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Dropstones in Rosso Ammonitico-facies pelagic sediments of the Southern Alps (southern Switzerland and northern Italy)

Daniel Bernoulli[1,2] · Peter Ulmer[1]

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Abstract Sparse isolated pebbles and cobbles of extraformational lithologies are occasionally found in fine-grained deep-water sediments. In the Middle and Upper Liassic deep-water marly limestones and marlstones of Rosso Ammonitico facies (Morbio and Rosso Ammonitico Lombardo Formations) in the western Southern Alps, Lombardy and Ticino, outsized 'exotic' clasts of volcanic and basement rocks occur sporadically. The clasts, of pebble size, are typically rounded. The rhyolitic volcanic clasts can be related to the Permian volcanic succession of the western Southern Alps, from which they must have been reworked; a quartzite pebble is obviously derived from the Hercynian basement. The clasts are best interpreted, in analogy to other occurrences, as dropstones transported to the site of final deposition by drift wood that occasionally occurs in the pelagic sediments. The only possible source area must be situated to the west of Lago Maggiore where the Permian volcanic suite was exposed in a fault block uplifted in the course of latest Triassic–Early Jurassic rifting.

Keywords Dropstones · Permian volcanics · Rosso Ammonitico Lombardo · Liassic · Southern Alps · Palaeogeography

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✉ Daniel Bernoulli
daniel.bernoulli@unibas.ch

1 Department of Earth Sciences, Swiss Federal Institute of Technology, ETH-Zentrum, 8092 Zurich, Switzerland

2 Institute of Geology, University of Basel, Bernoullistrasse 32, 4056 Basel, Switzerland

1 Introduction

Dropstones form typically outsized extraformational (exotic) clasts in a fine-grained matrix. They share this characteristic with the exotic clasts of mud-supported mass-flow deposits and blocks in sedimentary and tectonic mélanges; however, the mostly undeformed depositional texture of the host sediment and the sedimentary association distinguish them clearly from the latter. Of course, dropstones can be involved in later mass flows affecting the host rock. The 'hydrodynamic paradox' (Bennett et al. 1996) created by the juxtaposition of outsized clasts and fine-grained un-deformed matrix can be resolved, in the case of dropstones, by the vertical gravitational emplacement of the clasts from some sort of raft. Dropstones have generally been related to ice-rafting (Peach 1912); however, transport by plants, roots, kelp, marine reptiles, mammals and birds or floatation are well documented (Emery 1955; Bennett et al. 1996, and references therein).

This paper documents a few exotic outsized clasts from the Middle and Upper Liassic Rosso Ammonitico-type pelagic sediments of the western Southern Alps. Two of the clasts have previously been mentioned (Leuzinger 1926; Vonderschmitt 1940; Bernoulli 1964), and similar occurrences were described from Middle Jurassic and Cretaceous pelagic successions of the Trento Plateau in the eastern Southern Alps (Trener 1910; Sturani 1964; Sorbini 1967; Sauro 1971; Massari and Savazzi 1981; Cestari et al. 2013).

2 Regional context

The Southern Alps present a complete transect of a passive continental margin of the Alpine Tethys floored by Hercynian continental crust and post-Hercynian Permian intrusive and volcanic rocks (Bernoulli et al. 1979; Winterer and Bosellini 1981; Bertotti et al. 1993; Berra et al. 2009; Fig. 1). Latest Triassic to Early Jurassic polyphase rifting along mainly N–S-trending faults segmented and disintegrated a Triassic sediment wedge, open to an oceanic domain in the east (Meliata, Vardar, Maliac) and extending over much of the peri-Adriatic area (Fig. 4 in Laubscher and Bernoulli 1977). Extension led to the formation of asymmetric deeper marine rift basins, separated by submarine highs on which only limited amounts of syn-rift sediments accumulated (Fig. 1b). In the Middle–Late Liassic, extensional tectonics shifted from the future proximal margin to the distal areas and finally, in the Middle Jurassic, to the opening Liguria–Piemonte ocean to the north and west (Manatschal and Bernoulli 1999; Ferrando et al. 2004; Manatschal 2004; Berra et al. 2009). By the end of rifting, in the Middle–Late Jurassic, the western and central segments of the margin had subsided to bathyal depth with pelagic sediments covering the syn-rift sediments. Sedimentation rates that were high in the basin during rifting were strongly reduced to the order of a few mm/10^3y (compacted) during thermal subsidence. A stratigraphic scheme of the pre-, syn- and postrift formations of the western Southern Alps is given in Table 1.

3 The exotic clasts

Four different lithologies could be distinguished amongst the exotic clasts. For locations see Fig. 1.

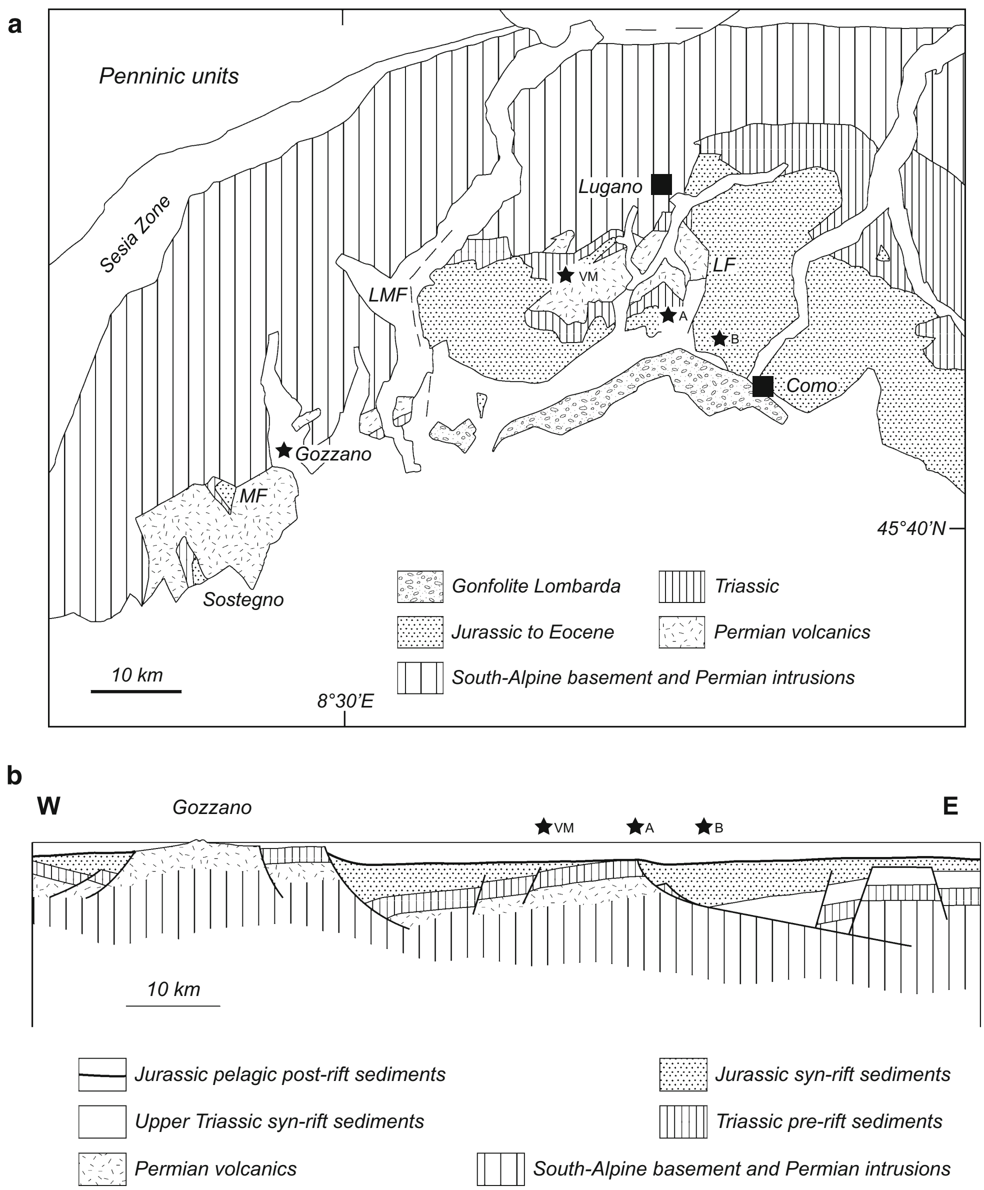


Fig. 1 **a** Schematic geological map of the western Southern Alps with the locations of the dropstones. **b** Palinspastic cross-section across the same area for Middle to Late Liassic (Pliensbachian–Toarcian) times. Locations on **a** and **b** are as follows: *A* Arzo, *B* Breggia, *LF* Lugano Fault, *LMF* Lago Maggiore Fault, *MF* Monte Fenera, *So* Sostegno, *VM* Val Molinaccio

Table 1 Stratigraphic scheme of the Permian to Early Jurassic succession of the western Southern Alps. Data from Bernoulli (1964), Kälin and Trümpy (1977), and Berra et al. (2009)

		Sostegno-M. Fenera	Gozzano	Monte Nudo Basin	Lugano High	Generoso Basin
Late Liassic	Toarcian–Aalenian	"Calcari spongolitici"		Valmaggiore Fm.	Rosso Ammonitico Lombardo	
Middle Liassic	L. Pliensbachian E. Pliensbachian	San Quirico Sst. Sostegno Breccia ?	? Besazio Limestone	Molino Member	Morbio Formation Besazio Limestone	Morbio Formation Molino Member
Early Liassic	Sinemurian Hettangian		Broccatello	Moltrasio Formation	Saltrio Fm. Broccatello	Moltrasio Formation
Late Triassic	Rhaetian	Gap		Campo dei Fiori Dol.	Tremona Series	Albenza Formation Rhaetian Formations
	Norian Carnian		Gap	Dolomia Principale Pizzella Marls	Dolomia Principale Pizzella Marls	Dolomia Principale
Early-Middle Triass	Anisian–Ladinian Anis.-E. Triassic?	Salvatore Dolomite		Salvatore Dolomite Bellano Formation	Salvatore/Meride Lst. Bellano Formation	Late Triassic to Liassic detachment fault
Late Permian						
Early Permian		Volcanics	volcanics	volcanics	volcanics	
Pre-Permian		Hercynian basement				

Syn-rift sediments in blue | Stratigraphic gap

Samples 1 and 2 originate from an outcrop of alternating nodular marly limestones and marls of the Toarcian–Aalenian Rosso Ammonitico Formation south of the village of Arzo (coordinates of the Swiss Topographic Map: 716′600/081′280). Above a pebbly mudstone with clasts of marly limestones of late Pliensbachian age, well-bedded red, nodular marly limestones and marls are exposed; they are dated by marine nannoplankton and ammonites to the Toarcian. Inserted into slump-folded limestones and marls of the same lithology and age are large, non-bedded masses of red marly limestones with a Pliensbachian nannoflora. Both samples come from these redeposited red marly Pliensbachian limestones; however, the isolated clasts are not related to the mass-flow processes that affected the fine-grained sediment into which the clasts had been previously included. They can therefore safely be considered to be dropstones.

Sample 1 is a subrounded pebble of rhyolite, 5.3 cm across with a pitted surface and adhering relics of the marly limestone hostrock with Pliensbachian nannofossils (Fig. 2a). The rhyolite exhibits a porphyritic texture and a microfelsitic matrix composed of quartz and feldspar. Phenocrysts are composed of (1) clear subhedral quartz, locally displaying embayment; (2) euhedral alkalifeldspar with Karlsbad twinning, partly zoned and strongly sericitized; (3) minor idiomorphic plagioclase is characterized by polysynthetic twinning and partly sericitized. Average anorthite-content is around An_{25}. Minor biotite has completely been transformed to fine-grained aggregates of sericite and opacs (Fe-oxides) (Fig. 3a, b).

Sample 2 is an elongate, rounded pebble of white quartzite, 7.2 cm long (Fig. 2c). It comes from a slightly deformed quartz vein. Large (~1–10 mm) quartz grains, recrystallized by subgrain rotation, and many subgrain boundaries are parallel to the trace of the prism planes. Prism-plane parallel subgrain boundaries can be related to the activity of the basal<a> slip-system. The activity of basal<a> slip-system together with the subgrain rotation recrystallization mechanism is usually observed in rocks deformed at about mid-greenschist facies conditions at ~400 °C (Stipp et al. 2002; Passchier and Trow 2005). The microstructure is locally overprinted by bulging recrystallization, mostly along the boundaries of deformed grains, which in places also show an undulous extinction. This overprint can be interpreted to have occurred at lower grade conditions at ~300–400 °C or higher strain rates (Stipp et al. 2002; Passchier and Trow 2005).

Sample 3 has been collected by A. Buxtorf and mentioned by P. Leuzinger (1926) from Val Molinaccio, 1 km west of Bédero north of Varese (Fig. 1, ~704′420/085′325, Fig. 2b) from the Molino Member (Pliensbachian, Wiedenmayer 1980) of the Moltrasio Formation (Sinemurian–Pliensbachian). It is a rounded pebble, 6 cm across, with a smooth surface. The rock is a rhyolite characterized by a porphyritic texture and a hemicrystalline matrix exhibiting devitrification, locally even perlitic

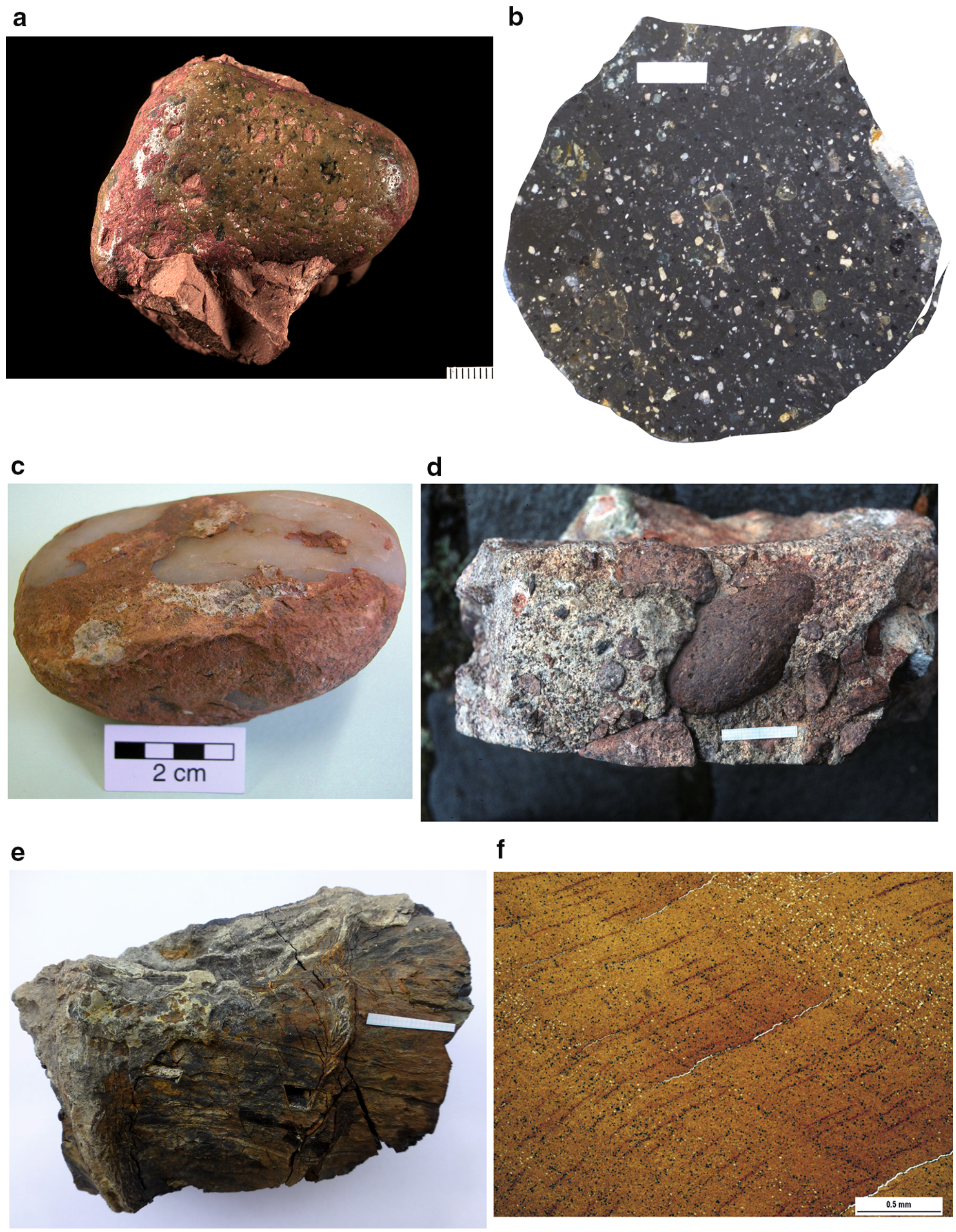


Fig. 2 **a** Rhyolite pebble from slump of marlstones of Morbio Formation (upper Pliensbachian) in Rosso Ammonitico Lombardo (Toarcian), Molinello, Arzo, *scale bar*: 8 mm; **b** rhyolite pebble from the Molino Member, Pliensbachian, Val Molinaccio, Varese, polished surface, *scale bar*: 1 cm; **c** quartzite pebble, Rosso Ammonitico Lombardo (Toarcian), Molinello, Arzo; **d** Rounded and angular clasts of rhyolite in matrix of crinoidal lime grainstone, Broccatello Formation, Sinemurian, Gozzano; the Liassic Gozzano High where the Broccatelo Formation unconformably overlies the Permian rhyolite succession is the probable source area of the dropstones, *scale bar*: 2 cm; **e**. Wood fragment, Rosso Ammonitico Lombardo (Toarcian), ancient cement factory, Ponte Chiasso, *scale bar*: 2 cm; **f**. Thin-section of e showing the well-preserved wood texture, Nicols parallel

textures around pheno- and microphenocrysts. Fluidal textures are observed in the devitrified matrix in which some coarser grained fragments, most likely volcanic (rhyolitic) lithic clasts are observed. The phenocryst assemblage is composed of (1) subidiomorphic clear quartz grains with very little rounding and some embayments; (2) sanidine with Karlsbad twinning, optically nearly uniaxially negative indicating Na-sanidine; (3) little plagioclase that is polysynthetically twinned and strongly sericitized; and (4) biotite relics mostly transformed but locally preserved with strong pleochroism (dark brown–light brown) and rimmed by fined-grained Fe-oxides. Overall, the aspect of the rock corresponds to an ignimbrite (Fig. 3c, d).

Sample 4 is a fragment of a larger, angular clast (5 × 25 × 35 cm, Vonderschmitt 1940) from the lower part of the Rosso Ammonitico Lombardo Formation (Toarcian–Aalenian) exposed in the gorge of the Breggia River southwest of the village of Morbio superiore (Fig. 1, 722′450/079′910; Vonderschmitt 1940; Bernoulli 1964). The clast is a crystal-rich fragment of a rhyolite with a porphyritic texture and a microfelsitic matrix composed of quartz and feldspar. Phenocrysts are: (1) clear subidiomorphic quartz crystals with embayments and melt inclusions; (2) polysynthetically twinned plagioclase (An_{25}) partly replaced by saussurite and sericite, many crystals are broken; (3) alkalifeldspar with Karlsbad twins, some perthitic exolutions, but still exhibiting sanidine optics (nearly uni-axial, negative); and (4) biotite completely replaced by chlorite and Fe-oxides (Fig. 3e, f).

4 Discussion

4.1 Provenance of the exotic clasts

Macroscopically, the described volcanic exotic clasts bear very close similarities with rocks occurring in the Permian volcanic succession of the Southern Alps. We therefore compared them to clasts of Permian volcanics occurring in the Liassic Broccatello Formation at Gozzano (Fig. 1). The Gozzano area is a potential source area of the clasts, because the Broccatello Formation unconformably overlies the Permian volcanics at this locality (Senn 1924; Montanari 1969; Berra et al. 2009). Moreover, rounded pebbles from Gozzano (Fig. 2d) are in proportions, size and shape very similar to samples 1 and 3 (Fig. 2 a, b).

Sample 1 (Arzo, Fig. 3a, b) compares directly with samples from Gozzano (Fig. 4e, f) with subhedral clear quartz, simply twinned alkalifeldspar and very minor and strongly altered plagioclase.

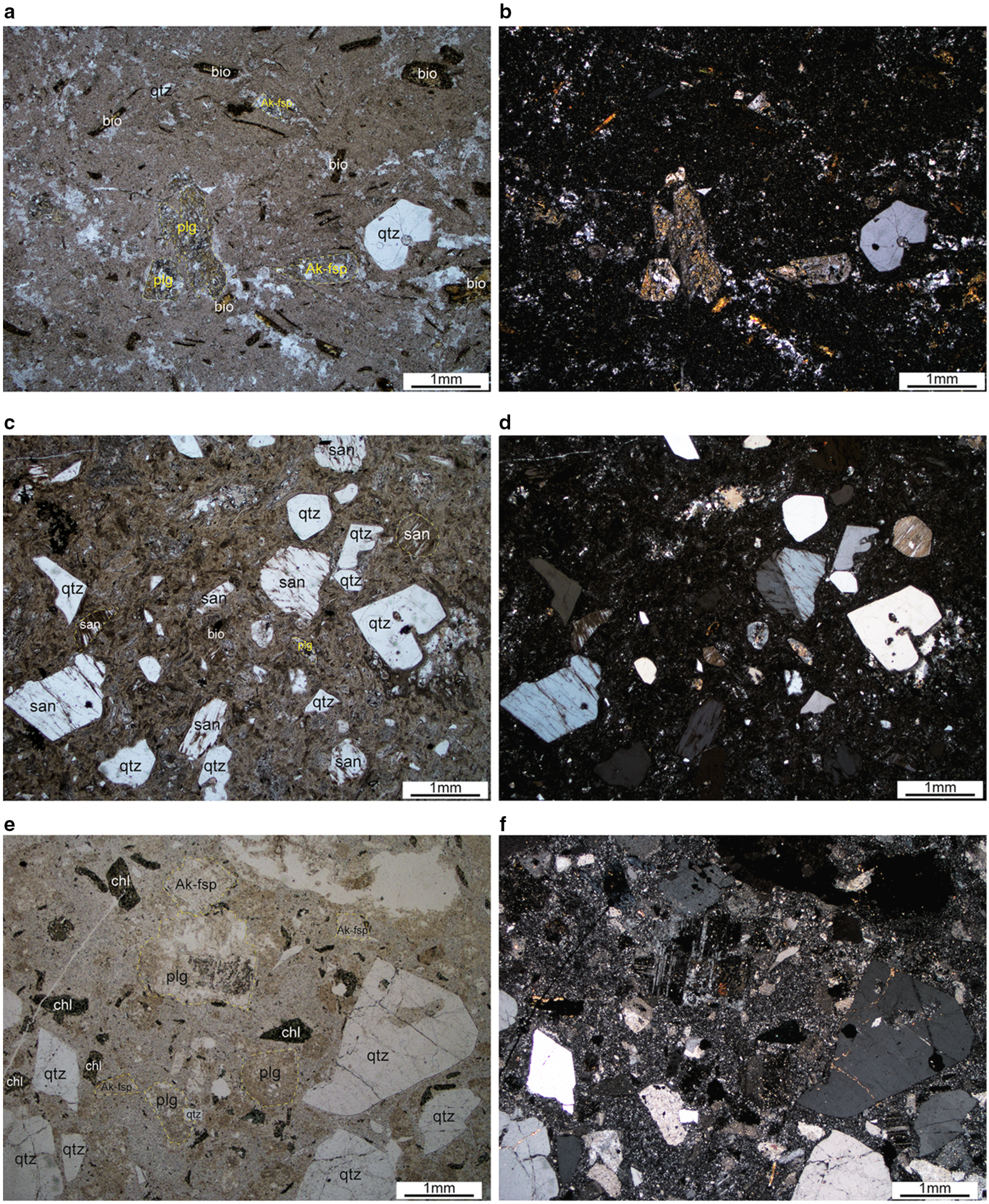
The quartzite (*Sample 2*, Arzo) shows no particular signatures that would reveal its provenance. Its texture and metamorphic overprint are identical to those of quartzites occurring ubiquitously in the Hercynian basement of the Southern Alps and, as pebbles occurring in the Anisian (?partly Lower Triassic) Bellano Formation that overlies the Permian volcanics and the Hercynian basement unconformably in the potential source area (Monte Fenera).

Sample 3 (Val Molinaccio) has already been compared by Leuzinger (1926) with a dark 'quartz porphyry' (rhyolite) from Gozzano described by Kaech (1904). The close resemblance is evident comparing Fig. 3c, d with Fig. 4a, b from Gozzano both displaying subhedral quartz and sanidine in a devitrified felsitic matrix with fluidal texture and some volcanic lithic clasts; plagioclase is a very subordinate phenocryst phase, whereas variably altered biotite is ubiquitous.

Sample 4 (Breggia, Fig. 3e, f), a crystal-rich rhyolite, possibly a 'block-and-ash' flow, strongly resembles the samples from Gozzano displaying the same general features of the volcanic fragments and single crystals including a devitrified felsitic matrix, subhedral embayed quartz, idiomorphic alkalifeldspars (Na-sanidine), biotite in various stages of alteration, and minor strongly altered polysynthetically twinned albite-rich plagioclase. It shows strong resemblance in mineralogy and texture with Figs. 4c, d from Gozzano.

Overall, the lithologies of the exotic volcanic clasts are indistinguishable from those of the rhyolite samples from Gozzano that most probably represent fragments of proximal ignimbrite, rhyolitic breccias, block-and-ash flows and/or lava flows and domes all exhibiting identical phenocryst assemblages and very similar textures. The only difference between some of the exotic clasts and the Gozzano samples investigated for comparison is the higher proportion of plagioclase phenocrysts in some but not all exotic clasts compared with the reference samples from Gozzano, i.e. they might be slightly less differentiated, more rhyodacitic than rhyolitic, however still clearly within the typical compositional range of the Permian volcanics in this area.

The correlation of the exotic clasts with volcanic rocks of the Gozzano High appears to fit very well with the palaeotectonic evolution of the western Southern Alps. East of Lago Maggiore (Fig. 1; Table 1), the Permian volcanic succession was covered everywhere during Middle–Late Liassic times by Triassic pre-rift and Lower Jurassic syn-rift deposits. Therefore the exotic clasts cannot be derived from this area. By contrast, during Early–Middle Liassic time and possibly later, Middle Triassic and Permian volcanics were exposed along the future distal continental margin. Along an uplifted rift shoulder, west of the ?Late Triassic–Early Jurassic Lago Maggiore fault (Cusio zone of Berra et al. 2009), the Middle Triassic carbonate sediments were removed by sub-aerial erosion, and the Permian volcanics are covered unconformably by Liassic sediments. At Gozzano, they are covered by Lower Liassic (Upper Sinemurian) crinoidal limestones (Parona 1892; Senn 1924; Sacchi-Vialli and Cantaluppi 1967; Montanari 1969; Berra et al. 2009) that, in terms of facies and fauna are identical with the Lower Liassic (Sinemurian) Broccatello Formation of the Lugano High (Wiedenmayer 1963; Sulser and Furrer 2005). The contact between the limestones and the volcanics is no longer exposed, but, at their base, these limestones include angular to well-rounded pebbles of different volcanic rocks (Fig. 2d). The Sinemurian limestones are in turn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◀ **Fig. 3** Thin-section micrographs of dropstones. **a, b** Sample 1, Rosso Ammonitico Lombardo Formation, Toarcian, south of the village of Arzo (Ticino). The rhyolite exhibits a porphyritic texture and a microfelsitic matrix composed of quartz and feldspar. Phenocrysts are composed of (1) clear subhedral quartz (qtz), locally displaying embayment; (2) euhedral alkalifeldspar (Ak-fsp) with Karlsbad twinning, partly zoned and strongly sericitized; (3) minor idiomorphic plagioclase (plg) is characterized by polysynthetic twinning, partly to strongly sericitized. Average anorthite-content is around An_{25}. Minor biotite (bio) has completely been transformed to fine-grained aggregates of sericite and opacs (Fe-oxides). **c, d** Sample 3, Molino Member of Moltrasio Formation, Pliensbachian, Val Molinaccio, west of Bédero north of Varese. Subhedral quartz (qtz) and sanidine (san) crystals are embedded in a devitrified felsitic matrix with fluidal texture and some volcanic lithic clasts (lit); plagioclase is a very subordinate phenocryst phase, whereas variably altered biotite is ubiquitous. **e, f**, Rosso Ammonitico Lombardo Formation (Toarcian), Breggia River (Ticino); The crystal-rich rhyolite fragment displays a porphyritic texture and a microfelsitic matrix composed of quartz and feldspar. Phenocrysts are: (1) clear subidiomorphic quartz (qtz) crystals with embayments and melt inclusions; (2) polysynthetically twinned plagioclase (An_{25}) partly replaced by saussurite and sericite (plg), many crystals are broken; (3) alkalifeldspar with Karlsbad twins, some perthitic exolutions, but still exhibiting sanidine optics (nearly uni-axial, negative, Ak-fsp); and (4) biotite completely replaced by chlorite (chl) and Fe-oxides. **a**, **c**, **e** Nicols parallel; **b**, **d**, **f** Nicols crossed

unconformably overlain by Pliensbachian micritic deep-water limestones.

The close lithological analogies of the volcanic dropstone clasts with the clasts in the Liassic syn-rift sediments at Gozzano and with the Permian volcanic succession in general leaves little doubt about their derivation from the Gozzano or an equivalent high in the west. Clasts of crystalline basement rocks, together with clasts of Permian volcanics and Middle Triassic dolomites in Liassic sedimentary rocks, testify to the exposure of crystalline basement rocks at the time (Casati 1978; Berra et al. 2009). Indeed, the time interval during which the dropstones were deposited in the east (Pliensbachian–Toarcian) coincides with the time of deposition of sediments in the Piedmont area (Sostegno, Monte Fenera) that also include pebbles of Permian volcanics and Hercynian basement rocks (Sostegno Breccia, San Quirico Sandstone, Berra et al. 2009; see Table 1).

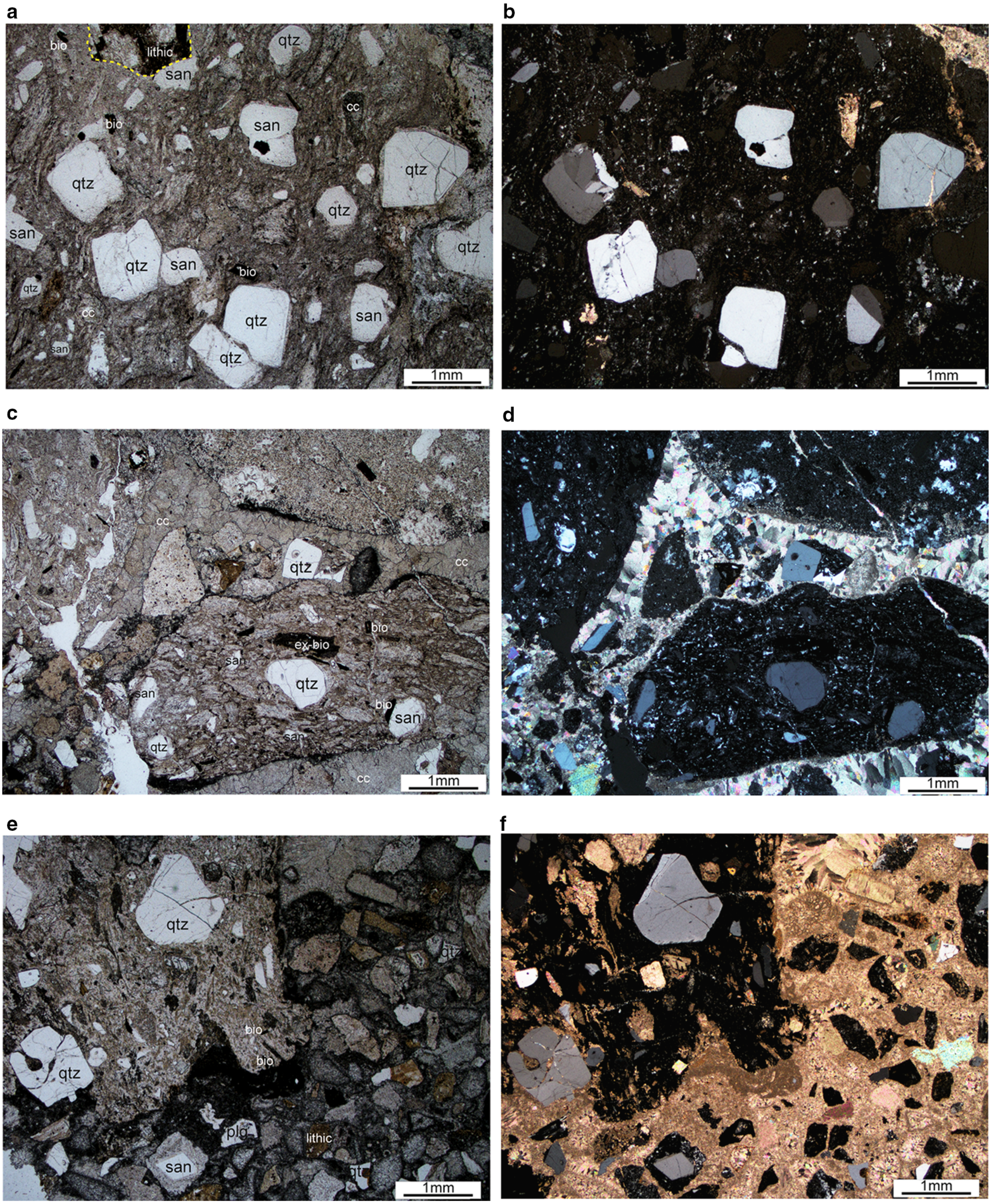
The exotic clasts in the Rosso Ammonitico Lombardo are in part well rounded. Early reworking of the rhyolite and quartzite fragments must have occurred in a river or on a beach. Much of the area west of Lago Maggiore that was emergent in the Early Liassic was occupied by karstified Middle Triassic dolomites (Berra et al. 2009) on which presumably no larger streams developed. At Gozzano, the rounded rhyolite pebbles occur in the lower part of the Lower Liassic crinoidal limestones; granules of rhyolite are, however, present throughout the formation. The depositional environment of this formation was, similar to that of the Broccatello Formation of the Arzo area, a current-swept offshore high near or at the base of the photic zone (Neuweiler and Bernoulli 2005) on which the rhyolite pebbles were concentrated as a residual lag deposit after drowning of the high.

4.2 Transport of the clasts

If the exotic clasts in the pelagic sediments of the central Lombardian Alps are derived from the area west of Lago Maggiore, they must have travelled, as the crow flies, for at least 35 (Val Molinaccio) to 45 km (Breggia). In Middle to Late Liassic times the area to become the western Southern Alps was at approximately 30°N latitude (Scotese 1991). The area was situated in the subtropical climatic belt; the clay mineral associations of the enclosing sediments, dominated by kaolinite, suggest a humid climate (Deconinck and Bernoulli 1991); the occurrence of plant remains (Sordelli 1892; Vialli 1949) and wood fragments (Fig. 2e, f) in the Middle–Upper Liassic sediments testifies to the presence of vegetation on the exposed land surfaces. Ice rafting can therefore safely be excluded as a transport mechanism.

Exotic pebbles including granite, volcanic and metamorphic rocks and serpentinite fragments occur at different locations within and above one and the same Middle Jurassic (latest Bajocian) submarine hardground on the Trento Plateau in the eastern Southern Alps (Sturani 1964; Sauro 1971). The concentration along the same stratigraphic level led Sauro (1971) to postulate an emplacement of these clasts by bottom currents induced by tsunamis, a sort of 'out-runner blocks' (Prior et al. 1982) as observed in submarine gravity-flows or of isolated blocks in hyper-concentrated gravity flows (Zaleha and Wiesemann 2005). However, the fact, that the clasts occur *within* the hardground or directly above it, suggests that the clasts on the hardground may have been accumulating over longer periods of time, an interpretation that is supported by the occasional coating of the exotic clasts by microbial mats (Sauro 1971, his Fig. 1). The concentration of 'erratic' rocks, many of them coated by manganese crusts, occurring on volcanic seamounts off the US West Coast (Paduan et al. 2007) indicates that dropstones may be accumulating on non-depositional surfaces where fine sediment is removed by currents. The exotic clasts described by Sauro (1971) and others from the Trento Plateau may therefore be interpreted as dropstones. Floatation, another mechanism proposed for dropstones (Bennett et al. 1996) may be excluded because this process is restricted to small grain sizes and certain lithologies like pumice.

Rafting of large clasts by drift wood or kelp has been demonstrated by many authors (Emery 1955, 1963, and references therein). Streams and marine erosion bring trees to the ocean; once afloat they can travel for great distances, hundreds of kilometres with the currents (e.g. Pratt 1970).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◀**Fig. 4 a–f** Thin-section micrographs of Permian volcanic clasts in the Broccatello Formation, Sinemurian, Gozzano. **a, b** The rhyolithe sample, displaying subhedral quartz (qtz) and sanidine (san) in a devitrified felsitic matrix with fluidal texture, some volcanic lithic clasts (lithic), subordinate plagioclase phenocrysts, and variably altered biotite (bio) compares well with the rhyolite dropstone from Val Molinaccio (Sample 3, Fig. 3c, d). Small amounts of secondary calcite (cc) occur in the matrix. **c, d** Rhyolitic clasts cemented by sparry calcite (cc). The clasts are composed of subhedral quartz (qtz) and sanidine (san) with minor, partly altered biotite (bio and ex-bio). The very fine-grained, devitrified matrix shows some fluidal texture and minor welding. **e, f** The rhyolite clast with subhedral clear quartz (qtz) with embayments, simply twinned alkalifeldspar (Ak-fsp) and very minor and strongly altered plagioclase (plg) compares well with the rhyolite clast from Arzo (Sample 1, Fig. 3a, b). The clasts are set in a matrix of bioclastic lime grainstone. **a**, **c**, **e** Nicols parallel; **b**, **d**, **f** Nicols crossed

Parts of the trees may become waterlogged and sink to the sea floor. Such trees may transport rocks over large distances. In most instances, particularly in an environment of relatively low sedimentation rates and oxidizing bottom water conditions, no trace of the wood remains; however, in some cases the association of dropstones with the tubes of wood-boring bivalves (Teredinids) as observed in Cretaceous pelagic sediments of the Southern Alps testifies to the former presence of drift wood that had been in the sea long enough for boring organisms to become established (Massari and Savazzi 1981). Similarly, the occurrence of single, isolated shells of rudists in the Scaglia Variegata Formation of the Venetian Alps has been related to transport by plant roots (Cestari et al. 2013). The occurrence of dropstones in clusters that is observed in other Jurassic pelagic sediments of the Alpine Tethys (e.g. Birkenmajer et al. 1960; Sauro 1971) is also in line with a transport by tree roots. In the Rosso Ammonitico Lombardo Formation, wood fragments (Fig. 2e, f), though not directly associated with the dropstones, occur sporadically.

Some researchers (e.g. Johnston et al. 1994) have suggested that smooth, polished or pitted surfaces on isolated clasts may be indicators of gastroliths. Gastroliths occur sporadically and in clusters associated with skeletal remains of marine reptiles (e.g. Schmeisser and Gillette 2009, and references therein); however, in the absence of skeletal material an identification based on surface textures alone remains doubtful (Schmeisser and Flood 2008). We have investigated the surfaces of the dropstones under the scanning electron microscope but could not find textures indicated by these authors as typical for gastroliths. Similar occurrences of randomly dispersed clasts in the Oligocene hemipelagic Scisti Varicolori Formation of the northern Apennines have been interpreted as gastroliths (Pandeli et al. 1998); however, the evidence has been questioned. Rather than 'outrunner clasts' from submarine gravity-flow deposits, as suggested by Donovan and Pickerill (1999), these exotic pebbles, up to 50 cm in length, might be better interpreted as dropstones transported by drift wood. Indeed, the dropstones in question could be derived from the emerged Alpine chain that exposed the lithologies represented by the dropstones (e.g., Garzanti and Malusà 2008) and was certainly, at least partly, covered by forests (e.g. Lorenz 1962; Charrier et al. 1964). We cannot exclude a priori the possibility of gastroliths, but the large size of clasts, 25 × 35 cm in the case of our sample 4; up to 20 and 30 cm of analogous outsize clasts in Jurassic and Cretaceous pelagic sediments in the Southern Alps (Sorbini 1967; Sauro 1971), and up to 45 cm in the Carpathians (Birkenmajer at al. 1960), argues for a transport by drift wood. Indeed, blocks of m-size have been observed in present-day 'floating islands' (Emery 1955). A similar conclusion was reached already by Darwin (1839, p. 549–550) to explain the occurrence of an isolated, well-rounded [volcanic] 'greenstone' fragment in, however, shallow-water carbonate rocks of an atoll near Keeling Island (Cocos Islands, Indian Ocean), an island in which no volcanic rocks are exposed. Although no trace of a tree remained, his conclusion is plausible in view of earlier observations by Chamisso (in Kotzebue 1821, p. 112; von Chamisso 1836, p. 216–217, cited by Darwin 1839), who had observed the association of tree roots with exotic rock fragments on one of the Marshall Islands. Indeed, Darwin's (1839, p. 550) statement 'If a few isolated stones are discovered in a mass of fine sedimentary strata, it cannot, after the above facts, be considered as very improbable, that they may have been drifted there by floating timber of a former epoch' appears to be still valid (although Darwin removed the sentence from later editions of his book).

5 Conclusions

Dropstones observed in the pelagic and hemipelagic Middle to Late Liassic (Pliensbachian–Toarcian) sediments of the Lombardian sector of the western Southern Alps can be related to a source some 40 km to the west in the Piemontese sector of the Southern Alps at or near the village of Gozzano. With all certainty, the outsized, exotic clasts have been transported by driftwood, probably entangled in the roots of conifer trees, to the final site of deposition. An equivalent scenario is suggested for similar occurrences of dropstones in the Jurassic–Cretaceous pelagic sediments of the Southern Alps.

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