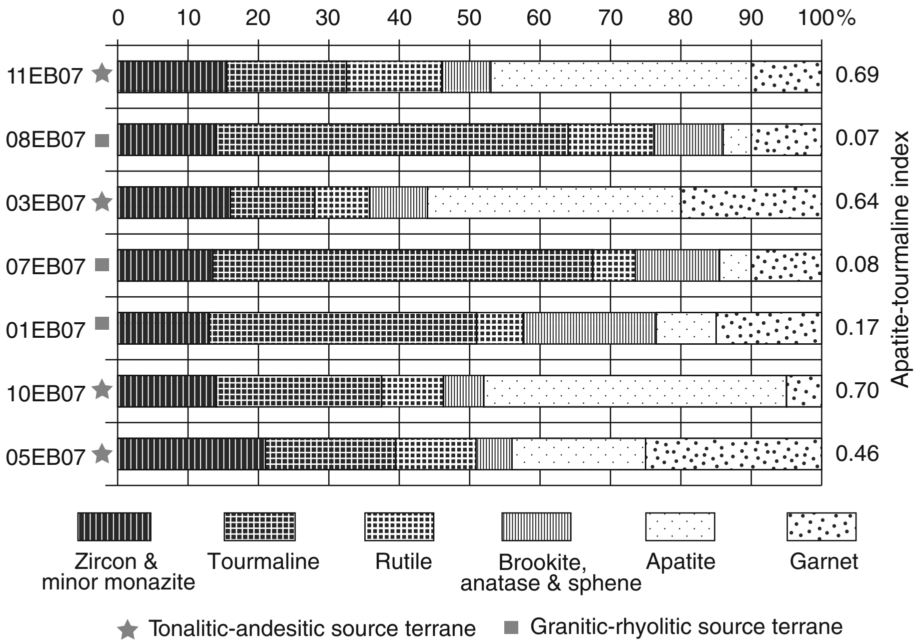


Fig. 4 Heavy mineral frequencies in investigated sandstone samples. The source terranes and the apatite–tourmaline index (ATi) for each sample is indicated (*right column*)

from transitional continental and cratonic basement is suggested (Fig. 3). This is in line with earlier studies in the Gurnigel Nappe between Lake Geneva and Central Switzerland (Winkler 1983, 1984; Winkler et al. 1985b). The analysis of conglomerate and breccia pebble petrography in the Schlieren Flysch Group indicates abundant dolomite, minor Late Jurassic radiolarian chert, and Early to Late Cretaceous pelagic limestone clasts (Winkler 1983), which document the reworking of the Mesozoic sedimentary cover of the source terranes.

The recorded transparent heavy-mineral associations include stable zircon, tourmaline, rutile and other Ti-bearing mineral grains (brookite, anatase and sphene in decreasing abundance), which are combined with 5–25% of garnet (Fig. 4). We distinguish three types of zircons: euhedral, sub-rounded and rounded. Rounded zircons occur in the range of 43–70% with an unweighted mean 55% of the total population. Euhedral zircons amount 10–25% of total zircons with an unweighted mean of 16%. These numbers indicate that an average of 55% of the zircons stem from recycling of older sediments. The prevailing zircon-tourmaline-rutile (ZTR) assemblage together with apatite points to a derivation of the siliciclastic detrital material from continental granitic and intermediate crustal lithologies in general. The presence of garnet, and the lack of other medium- to high-grade metamorphic minerals, may be interpreted to indicate derivation from metamorphic aluminous schistos rocks as also described from the various sections of the Gurnigel Nappe (Morel 1978; van Stuijvenberg 1979; Winkler 1983; Winkler et al. 1985b).

Both petrographic methods support each other by showing source terrane specific apatite-tourmaline indices (ATi = 100 × {apatite/total apatite + tourmaline}; Morton and Hallsworth 1994) depending on the basement composition of the two source terranes (Winkler 1983; Bütler 2009): Sandstones originating from the tonalitic–andesitic source are characterized by higher occurrences of apatite (ATi = 50–75), and such from the granitic-rhyolitic source are clearly enriched in tourmaline (ATi = 8–18). Consequently, the ZTR index is higher in samples from the granitic-rhyolitic source terrane (Fig. 4). Another discriminating feature is the nearly exclusive presence of (Triassic) dolomite lithoclasts in conglomerates of the tonalitic–andesitic source terrane (Winkler 1983).

We observe a wide range of U/Pb ages for the detrital zircons including also particularly old grains (Fig. 5). The latter can be identified also in heavy mineral mounts by their metamictic aspect due to protracted radioactive damage. Such Proterozoic grains (older than 800 Ma with maximum ages up to 1.9 Ga) do not form clear populations. This suggests (multicyclic) reworking of this very stable mineral, presumably by sedimentary processes into Palaeozoic and younger sediments. The presence of low-grade metamorphic sandstones, quartzites, phyllites and gneisses in conglomerates and breccias (Winkler 1983) would support this suggestion.

Otherwise, two major populations and a minor one are well defined in the age histograms and probability curves in Fig. 5. Compound populations of Late Neoproterozoic to Early Paleozoic zircon grains show significant peaks between 585 and 425 Ma. Independent of the number of zircons dated in the different samples, a general decrease of Devonian detrital zircons ages separates the older group from a younger one showing peaks from 345 to 315 Ma

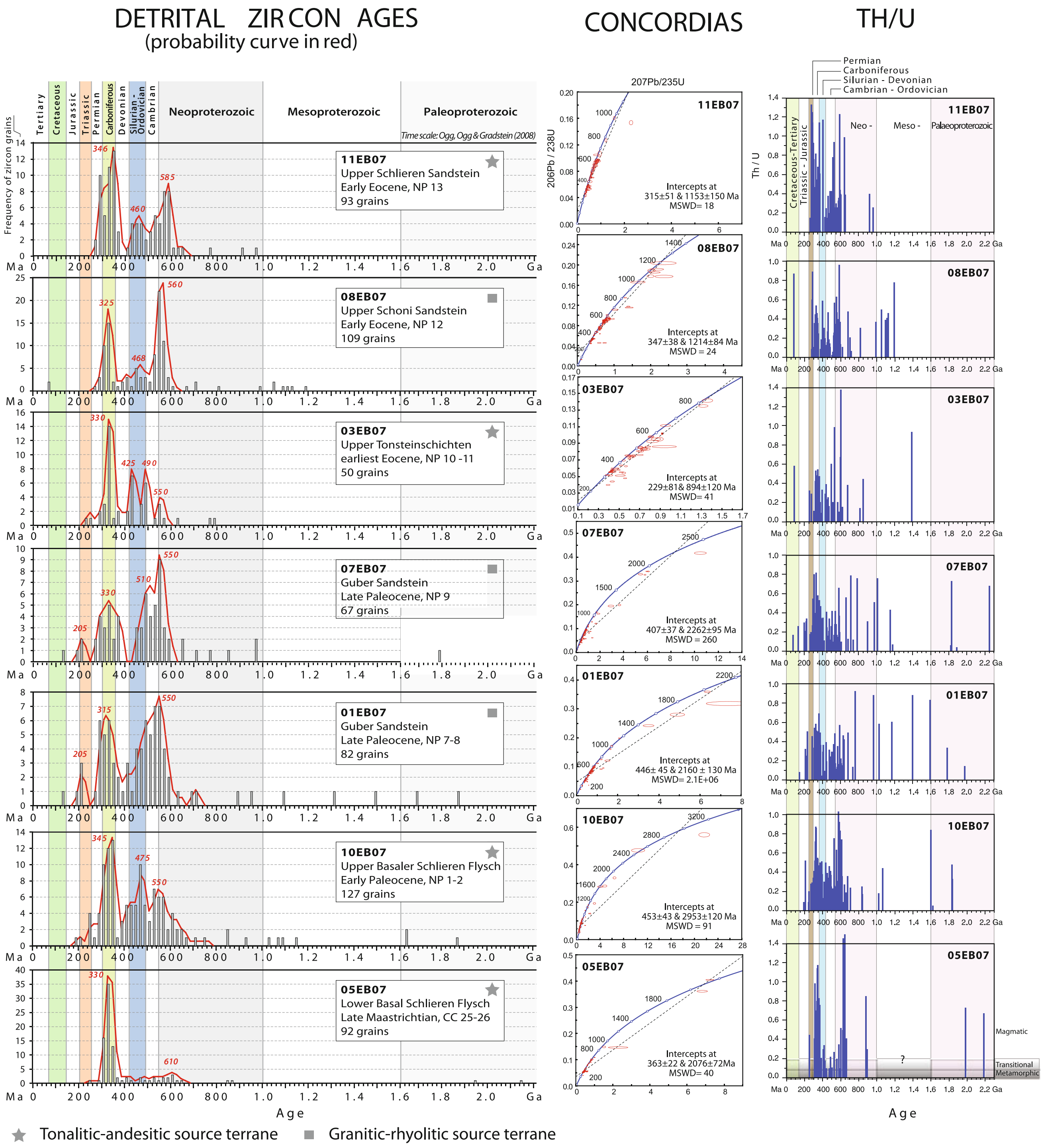
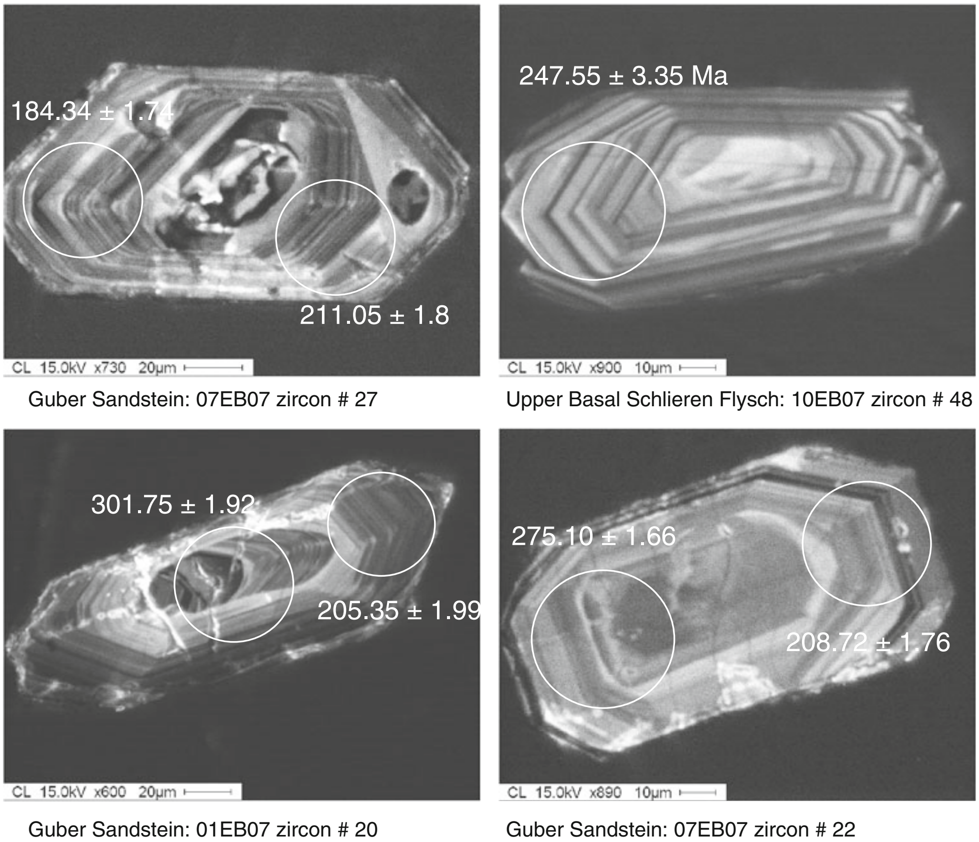


Fig. 5 Detrital zircon age histograms and probability curves, concordia diagrams and Th/U ratios according to ages of zircons. Time scale after Ogg et al. (2008)

within the Carboniferous period (Middle Mississippian to Early Pennsylvanian).

Triassic to Early Jurassic (in the limits of errors) zircons represent a third, minor population peaking at about 205 Ma (Late Triassic, Norian). This population is discerned by 2.7, 2.3 and 5% of total zircons in the two samples from the Guber Sandstein and the one of the Upper Basal Schlieren Flysch, respectively (Fig. 5). The percentage of zircons increases with the total number of zircons dated in the samples as proposed by Vermeesch (2004). In Fig. 6 a selection of dated zircons is given. They generally show a idiomorphic habit and may contain older



Guber Sandstein: 07EB07 zircon # 27

Upper Basal Schlieren Flysch: 10EB07 zircon # 48

Guber Sandstein: 01EB07 zircon # 20

Guber Sandstein: 07EB07 zircon # 22

Fig. 6 Selection of detrital zircons yielding Triassic to Early Jurassic U/Pb ages in sandstones of the Schlieren Flysch

cores. Both sandstone types, wether supplied from the granitic–rhyolitic or the tonalitic–andesitic source terrane, contain sporadic, Cretaceous zircons, but their origin remains enigmatic.

Sandstones derived from the granitic–rhyolitic (K-feldspar and plagioclase-bearing) source terrane show a relative high number of Pan-African zircons (Fig. 5, samples 01-, 07- and 08EB07). By comparison, in sandstones originating from the tonalitic–andesitic (exclusively plagioclase-bearing) source terrane, zircons from the Variscan orogenic cycle show a higher abundance (Fig. 5, 05-, 10- and 0311EB07). The detrital zircons dated in the lower Basal Schlieren Flysch show a clear dominance of Variscan ages compared with all younger samples. Thus, the basement of its hinterland source presumably had a quantitatively different lithostratigraphic composition, which could not be resolved by standard sandstone petrography methods (modal composition and heavy minerals).

Th/U ratios of the detrital zircons may be used for discriminating magmatic from metamorphic zircons (Rubatto and Gebauer 2000; Hoskin and Schaltegger 2003). In addition, metamorphic zircons are not zoned. However, the geochemical limits are a matter of debate (pers. comm. U. Schaltegger 2011). In the Schlieren Flysch samples, an average of 63% of the zircons reveal ratios Th/U >0.2 and may mainly originate from igneous rocks. A minority of 16% shows Th/U ratios <0.1 pointing to a derivation from metamorphic rocks. 21% of the zircons lay in a transition zone Th/U = 0.1–0.2, which according to Hoskin and Schaltegger (2003) and D. Rubatto (pers. comm. 2010) rather can be attributed to crystallization from melts. In summary, according to geochemistry, the majority of the dated zircons have a magmatic origin, which is also supported by the minor occurrence of non-zoned zircons and rims visible in the relevant cathodo-luminescence pictures (Bütler 2009).

5 Discussion and interpretations

We demonstrate that two major zircon age populations record the two sediment sources of the Schlieren Flysch. The older, composite population approx. covers the periods Cryogynian–Edicaran (Neoproterozoic)–Cambrian–Ordovician (ca. 650–450 Ma). These ages correlate with the Pan-African thermal and orogenic event (650–450 Ma), during which at ca. 500 Ma various mobile belts were accreted between continental blocks forming the later Gondwana supercontinent (e.g., Kröner and Stern 2004). This suggests that high volumes of igneous rocks of the Pan-African orogenic cycle (Cadomian in Europe) and/or recycled products were exposed in the source areas of the

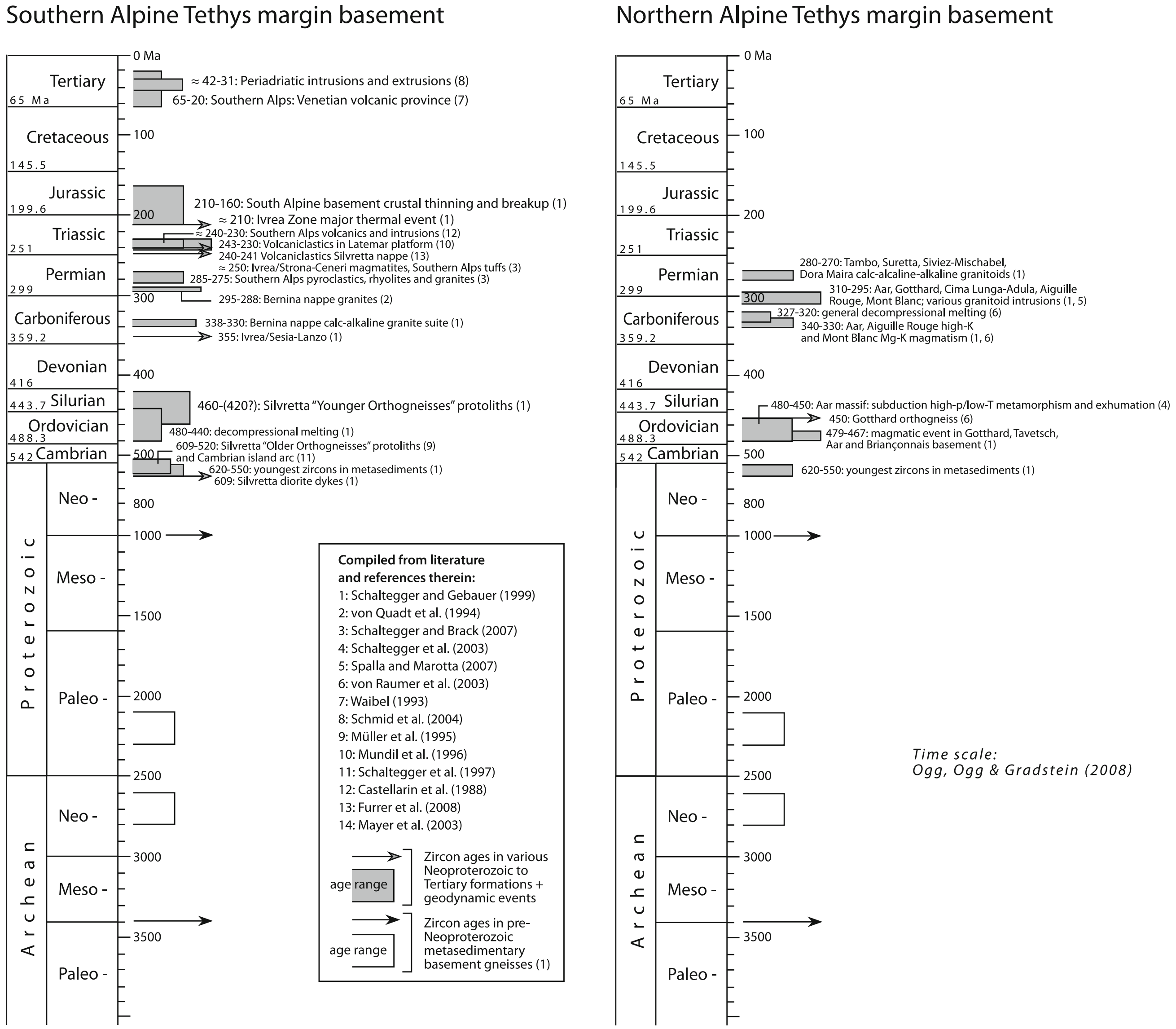


Fig. 7 Compilation of igneous, metamorphic and geodynamic events recorded in the basement of the northern and southern margins of the Alpine Tethys. The variable length of the *horizontal bars* is only chosen for better readability

Schlieren Flysch. A possible source could have been equivalents of the volcaniclastic and magmatic series of the Ouarzazate and Anti-Atlas supergroups today outcropping in the Anti-Atlas of Marocco (e.g., Gasquet et al. 2005).

The younger Carboniferous (ca. 360–320 Ma) zircon populations indicate the derivation of the detrital material mostly from igneous rock formed during the Variscan thermal and magmatic events (e.g., von Raumer et al. 2003) involving parts of Africa, Americas, Europe and Baltica. Both age populations are recognized in the basement of the Alpine orogeny (Fig. 7) as well as the lack of Devonian geochronological data in the southern and northern basement of the Alpine orogen. This time is known as the extensional period in the Variscan orogeny, often recorded by carbonate platform development. The pronounced shape of the detrital zircon age histograms with a clear differentiation between Precambrian-Early Paleozoic and Variscan ages, underlined by the recurring lack or low abundance of Devonian zircons, suggests that these basement complexes represented the primary sources. However, with respect to the high abundance of rounded zircons, a considerable part of the dated zircons most probably was recycled from Late Palaeozoic Variscan or younger sediment series.

An attempt at finding discriminating arguments for the derivation of the clastic material from the northern or southern Alpine Tethys margin needs a thorough compilation of data on the geochronology of igneous, metamorphic and geodynamic activity documented in the margins as depicted in Fig. 7. Both margins show quite similar successions of pre-Alpine events. This is not surprising, because the northern and southern basement was only separated by rifting and spreading during the Mesozoic–Early Cretaceous, but had a common history before. However, at the present state of knowledge, for example, Silurian events as the "Younger Orthogneiss" protoliths in the Silvretta Nappe of the southern margin are not known from the northern margin. Triassic igneous events and related volcaniclastic deposits, whose geodynamic significance is still under discussion, are only evident from the southern Alpine Tethys margin (Fig. 7, e.g., Castellarin et al. 1988; Mundil et al. 1996; Schaltegger and Gebauer 1999; Furrer et al. 2008). On the other hand, from the northern margin, a higher quantity and continuity of data on Carboniferous–Permian magmatic events is documented (references in Fig. 7). It is difficult to evaluate wether these differences are real or an effect of incomplete investigation. However, preliminary data from the Early–Middle Jurassic, rift-related Levone series in the Canavese zone (Ferrando et al. 2004), contain a number of contemporaneous zircons. The bulk of zircons match Variscan and Pan-African ages (A. Beltrán, personal comm. 2011) as in the Schlieren Flysch. In our view, the detection of a minor population of Triassic–Early Jurassic detrital zircons in sandstones of the Schlieren Flysch may be indicative of reworking of Triassic and Jurassic rift sediments into the Schlieren Flysch basin, i.e., the sourcing in the southern margin of the Alpine Tethys.

Thus, there will be a strong need to further quantify the geochronology of detrital zircons in various extension- and convergence-related Alpine sediment series (project in progress) to test existing palaeogeographic models.

The Gurnigel Nappe is known to contain also millimetre scale yellow and white bentonitic ash layers of Late Maastrichtian to Early Eocene age (Winkler et al. 1985a, 1990). They are characterized by the presence of airborne euhedral zircons, apatites and minor biotites. One Selandian bed in the Schlieren Flysch (biostratigraphically correlated with the Palaeogene nannofossil zone NP 5) had been dated by the zircon fission-track method at 57.8 ± 2.7 Ma (Winkler et al. 1990). In the present study, a special effort was made to find contemporaneous zircons also in turbiditic sandstones. However, no significant evidence for Tertiary zircons was found. Probably, the contribution of the volcanic sources was volumetrically very small and/or the number of dated zircons was insufficient.

In summary, the detection of a Triassic–Early Jurassic detrital zircons, together with various sedimentologic evidence and sedimentary transport indicators, would confirm the position of the detrital sources of the Schieren Flysch basin on the southern Alpine Tethys margin. Further petrographical support is provided by the presence of radiolarian chert and abundant dolomite clasts, which are typical for Late Jurassic and Triassic pre-flysch formations in the Austroalpine and South Alpine realms.

6 Conclusions

Laser ablation ICP-MS U/Pb dating of single detrital zircons from the Schlieren Flysch series are in line with standard petrographic provenance analysis and completes them with important information on the geochronology of the clastic source terranes. A multicycle reworking of a part of detrital zircons via erosion of clastic sediment formations pre-dating the Schlieren Flysch deposition must be accounted for.

1. The turbidite beds of the Schlieren Flysch series were dominantly supplied from Pan-African (650–450 Ma) and Variscan (360–320) basement source terranes and their sedimentary covers. A reworking of Pan-African and older zircons via erosion of Palaeozoic clastic sediments is likely.
2. The bimodal supply of the Schlieren Flysch basin is matched by variable feldspar contents and transparent heavy mineral frequencies in the turbiditic sandstones, and by the quantitative age patterns of the detrital zircons.
3. The dominance of Pan-African zircons in sandstones derived from the granitic–rhyolitic source terrane well distinguishes them from sandstones supplied from the tonalitic–andesitic source area where Variscan zircons are more abundant.
4. A minor Triassic–Early Jurassic detrital zircon population is recorded, which can be attributed to reworking of igneous formations present in the Southern Alps, probably related to the rifting stage of the Alpine Tethys.
5. The sum of arguments including sedimentological, petrographical and geochronological results suggests that the source terranes were situated on the southern margin of the Alpine Tethys.
6. Similar investigations in sandstone formations related to rifting, drifting and convergence in the Alpine Tethys are strongly required for refining the palaeogeographic model.

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