The Monte Orfano Conglomerate revisited: stratigraphic constraints on Cenozoic tectonic uplift of the Southern Alps (Lombardy, northern Italy)

Dario Sciunnach*

Regione Lombardia, Direzione Generale Territorio e Urbanistica, Via Sassetti 32/2, I-20124 Milano, Italy. E-mail: Dario_Sciunnach@regione.lombardia.it

Giancarlo Scardia

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano-Pavia, Via Bassini 15, I-20133 Milano, Italy

Fabrizio Tremolada

RPS Energy, RPS Group PLC, Goldsworth House, Denton Way, Goldsworth Park, GU21 3LG Woking, United Kingdom

Isabella Premoli Silva

Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano, Via Mangiagalli 34, I-20133 Milano, Italy

* Corresponding Author

Abstract

The Monte Orfano Conglomerate (MOC), exposed in the foothills of the Southern Alps (northern Italy), is one of the few outcrops of sediments documenting the Cenozoic tectonic evolution of the Alpine retrowedge. Calcareous nannofossil biostratigraphy allowed us to constrain the upper part of the MOC, formerly attributed to the Early-Middle Miocene in the type-locality, to the earliest Miocene (Neogene part of the NN1 nannofossil zone). A likely latest Oligocene age is therefore suggested for the bulk of the underlying conglomerates, whose base is not exposed. Deposition of the MOC can be framed into the post-collisional tectonic uplift of the Alps, documented in the Lake Como area by the

Como Conglomerate (CC) at the base of the Gonfolite Lombarda Group, and supports the correlation with Upper Oligocene clastic sediments cropping out further to the East, in the Lake Garda and in the Veneto-Friuli areas (*“molassa”*). The remarkable difference in petrographic composition between the western (CC) and eastern (MOC) clastics deposited in the Alpine retro-foreland basin highlights the synchronous tectonic activity of two structural domains involving different crustal levels. Whilst the bulk of the CC, that straddles the Oligocene/Miocene boundary, records the tectonic exhumation of the Alpine axial chain crystalline complexes, the coeval MOC consists of detritus deriving from the Alpine retrowedge superficial crustal section (Triassic to Paleogene sedimentary rocks), and constrains the onset of the post-collisional deformation phase of the Southern Alps as not younger than the latest Oligocene.

Key-words: Southern Alps; Cenozoic; calcareous nannofossil biostratigraphy; clastic provenance; shelf fan-delta; retro-foreland basin.

Introduction

Foreland basins are important natural archives of geological information; they are particularly useful to reconstruct the evolution of mountain belts by recording events occurring within the range. Often such events are not preserved in the range itself due to subsequent orogenic uplift and erosion. Thrusting and folding of the foredeep sediments during the late evolution of the orogen commonly exposes them in a belt of foothills.

The present paper focuses on the Alpine retro-foreland basin (Bertotti et al., 1998), that developed since the Oligocene as an effect of the continental collision between the Adriatic and the European plates. Persistent compressional stress after collision caused retro-wedging in the Alpine orogen (Willet et al., 1993; Schmid et al., 1996), backthrusting the Southern Alps towards the Adriatic foreland and implication of the Variscan metamorphic basement and its Permian to Mesozoic sedimentary cover into the post-collisional mountain belt.

Timing of tectonic evolution and deformation in the Southern Alps can be constrained by studying the retro-foreland basin clastic sediments, that recorded the uplift of the Alps at

its southern margin for nearly 20 My, from the Oligocene to the latest Miocene (Pieri & Groppi 1981; Dalla et al. 1992; Schumacher et al. 1997; Sciunnach & Tremolada 2004).
The Monte Orfano Conglomerate (MOC), exposed between Lake Iseo and the city of Brescia (northern Italy), represents one of the few outcropping deposits of the Alpine retro-foreland basin, allowing the study of the Cenozoic evolution of the Southern Alps. The MOC has been often correlated to more or less equivalent clastic sediments cropping out to the west (Gonfolite Lombarda Group: Cita 1957; Gunzenhauser 1985; Bersezio et al. 1993; Schumacher et al. 1997) and to the east ("Lake Garda clastics" in Gunzenhauser 1985; *"molassa" veneto-friulana* of Massari et al. 1986; Stefani et al. 2007), but unfortunately it has not been exhaustively studied for over 50 years after a thorough description by Vecchia and Cita (1954). Therefore, more precise correlations have been hampered by the poor resolution of the biostratigraphic data available for the MOC in the literature, that suggested a general Early to Middle Miocene age (Vecchia and Cita 1954).
New field work, undertaken within the mapping project of the Italian Geological Survey (Sheet 099 "Iseo" at the 1: 50 000 scale: Cassinis et al. 2009), was complemented in the present work with the measurement of stratigraphic sections, sampling of muddy and sandy intervals, and the collection of macrofossils. Analytical work includes arenite petrography as well as calcareous nannofossil and foraminiferal biostratigraphy.
The aim of the present paper is threefold: 1) to refine the biostratigraphic ages for the MOC through the analysis of calcareous nannoplankton, a reliable stratigraphic tool never employed in the study area; 2) to reconstruct a paleotectonic scenario, by defining the structural levels involved in the drainage basin and the depositional setting of the MOC; and 3) to frame the MOC into the regional setting of the Alpine retro-foreland basin, documented by the coeval Cenozoic clastics, presently exposed at the foothills of the Southern Alps or drilled by oil exploration wells in the subsurface of the Po Plain.

Previous studies

"Monte Orfano Conglomerate" is an informal name of long historical standing. It is applied to the mostly conglomeratic succession, that is over 800 m (Vecchia and Cita 1954; Boni and Cassinis 1973) and possibily up to 2000 m thick (Gunzenhauser 1985; Schönborn

1992), and forms the pre-Quaternary bedrock of the whole Monte Orfano, south of Lake Iseo, and of two smaller hills (Badia and Sale) on the western bank of the Trompia Valley, just a few km west of Brescia (Fig. 1). Monte Orfano should not be confused with other isolated reliefs in the Southern Alps, namely Montorfano near Como (consisting of Paleocene conglomerates, Kleboth 1982) and Montorfano near Mergozzo (consisting of post-Variscan granites). In the literature, the term “Montorfano bresciano” has been used as a synonym of Monte Orfano (Gunzenhauser 1985).

The continental nature of the conglomerates at Badia and Sale was recognised earlier based on findings of fresh-water molluscs (Deshayes 1860; Ragazzoni 1862) suggesting an Aquitanian age (Deshayes 1860; Sordelli 1882). Vecchia and Cita (1954) provided detailed lithologic descriptions and biostratigraphic documentation of the Early-Middle Miocene based on benthic (*Cibicides*, *Elphidium*) and planktonic (*Globoquadrina*) foraminifera.

Brambilla and Penati (1987) suggested a subtropical climate and a Miocene (pre-evaporitic Messinian?) age for the Badia deposits by analysing plant macrofossils. New structural interpretations on the Monte Orfano were cursorily provided by Picotti et al. (1997), who reported field evidence of four successive generations of paleostress reconstructed from brittle deformation. The earlier two events were indirectly ascribed to the Middle Miocene (“Valtrompia-Valsugana Phase” of Castellarin et al. 1992).

Geological framework

The study area belongs to the Adriatic Plate, that recorded Variscan deformation and metamorphism during the Carboniferous, followed by continental wrenching and magmatism during the Early Permian. Late Permian to Triassic transgression of continental, transitional and marine sediments culminated in the Early Jurassic rifting of the Alpine Tethys, where deposition of siliceous and calcareous oozes characterised the Middle and Late Jurassic. Early Cretaceous tectonic activity in the Eastern Alps (“pre-Gosau Phase”) caused deposition of thick flysch successions in confined basins up to Campanian times, while pelagic marls in *Scaglia* facies sedimented in protected areas and during quiescence stages, up to the Early Eocene. Middle Eocene to Oligocene reprise of tectonic activity due to subduction of the Alpine Tethys and continental collision between Adria and Europe typically resulted in widespread Periadriatic plutonism and deposition of discontinuous clastic to volcanic successions, until vigorous uplift of the Alps since the Late Oligocene created a thick foredeep succession, that was partly accreted to the orogenic front by a Middle-Late Miocene thrusting "phase" ("Lombardic Phase" of Schumacher et al. 1997).

Among the Oligo-Miocene sediments of the Alpine retro-foreland basin, the MOC is the only formation bridging a wide gap of outcrops between Brianza (north of Milan) and Lake Garda. The Monte Orfano is an isolated relief 452 m high and extending for about 5.4 km from WNW to ESE and 1.2 km from NNE to SSW south of Lake Iseo and south of the frontal anticline ("*flessura pedemontana*"; Bersezio et al. 1993) in which the Mesozoic sedimentary succession of the Southern Alps is widely exposed (Fig. 1; Boni and Cassinis 1973; Cassinis et al. 2009). North of Lake Iseo, the Camonica Valley cuts through the volcanic to clastic succession of Permian age exposed in the Cedegolo and Camuna Anticlines – the latter also named *Massiccio delle Tre Valli Bresciane*; Val Trompia-Val Caffaro basin of Schaltegger and Brack 2007– overlain by a mostly carbonate succession, there of Triassic age (Assereto and Casati 1965). Further to the north, the Paleogene Adamello Batholith (Callegari and Brack 2002) is exposed in the present-day drainage area of the Camonica Valley.

The MOC succession plunges SE to W with an unusual "fan-like" arrangement of the dip of bedding planes (Pl. I), that might partly reflect the original morphology of the clastic body or, alternatively, could result from gentle tectonic buckling with a N-directed hinge line. The succession belongs to the southern limb of a ramp anticline at the front of a buried south-verging thrust represented on the seismic section 6 of Pieri and Groppi (1981), the balanced section H of Schönborn (1992) and the balanced cross-section AA' of Picotti et al. (1997). Sharp lateral truncations of the Monte Orfano to the E and W with a likely triangular facet at the SE end suggest that the thrust front was segmented by NNE-SSW-trending faults, possibly representing oblique ramps.

The base of the MOC is not exposed. In the ENI/Agip exploration well Coccaglio 1, drilled ~ 2 km south of Monte Orfano (Fig. 1), several hundred metres of mudstones with thin intercalations of fine-grained sandstones span the nannofossil zones CP16b to CP18 of Okada and Bukry (1980), which correspond to nearly the whole Early Oligocene (Valdisturlo et al. 1998). In the ENI/Agip exploration well Chiari 1, drilled ~ 4 km south of Monte Orfano, a comparable pelitic facies, less-precisely dated on cuttings, seems to extend up to nannofossil zone NN1, that straddles the Oligocene/Miocene boundary (Valdisturlo et al. 1998, fig. 3).

The Badia and Sale hills are even smaller reliefs, 220.5 and 186 m high respectively, rising only 90 and 45 m respectively above the surrounding topography. They are both located in the western hinterland of the city of Brescia, on the western bank of the Mella River. Bedding planes gently dip to the W/SW suggesting, at a first look, that the succession, unconformably overlying the Mesozoic thrust stack, is undeformed and that the observed dip might reflect the original topographic gradient. Such a model would possibly be in line with the Messinian age proposed by Brambilla and Penati (1987).

On the other hand, field observations such as: 1) relatively high dip angles in the basal part of the Badia succession; 2) open parasitic folds recognised at outcrop scale; and 3) a well-developed system of parallel near-vertical fractures with average strike 100°N (roughly parallel to the mountain front and interpreted as an axial plane fracture cleavage; Fig. 2), support an alternative interpretation. Actually, we suggest that the clastic succession of Badia and Sale, though presumably unconformable on the Mesozoic and Paleogene bedrock, was deformed by the same thrust system involving the bedrock, and that the gentle dip of the clastic succession reflects its proximal position to the hinge line of a broad ramp anticline as also suggested by the balanced section H of Picotti et al. (1995).

Sedimentology

Conglomerates are prevailing within the formation. They are almost invariably well-cemented orthoconglomerates, in which individual clasts display variable roundness depending on petrography (chert occurs as sharply angular clasts, carbonates and other clast types are subangular to rounded) and are commonly bladed to flattened in form (Pl. IIa). Clasts range in size from pebble to cobble (boulders occur exceptionally) and almost invariably consist of limestone, cherty limestone, chert and dolostone, with subordinate marlstone and sandstone. In addition, a single cobble of subvolcanic porphyrite was observed at Monte Orfano (D. Corbari, pers. comm. 2007). In outcrop, cherty limestone and chert clasts are differentially weathered out (Pl. IIb). A number of distinctive clast types are easily recognised in outcrop based on their lithofacies and can be ascribed to sedimentary formations of the Southern Alps, exposed less than ten km to the north:

1) white to light brown calcilutite, with stylolites, yellow to brown chert nodules and conchoidal fracture (Maiolica, latest Jurassic to early Aptian);
2) varicoloured, dominantly red radiolarites in thin beds sandwiched between pinkish marly limestones (Selcifero Lombardo Group, Middle-Late Jurassic);
3) blackish marly limestone, locally silicified and/or containing dark chert nodules, with traces of parallel lamination (Medolo Group, Early Jurassic);
4) grey, coarsely crystalline dolostone with “dusty” appearance and locally-preserved stromatolites (Dolomia Principale, Norian).

Other less distinct limestone clasts can be broadly ascribed to lithostratigraphic units belonging to the Southalpine Upper Triassic to Cretaceous sedimentary succession (Zu Limestone, *Conchodon* Dolomite, “*Corna*”, etc.). Gunzenhauser (1985) described pebbles that, upon observation on thin section, revealed an assemblage of large benthic foraminifera diagnostic for the Brenno Formation (Kleboth 1982; Tremolada et al. 2008), a Late Campanian to Maastrichtian formation in *Scaglia* facies. No clasts from older rocks (Variscan metamorphites, Collio volcanics, Verrucano Lombardo-Servino clastics) or from the Adamello batholith, cropping out in the present-day drainage basin of the Camonica and Trompia Valleys, were detected after screening several thousand pebbles, cobbles and boulders from MOC outcrops.

The conglomerates are massive- to poorly-bedded, commonly display maximum clast elongation parallel to bedding planes. Clast-supported, horizontally-stratified gravel (*Gh*) and clast-supported, massive gravel (*Gcm*) lithofacies prevail (Miall 2006; in order to avoid the introduction of new facies codes and emphasizing similarities in depositional processes, Miall codes were applied also to fan-delta deposits). Upcurrent-dipping imbricated clasts are locally observed (Pl. IIc; flow direction south to southwest), whilst grading, usually normal, is hardly recognized at Monte Orfano. Large thick-shelled bivalves (Pectinacea) are locally preserved as disarticulated and abraded valves with convex-upward orientation at the top of beds (Pl. IId).

At Badia, aligned elongate pebbles are commonly observed on the bedding planes of conglomerate strata indicating NE to SW flow direction with their long axes (SenGupta 1966; Fig. 2).

Sandstones, fairly rare at Monte Orfano, are instead widespread at Badia and Sale. There, they commonly consist of channelised medium to very coarse-grained sandstones and pebbly sandstones (planar cross-laminated sand lithofacies, S*p* of Miall, 2006; Pl. IIe) locally displaying high-angle and, less commonly, trough cross-lamination. Invariably unfossiliferous, the sandstones are organised in individual tabular to lenticular, several dm-thick beds, and are typically intercalated within finer-grained sediments or represent the basal part of coarsening-upward cycles topped by conglomerates. At Monte Orfano instead, sandstones are limited to the plugs, not exceeding 30 cm in thickness, of individual fining-upward conglomerate beds and represent the finer-grained tail of single depositional events. The sandstones are well cemented ("*calcarenite saldissima*" of Vecchia and Cita 1954). Gastropods and disarticulated bivalves are locally preserved as broken and abraded shells filled by internal moulds.

Fine-grained clastic facies display at least three distinct subfacies types:

1) whitish and yellowish, massive, sandy to silty mudrocks, with a "chalky" appearance (massive mud and silt lithofacies, *Fm* of Miall 2006 – here renamed *Fm*$_1$; Pl. IIf). This facies, remarkably light in the hand, forms discontinuous intercalations between conglomerate beds and is restricted to the Monte Orfano. Calcareous nannoplankton and foraminifera do occur (see below).

2) grey to yellowish, massive, silty marls arranged in m-thick planar beds with gastropods and bivalves (lithofacies *Fm* of Miall 2006 – here renamed *Fm*$_2$). This facies, resembling an hemipelagite polluted by a conspicuous siliciclastic input, is rare and also restricted to the Monte Orfano.

3) yellowish to brownish calcareous siltstones and very fine-grained sandstones, with pedogenetic features, in dm- to m-thick intervals (parallel-laminated siltstone and mudstone lithofacies, *Fl* of Miall 2006). This facies, which contains rare plant remains and freshwater molluscs, was observed only at Badia and Sale. Typically, lithofacies *Fl* is oxidised and shows rhizoconcretions, locally associated with caliche close to the top of

individual layers. Caliche is commonly clustered in pluricentimetric to decimetric horizons, denser towards the top of the bed, and sometimes culminating in a continuous or nodular calcrete layer.

A representative stratigraphic section for Monte Orfano, measured along the road from Cologne to the Cappella Alpini (stratigraphic section on Pl. I) and displaying most of the described lithofacies, is reported in Fig. 3A. A vertical plot of maximum and modal grain size of clasts depicts a sequence of coarsening-upwards (CU) cycles, a few tens of metres-thick each, that is not easily appreciated in the field. Thinner fining-upwards cycles are locally superimposed on the main CU trend.

The vertical lithofacies stacking pattern, the planar geometry of strata at outcrop scale and the occurrence of shallow-marine fossils point to a gravel-dominated shelf fan-delta with distributaries subjected to strong lateral migration and amalgamation. Conversely, interdistributary areas are poorly represented. As a consequence, Fm_1 and Fm_2 lithofacies are volumetrically negligible but are crucial to demonstrate the marine environmental conditions, that are difficult to recognize because of the overwhelming *Gh* facies.

A composite stratigraphic log for the Badia hill was measured from the Sant'Anna Church to the Badia Alta House (Fig. 3B). In the basal part, lithofacies *Sp* and *Fl* are arranged in metric fining-upward cycles, interpreted as overbank deposits in an alluvial plain setting. Upsection, conglomerates in metric beds commonly overlie much thinner alternations of *Sp* and *Fl* lithofacies, corresponding to coarsening-upward cycles with an overall negative (prograding) trend, in contrast to the underlying alluvial plain stratal packages. High-energy intervals, episodically interrupted by metric deposits in *Fl* lithofacies, prevail up to the top of the section. Thick *Fl* intervals with local soil horizons are interpreted as evidence of persistent overbank settings, whilst laterally discontinuous and lenticular sandstone beds embedded in the *Fl* facies may represent natural levee/crevasse-splay deposits. The lack of marine fossils, the persistence of the *Fl* lithofacies throughout conglomerate-dominated cycles and the overall prograding trend imply a distal alluvial fan setting. The observed pedogenetic features document the occurrence of weakly to moderately developed soils in the Badia hill section. Massive precipitation of $CaCO_3$ close to the top of the *Fl* layers suggests hot and semi-arid to sub-humid climatic conditions (Retallack 1990).

Sandstone petrography

A total of 10 modal analyses (point-counting target = 300 points) was performed on moderately-sorted sandstones in the grain size range F = -0.50 ÷ 2.00 in order to investigate in detail the provenance of the MOC. Thin sections were completely stained with red alizarine to discriminate calcite from dolomite. Seven out of ten samples were taken from Monte Orfano, two from Badia and one from Sale.

MOC sandstones are nearly pure sedarenites (Folk 1974) consisting almost exclusively of carbonate and cherty lithics (on the average, $Q_1F_0R_{99}$). However, subordinate quartz, volcanic lithics and sandstone rock fragments also occur. Carbonate extrabasinal grains (CE, DE *sensu* Zuffa 1987) are dominant (75-90% of the sandstone framework) among sedimentary lithics. Thus, working categories based on carbonate texture were employed to better discriminate provenance following Dunham's (1962) classification of limestones (Table 1).

Inspection of calcareous to marly clasts revealed the occurrence of Cretaceous macro- and microfossils, and of Paleogene planktonic foraminifera. In detail, clasts of calpionellid lime mudstone (Maiolica) contain *Calpionella alpina* (latest Tithonian to possibly earliest Berriasian), *Calpionellopsis oblonga* (middle to latest Berriasian) and radiolarians (particularly common in the Maiolica before the Early Valanginian): thus, the Maiolica seems totally represented. Few clasts with dark micrite contain *Rotalipora appenninica* gr., *Globigerinelloides ultramicrus*, *Heterohelix* sp., possible *Paracostellagerina* sp. and possible fragment of *Planomalina buxtorfi*, pointing to the uppermost Albian, that is represented in the study area by the Sass de la Luna (Bersezio, 2005). *Globotruncana bulloides*, *G. hilli*, *Archaeoglobigerina* sp. and other not diagnostic cuts of double-keeled globotruncanids indicate a Late Cretaceous, probably Campanian age for other clasts; very rare Inoceramid fragments also indicate the Cretaceous. Finally, two sparse specimens with cancellate wall generally indicate the Paleogene.

Intrabasinal grains (also including echinoid fragments and a single ferricrete chip) never exceed 3% of the rock volume in samples from Monte Orfano, whilst feldspars and heavy minerals, including detrital micas, are extremely rare. Primary pores were filled by sparse micrite and by a widespread, sparry calcite cement. All the studied sandstones match the composition of modern "non-metamorphic calclithite sands" documenting an "undissected stage of continental block provenance" according to Garzanti et al. (2006).

Quantitative data obtained from modal analyses (Table 1) indicate that the most common sedimentary lithic type are micritic limestones (lime mudstones, wackestones and microsparites), which represent one third to half of the rock volume. Granular limestones (packstones, grainstones) are subordinate, but their abundance is unrelated – unlike it might be expected – to the sandstone grain size. Among all kind of lithics, and more notably among carbonate lithics, pseudodolosparites are the grain type that records the maximum variations in abundance from sample to sample (from 0.0 to 22.3% of rock volume, reflecting in fluctuations of the DE/[DE+CE] ratio by one order of magnitude). Chert abundance and relative proportions among radiolarian, spicular and unclassifiable cherts remain instead fairly constant in the investigated sample population. Sandstone rock fragments, monocrystalline and polycrystalline quartz as well as very rare K-feldspar, muscovite/biotite flakes and garnet grains (Pl. IIIe-f) might have been recycled from outcrops of Cretaceous flysch units. In those units, fed also by the Variscan basement during an early stage of tectonic structuring of the Alps, garnet can be the dominant heavy mineral in particular stratigraphic intervals (Bernoulli and Winkler 1990). Rare and deeply-altered volcanic lithics, which display vitric and microlithic structures, can be assigned to the subvolcanic Paleogene porphyrites sparsely intruded in the Mesozoic succession (Fantoni et al 1999).

Sharply angular chert grains (Pl. IIIb) vs. subangular to rounded carbonates are explained by differential rounding of clasts during stream transport and deposition in a high-energy environment before burial. Such evidence clearly indicates first-cycle sedimentation with exceptional "textural inversions" (Folk 1951: e.g., rounded quartz vs. subangular carbonate grains) pointing to very limited recycling of older sandstones. Erratic abundance variation of dolostone grains seems to reflect limited and accidental incision into carbonate platform facies of the Triassic succession, which is everywhere topped by a thick slab of Dolomia Principale.

Mineralogy of the muddy *Fm1* lithofacies

X-ray mineral diffraction (courtesy of M. Dapiaggi, University of Milan) and standard calcimetry measurements were carried out on four samples from the *Fm1* lithofacies. Results are summarised in Table 2.

Calcite is the dominant mineral in the Fm1 lithofacies, but quartz is also widespread. No opal-CT, commonly described in “tripolaceous” facies (Amorosi et al. 1995; Falorni 2003) was detected.

Dolomite, interpreted as detrital in origin, occurs only in sample MO14. The absence of dolomite in three out of the four samples confirms the limited contribution to the MOC from detritus derived from the Dolomia Principale and possibily older dolostone-dominated Triassic units. Another “rumorous absence” concerns detrital mica flakes, which are expected to be concentrated in finer-grained sediment fractions by virtue of hydraulic sorting processes.

Thin-section analyses show that the *Fm1* lithofacies is characterised by an irregular honeycomb structure (Pl. IIIg) with conspicuous and roughly equidimensional secondary pores that point to diagenetic dissolution of subspherical particles. This process has taken place when the muddy matrix was lithified enough to prevent pore collapse. Very high secondary porosity accounts for low density and extreme mechanical weakness of the *Fm1* lithofacies.

Calcareous nannofossil biostratigraphy

Calcareous nannofossil biostratigraphic investigations have been performed on 12 samples collected from lithofacies *Fm1* and *Fm2* of the MOC. Samples were taken from the stratigraphic section (Fig. 3A) and sparse outcrops at Monte Orfano (Table 2). Due to the lack of a continuous section throughout the MOC, stratigraphic position can be assessed only within the stratigraphic section. However, location of the sampling sites with respect to the bedding allowed us to attribute most of the studied samples to the upper part of the exposed succession. All samples were prepared using standard techniques described by Bown and Young (1998). Smear slides were analyzed using standard light-microscope techniques under crossed polarizers and transmitted light at 1250x magnification. Calcareous nannofossils were identified at the species level (Pl. IV) by using the taxonomic schemes of Perch-Nielsen (1985), de Kaenel and Villa (1996), and Young (1998). The biozonations of Martini (1971) and the timescale of Berggren et al. (1995) were adopted in this study.

Samples MO12 and MO14 are barren of calcareous nannofossils, whilst MO10 and MO11 contain only *Watznaueria barnesae*, a reworked Mesozoic taxon. A single specimen of *Reticulofenestra bisecta* (*R. scissura* of several authors; NP15-NN1) has been observed in the sample MO13. Conversely, calcareous nannofossils are fairly abundant in the samples MO1, MO3, MO5, MO6, MO7, M15a, and M15b, but characterized by moderate preservation. Evidence of reworking from Mesozoic and Paleocene-Eocene formations has been observed in all these samples. Reworked Mesozoic taxa are extremely abundant and are represented by *Watznaueria barnesae*, *W. britannica*, *W. manivitae*, *Cretarhabdus* spp., *Rhagodiscus* spp., *Cribrosphaerella ehrembergii*, *Biscutum* spp., *Zeughrabdotus* spp., *Micula staurophora*, *Nannoconus* spp., and *Tranolithus* spp. Paleogene species are less abundant, but *Neochiastozygus* spp., *Chiasmolithus* spp. (especially *C. consuetus*), and *Toweius gammation* make up the 6-8% of the total nannofloral assemblages. However, the samples contain similar Neogene calcareous nannofossil communities. The most abundant taxa are long-range calcareous nannofossils such as *Cyclicargolithus floridanus*, *Sphenolithus moriformis*, *Reticulofenestra minuta*, *Discoaster deflandrei,* and *Coccolithus pelagicus*; nonetheless, coccoliths with a high biostratigraphic significance are frequent and allowed us to define a fairly precise biostratigraphy. All samples show the concurrent presence of *Cyclicargolithus abisectus* (NP24-NN1), *Zygrhablithus bijugatus* (NP7-NN2), *Reticulofenestra lockeri* (NP23-NN2), *Helicosphaera recta* (NP24-NN1), *Helicosphaera carteri* (intra NN1-Recent), and *Triquetrorhabdulus carinatus* (NP25-NN2), whilst taxa such as *Sphenolithus ciperoensis* (NP24-NP25), *Sphenolithus distentus* (NP23-NP24), *Discoaster druggii* (NN2-NN4), *Sphenolithus disbelemnos* (NN2-NN3), and *Helicosphaera* *ampliaperta* (NN2-NN4) are absent. These findings suggest that all samples can be assigned to the NN1 nannofossil zone, which straddles the Oligocene/Miocene boundary. In particular, the Last Occurrence (LO) of *S. ciperoensis* marks the base of CN1 in the nannofossil biozonation of Okada and Bukry (1980), whilst the base of NN1 (Martini 1971) was originally defined by the LO of *H. recta*. However, it is now well established that *H. recta* has its LO in the Miocene and the LO of *S. ciperoensis* is formally used as the nannofossil event indicating the base of NN1 nannofossil zone (Young 1998 and references therein). The presence of *R. bisecta,* whose LO is used to define the base of the Miocene (e.g., Berggren et al. 1995), may be the result of reworking since the occurrence of *H. carteri* (intra NN1-recent) excludes an age older than Miocene (e.g., Young 1998). The continuous occurrence of *H. carteri* in this study indicates an earliest Miocene age (Neogene portion of NN1) for the muddy lithofacies *Fm_1* of the MOC.

Microfossils

Foraminiferal investigations have been performed on the same samples studied for calcareous nannofossils collected from lithofacies *Fm_1* of the MOC. Eight samples were taken from the stratigraphic section (Fig. 3A) and isolated outcrops on the Monte Orfano (Table 2). The samples were washed following standard techniques.

The fossil assemblages are, if present, overall very poor and the specimens are very poorly-preserved. The only exception is sample MO1, the residue of which yielded some benthic and rare planktonic foraminifers, 5-6 specimens of radiolarians, common echinoid spines, one mollusc fragment and a few tubular moulds of possible burrows. The inorganic residue consists of quartz.

In spite of the poor preservation, a few benthic and planktonic taxa could be identified. The rare planktonic foraminifera are of mixed ages and include specimens of middle to late Eocene *Globigerinatheka* spp. and Late Cretaceous globotruncanids, the latter reported also by Cita (in Vecchia and Cita 1954). The benthic foraminiferal assemblage is moderately diversified though each taxon is represented by one single specimen. The species identified are:

Textularia sp.

Lenticulina cf. *inornata* (d'Orbigny)
Heterolepa cf. *floridana* (Cushman)
Anomalinoides helicinus (Costa)
Cibicidoides sp.
Ammonia beccarii (Linneus)

Cita (in Vecchia and Cita 1954) described a foraminiferal assemblage from the MOC comprising both benthic and planktonic foraminifers, dated as not older than Miocene. However, the rather rich assemblage described by Cita does not contain the species listed above from sample MO1, which, on the other hand, is devoid of planktonic taxa of Miocene age. Nevertheless, the few benthic species identified in sample MO1 mainly appear in the Miocene (Agip 1982). In particular, according to Cahuzac and Poignant (2002) and Daneshian and Dana (2007), the first occurrence of *Ammonia beccarii* indicates the earliest Miocene. Despite the paucity of foraminifera in terms of index species and preservation, the Miocene age of the MOC indicated by Cita (in Vecchia and Cita, 1954) is here confirmed, although restricted by the calcareous nannoplankton data to the very onset of the Miocene. The planktonic foraminifera of middle to late Eocene and Late Cretaceous ages, as well as the few radiolarians, must be considered as reworked. Palynologic analyses (courtesy of S. Torricelli, ENI E&P) were performed on samples from fine-grained facies exposed at Monte Orfano and Badia. Samples from Badia (lithofacies *Fl*) were found to be barren or bearing very badly-preserved pollen. Pollen assemblages from Monte Orfano (lithofacies Fm_2) did not provide any chronologic information, but suggest a low grade of burial diagenesis.

Macrofossils

Molluscan and plant remains are known since the earliest works on the MOC. At Badia, *Helix ramondi* Brongniart, *H. noueli* Deshayes, *Cyclostoma antiquum* Brongniart and *Glandina* sp. were found (Deshayes 1860; Sordelli 1882). Sordelli (1882) identified plant remains such as *Cyperacites* sp. and *Myrica ragazzonii* Sordelli. *H. ramondi* points to a latest Chattian age (Sige et al. 1995).

In addition to these previous findings, our study also documents at Monte Orfano the occurrence of a limited molluscan assemblage, in which E. Robba (pers. comm. 2007) identified the pectinid bivalves *Oopecten rotundatus* Lamarck (Pl. IId) and *Pecten* (*Amussiopecten*) *burdigalensis* Lamarck (Pl. Va), the tellinid bivalve *Tellina* sp. (Pl. Vb) and the gastropod cf. *Bolma* sp. (Pl. Vc-g). The occurrence of *O. rotundatus* points to an Egerian age (Mandic 2007), which spans the entire NP25 and NN1 nannofossil zones following the timescales of Berggren et al. (1995) and Cicha et al. (1998). The taxa *Pecten burdigalensis* and *Bolma proborsoni* Sacco are common forms in the Lower Miocene of Piedmont. These scarce and poorly-preserved molluscan taxa, which suggest shallow-marine and high-energy depositional settings, have relatively long stratigraphic ranges that, however, match an Early Miocene age.

Although the sediments at Badia-Sale do not contain marine fossils, we tend to correlate them with the fan-delta deposits of Monte Orfano. This age attribution is in contrast to the Messinian age proposed by Brambilla and Penati (1987).

Discussion

Sand provenance. Data on sandstone framework grains can be interpreted in terms of provenance. Key features of the almost pure sedarenites sporadically interbedded in the MOC are: 1) the practical absence of crystalline basement and pre-Cenozoic volcanic grain types; 2) the low and erratic abundance of dolostone grains; and 3) the relatively high chert/carbonate ratio in the sand fraction compared to the rock types exposed in the present-day catchement area (Lake Iseo and Camonica Valley).

Consistent with observation on pebbles, composition of sand grains indicates provenance from a sedimentary succession extending from Triassic dolostones to Cretaceous-Paleogene marls. Chert enrichment might be due to selective dissolution of limestones during erosion, transport and residence in the depositional environment before final deposition. Although the Oligocene-Miocene transition is regarded not to be as arid as the Late Miocene (Harzhauser et al., 2007), it is unlikely that carbonate dissolution under humid climatic conditions affected significantly the chert/carbonate ratio because: 1) efficient transport mechanisms are indicated for the MOC; and 2) a semiarid to arid climate is documented by the conditions of soil formation at Badia. In fact, evidence for carbonate dissolution (oxidised limestone grains and intrabasinal silcrete/ferricrete clasts) is extremely poor. If we accept the assumption that composition of the MOC closely reflects the composition of rock types exposed in the Southern Alps drainage basin, possibly modified by processes acting during sediment transport such as differential rounding, we must conclude that, in the drainage basin of the MOC, a superficial section of cherty Mesozoic formations was exposed, with erosion only sporadically reaching into the Dolomia Principale and certainly not cutting into deeper stratigraphic levels. In our interpretation, however, the drainage basin should not have been too small or local based on 1) relatively homogeneous, pebbly-cobbly grain size, 2) absence of matrix-supported mass flow deposits, 3) rounding of carbonate clasts, and 4) homogeneous petrography over a relatively wide area.

Therefore, we favour a paleotectonic scenario in which the Camuna Anticline and the Adamello Batholith had not yet been exhumed (see below). This model is also supported by paleotectonic reconstructions, according to which the overthrusting of the Camuna Anticline (Thrust System 2B – Trompia Unit of Schönborn 1992; Unit I of Cassinis et al. 2009) onto the Mesozoic succession occurred only during the Middle to Late Miocene ("Valtrompia-Valsugana phase" of Castellarin et al. 1992; "Lombardic phase" of Schumacher et al. 1997), after deposition of the MOC.

Lithostratigraphy. Grouping the sedimentary rocks exposed at Monte Orfano and at Badia-Sale into a single formation poses some unresolved questions. Whereas similar lithologies and clast content support the current attribution of all these outcrops to the MOC, remarkable differences in depositional setting (shallow-marine fan-delta vs. alluvial plain to alluvial fan) and distinct fossil content exist, that might be sufficient reasons (Salvador 1994) to split the MOC into two spatially distinct formations. On the other hand, the same petrographic composition of both the gravelly and sandy fractions of the sediments at Monte Orfano and Badia-Sale strongly shows that all these sediments belong to one and the same petrofacies (Dickinson and Rich 1972), reflecting an early stage of tectonic uplift during the formation of the Southern Alps. As far as the Messinian age proposed by Brambilla and Penati (1987) for the Badia-Sale sediments is concerned, we consider highly unlikely that, after the Tortonian phase of Alpine deformation and uplift, the drainage area was still shedding the same “undissected-stage” detritus that it had shed over 15 My before.

We recommend not only to keep the MOC as a single formation, but also to include it into the Gonfolite Lombarda Group (GLG) of the Como-Varese area (Cita 1957; Gunzenhauser 1985; Bersezio et al. 1993; Schumacher et al. 1997) together with all syn-orogenic clastics of the Southalpine foredeep buried below the Po Plain (Dondi and D’Andrea 1986; Picotti et al. 1997). Although the MOC strongly deviates from the average petrography and sedimentology of other GLG formations (compare with Gunzenhauser 1985; Gelati et al. 1988; Carrapa and Di Giulio 2001; Sciunnach and Tremolada 2004), its paleotectonic significance and age are the same. Also the MOC represents, in fact, a coarse clastic formation deposited in the Oligo-Miocene retro-foreland basin at the front of the Southern Alps retrowedge after the Alpine collision, and, likewise, reduced to a deformed wedge-top succession by the Middle to Late Miocene tectonics.

Age and regional correlation. Based on literature and present data, we believe that the bulk of the MOC, almost certainly younger than zone CP19a (Valdisturlo et al. 1998), is essentially latest Oligocene in age. This because nannofossil zone NN1, straddling the Oligocene/Miocene boundary, is documented only in the upper part of the succession. Even though the Miocene part of nannofossil zone NN1 is documented, the thickness of the underlying conglomerates makes a latest Oligocene age probable for their base. The fine-grained lithofacies occurring in the Chiari 1 well is coeval to the MOC and would therefore suggest a downslope lithofacies change from proximal conglomerates to distal mudstones and sandstones over a distance of nearly 4 km.

If our assumptions are correct, a correlation with the Como Conglomerate (base of the GLG, dated to nannofossil zones NP25-NN1; Scardia et al. 2007) can be established (Fig. 4); both events would reflect the same phase of rapid deformation and uplift of the Alps during the late Chattian (Giger and Hurford 1988; Bersezio et al. 1993; Ford et al. 2006). Available ages and lithologic descriptions of Oligo-Miocene sediments are comparatively poor in the Lake Garda sector, east of the study area. At Monte Brione (Riva del Garda), glauconitic sandstones and conglomerates of late Chattian-Aquitanian age (“*glaukonitische, sandige Kalke*” of Hagn 1956; Mt. Brione Formation of Luciani 1989) unconformably overlie Rupelian bioclastic limestones (“*Lithothamnien-Kalke*” of Hagn 1956; Linfano Limestone of Luciani 1989). Other Oligo-Miocene clastic sediments from the southern Lake Garda area (Zinoni 1951; Manerba Fm. of Boni and Cassinis 1973) are too loosely dated and poorly characterised in terms of petrography and provenance to allow meaningful correlations for the moment.

Further to the East, in the Veneto and Friuli regions, the base of the *“molassa”* (a clastic wedge up to 4000 m-thick recording Alpine uplift throughout the Miocene) is also dated as late Chattian to Aquitanian (Massari et al. 1986; Stefani et al. 2007). Recent calcareous nannofossil data from the Dinarides indicate that, after a stratigraphic gap spanning most of the Oligocene, sedimentation resumed in the northern part of the Dinaric foredeep during nannoplankton Zones NP24 to NP25 (Mikes et al. 2008). This Chattian to Miocene part of the Outer Dinarides Flysch is broadly equivalent to the Cavanella Group (Nicolich et al., 2004).

The rough, but substantial synchrony of the latest Oligocene unconformity over a wide region requires a major tectonic event that involved the whole Southern Alps-Dinaric foredeep, and can be hardly accounted for by an eustatic lowstand only. The end-Oligocene global eustatic fall (Berggren et al. 1995; Harzhauser et al., 2007) might have enhanced coarse clastic deposition, but the eustatic signal is often ambiguously recorded, or completely outstripped, by the tectonic signal in active settings (see discussion in Gelati et al. 1988 for the significance of the base of the GLG).

Tectonic implications. The tectonic position of the MOC has been clarified by structural cross-sections based on seismic data (Pieri and Groppi 1981), on balanced palynspastic sections (Schönborn 1992), or on both (Picotti et al. 1997). It belongs to a structural horse that displays a thick supracrustal section, extending from the Variscan basement namely to the MOC. In more internal (northern) areas of the Alps, correlatable crustal sections had been thrusted southwards during two distinct tectonic pulses, starting since the Late Cretaceous (pre-Gosau “Phase”) and surely not younger than the Middle Eocene (*i.e.*, pre-Adamello). The uplift recorded by the MOC can be ascribed to early post-Adamello orogenic movements (Thrust system 2B of Schönborn 1992) in the hinterland of the MOC basin, where about 4 km of sediments at least had been exhumed. The revised biostratigraphic age here proposed for the MOC documents the importance of such early post-Adamello tectonics and related uplift, that brought to erosion stratigraphic units as young as the Cretaceous-Eocene.

A tentative paleotectonic scenario at the MOC time (latest Oligocene) has been proposed by restoring a geologic cross-section (Fig. 5) through the Southern Alps and the Po Plain in the study area. The cross-section has been modified from Fantoni et al. (2004), Fantoni and Franciosi (2008) and depth-extrapolated following the considerations about the Southern Alps thick-skinned tectonic style proposed in Picotti et al. (1995; 1997) and Doglioni (2007). The palinspastic restoration process accounted for, in this order: the ~5° southward Pliocene tilting of the Southern Alps due to the Pliocene Apennine flexuration, the out-of-sequence thrusting of the frontal anticline ("*flessura pedemontana*"), and the Burdigalian to Tortonian in-sequence outward thrusting (Schönborn 1992; Bersezio et al. 1993; Picotti et al. 1995; 1997). The inferred sea level in the latest Oligocene paleotectonic scenario is constrained by the MOC depositional environments, spanning from alluvial plain to shallow-water settings.

In our interpretation, blind thrusting of the Orobic anticlines and carbonate allochtonous units (Fantoni et al., 2004) were active during the latest Oligocene, mainly upthrowing the pre-Adamello thin-skinned structural stack of Mesozoic carbonate cover. In the study area, the metemorphic basement was not exhumed, lying well below the erosion base level, whilst the ongoing erosion of the Aptian to Paleogene flysch and marls, whose clasts have been identified in the MOC sediments, is documented.

Comparison of coeval clastics from the GLG (Carrapa and Di Giulio 2001; Vezzoli et al. 2007) and the MOC reveals that different structural levels were eroded in western and eastern Lombardy at the onset of the Alpine post-collisional deformation. Whilst nearly "ideal arkose" (Dickinson 1985; Garzanti et al. 2006) were being deposited in the Como Conglomerate (Vezzoli et al. 2007), almost pure sedarenites constituted the MOC.

Conclusions

The MOC was deposited along the uprising front of the Southern Alps in a shallow-marine settings for its main part at Monte Orfano, and in a continental setting for the Badia-Sale area, as suggested by faunal and sedimentological evidence. Even though a precise correlation between the outcrops at Monte Orfano and Badia-Sale could not be established, identical sandstone petrofacies supports a rough chronological correlation of clastic sediments deposited in laterally contiguous environments.

The new biostratigraphic data, obtained from the analysis of calcareous nannoplankton, suggest that the age of the MOC is substantially older than hitherto estimated. The bulk of the succession may probably be assigned to the late Chattian and the top part is surely not younger than the earliest Miocene instead of Early to Middle Miocene. The new biostratigraphic constraints provided in this study allowed us to indirectly refer the early stage of post-collisional thrusting of the Southern Alps to the latest Oligocene at least and to frame it into a more coherent regional scenario of strong Alpine tectonic activity and uplift during the Late Oligocene. In fact, if a latest Oligocene age is assumed for the thick conglomerate succession underlying the sampled mudrock intervals, the onset of the deposition of the MOC was roughly coeval with deposition of foredeep turbidites and other mass-flow deposits in western Lombardy and Piedmont (GLG: Scardia et al. 2007). In addition, the deposition of the MOC correlates with other local clastic formations cropping out to the east, in the Lake Garda area (M. Brione Fm.) and, farther eastwards, in the Veneto-Friuli region (*"molassa" veneto-friulana*) and in the Outer Dinarides foredeep. While the Como Conglomerate was fed by crystalline basement rocks (thence their arkosic composition), the MOC records the incipient unroofing of newly-uplifted sedimentary basins. This indicates that the Alpine retro-foreland basin recorded as a whole the synchronous tectonic activity of two distinct structural domains. The MOC was fed by the structuring of a proximal Southern Alps retrowedge and, in the contrast, the Alpine axial chain was feeding the GLG. Although of limited extent, the MOC proved to be a key *tessera* in reconstructing the timing and regional distribution of the mosaic of clastic bodies that records the early stages of the post-collisional Alpine uplift during the Cenozoic Era.

Acknowledgements

Field work by two of us (DS & GS) was initiated by Daniele Corbari & Paolo Falletti and assisted by Davide Cantelli & Franco Previtali. X-ray diffraction analyses were kindly provided by Monica Dapiaggi. Elio Robba and Vittorio Lenza provided fundamental help with the malacofaunal data. Stefano Torricelli screened the MOC sediments for palynomorphs. Useful discussions with Cipriano Carcano and Sergio Rogledi on subsurface geology and paleotectonics are appreciated. Thin sections by Curzio Malinverno; photomicrograph assistance by Fabrizio Berra and Giovanni Vezzoli. The geologic cross-section was restored with 2Dmove, under the appreciated technical assistance of Chiara D'Ambrogi. Support by CARG-Lombardia and INGV funds is acknowledged. An earlier draft of the manuscript was improved by the accurate reviews of Daniel Bernoulli and Vincenzo Picotti.

References

Agip (1982) Foraminiferi padani (Terziario e Quaternario). Atlante iconografico e distribuzione stratigrafica. 2nd edn. Agip S.p.A. San Donato Milanese, 52 ppll

Amorosi A, Ricci Lucchi F, Tateo F (1995) The Lower Miocene siliceous zone: a marker in the paleogeographic evolution of the northern Apennines. Palaeogeogr Palaeoclimatol Palaeoecol 118: 131-149

Assereto R, Casati P (1965) Revisione della stratigrafia permo-triassica della Val Camonica meridionale (Lombardia). Riv It Pal Strat 71: 999–1097

Berggren WA, Kent DV, Swisher CC III, Aubry M-P (1995) A revised geochronology and chronostratigraphy. In: Berggren WA, Kent DV, Aubry M-P, Hardenbol J (eds) Geochronology, time scales, and global correlation, SEPM Spec Publ 54, pp 129-212

Bernoulli D, Winkler W (1990) Heavy mineral assemblages from Upper Cretaceous South- and Austroalpine flysch sequences (Northern Italy and Southern Switzerland): source terranes and palaeotectonic implications. Ecl Geol Helv 83: 287-310

Bersezio R (2005) Sass de la Luna. In: Cita MB, Abbate E, Aldighieri B, Balini M, Conti MA, Falorni P, Germani D, Groppelli G, Manetti P, Petti FM (eds) Carta Geologica d'Italia – 1: 50.000, Catalogo delle Formazioni – unità validate. Quad APAT Ser III 7/VI: 106-110

Bersezio R, Fornaciari M, Gelati R, Napolitano A, Valdisturlo A (1993) The significance of the Upper Cretaceous to Miocene clastic wedges in the deformation history of the Lombardia southern Alps. Géol Alp 69: 3-20

Bertotti G., Picotti V., Cloething S. (1998) Lithospheric weakening during “retro-foreland” basin formation: tectonic evolution of the central South Alpine foredeep. Tectonics 17: 131-142

Boni A, Cassinis G (1973) Carta geologica delle Prealpi bresciane a sud dell'Adamello. Note illustrative della legenda stratigrafica. Atti Ist Geol Univ Pavia 23:119-159

Bown PR, Young JR (1998) Techniques. In: Bown P (ed) Calcareous Nannofossil Biostratigraphy. Kluwer Academic Publishers, London, pp 16-28

Brambilla G, Penati F (1987) Le filliti mioceniche del colle della Badia di Brescia. Natura Bresciana 23 (1986): 79-102

Cahuzac B, Poignant A (2002) Associations de foraminifères benthiques dans quelques gisements de l'Oligo-Miocène sud-aquitain. Rev Micropaléont 45: 221-256

Callegari E, Brack P (2002) Geological Map of the Tertiary Adamello Batholith (Northern Italy). Explanatory Notes and Legend. Mem Sci Geol 54: 19-49

Carrapa B, Di Giulio A (2001) The sedimentary record of the exhumation of a granitic intrusion into a collisional setting: the lower Gonfolite Group, Southern Alps, Italy. Sed Geol 139: 217-228

Cassinis G, Corbari D, Falletti P, Perotti C (2009) Note Illustrative della Carta Geologica d’Italia alla scala 1:50.000, Foglio 099 Iseo. APAT - Dipartimento Difesa del Suolo-Servizio Geologico d’Italia, Roma, in press

Castellarin A, Cantelli L, Fesce AM, Mercier J, Picotti V, Pini GA, Prosser G, Selli L (1992) Alpine compressional tectonics in the Southern Alps. Relations with the N-Apennines. Ann Tecton 6: 62-94

Cicha I, Rögl F, Čtyroká J, Rupp Ch, Bajrktarevic Z, Baldi T, Bobrinskaya OG, Darakchieva St, Fuchs R, Gagic N, Gruzman AD, Halmai J, Krashenninikov VA, Kalac K, Korecz-Laky I, Krhovsky J, Luczkowska E, Nagy-Gellai A, Olszewska B, Popescu Gh, Reiser H, Schmid ME, Schreiber O, Serova MY, Szegö E, Sztrakos K, Venglinskyi IV, Wenger W (1998) Oligocene-Miocene Foraminifera of the Central Paratethys. Abh Senckenbergischen Nat Ges 549: 1-325

Cita MB (1957) Studi stratigrafici sul Terziario subalpino lombardo. VII. Sintesi stratigrafica della Gonfolite. Riv It Pal Strat 63: 79-121

Corbari D (2006) The main geological and geomorphological features of the amphitheatres of the Sebino region (Lake Iseo, Lombardy). In: Donegana M, Ravazzi C (eds) Quaternary Stratigraphy and Evolution of the Alpine Region in the European and Global Framework. INQUA-SEQS 2006 field trip guide: 112-116

Dalla S, Rossi M, Orlando M, Visentin C, Gelati R, Gnaccolini M, Papani G, Belli A, Biffi U, Catrullo D (1992) Late Eocene-Tortonian tectono-sedimentary evolution in the western part of the Padan basin (northern Italy). Paleont Evol 24-25: 341-362

Daneshian J, Dana LR (2007) Early Miocene benthic foraminifera and biostratigraphy of the Qom Formation, Deh Namak, Central Iran. J Asian Earth Sci 29: 844–858

de Kaenel E, Villa G (1996) Oligocene-Miocene calcareous nannofossil biostratigraphy and paleoecology from the Iberia Abyssal Plan. In: Whitmarsh RB, Sawyer DS (eds) Scientific Results of the Ocean Drilling Project 149, pp 79-145

Deshayes GP (1860) Description des animaux sans vertèbres du Bassin de Paris. Baillière et fils, Paris, 2538 pp

Dickinson WR (1985) Interpreting provenance relations from detrital modes of sandstones. In: Zuffa GG (ed) Provenance of arenites, NATO-ASI Series, Reidel, pp 333-361

Dickinson WR, Rich EI (1972) Petrologic intervals and petrofacies in the Great Valley Sequence, Sacramento Valley, California. Geol Soc Am Bull 83: 3007-3024

Doglioni C (2007) Tectonics of the Dolomites. Bull angew Geol 12/2: 11-15

Dondi L, D’Andrea MG (1986) La Pianura Padana e Veneta dall’Oligocene superiore al Pleistocene. G Geol, Ser III 48/1-2: 197-225

Dunham RJ (1962) Classification of carbonate rocks according to depositional texture. In Ham WE (ed) Classification of carbonate rocks. Am Ass Petr Geol Mem 1: 108-121

Falorni P (2003) Formazione di Contignaco. In: Delfrati L, Falorni P, Izzo P, Petti FM (eds) Carta Geologica d’Italia – 1: 50.000, Catalogo delle Formazioni – unità validate. Quad APAT Ser III 7/V: 67-74

Fantoni R, Franciosi R (2008) Geological framework of Po Plain and Adriatic Foreland System. Proc 70th EAGE Conf Exhib, Rome: P134, 5 pp

Fantoni R, Bersezio R, Forcella F, Gorla L, Mosconi S, Picotti V (1999) New dating of the tertiary products of the central Southern Alps, bearing on the interpretation of the Alpine tectonic history. Mem Sci Geol 51: 47–61

Fantoni R, Bersezio R, Forcella F (2004) Alpine structure and deformation chronology at the Southern Alps-Po Plain border in Lombardy. Boll Soc Geol It 123/3: 463-476

Folk RL (1951) Stages of textural maturity in sedimentary rocks. J Sed Petr 21: 127-130

Folk RL (1974) Petrology of sedimentary rocks. Hemphill Publ Co, Austin, 182 pp

Ford M, Duchêne S, Gasquet D, Vanderhaeghe O (2006) Two-phase orogenic convergence in the external and internal SW Alps. J Geol Soc London 163: 815-826

Garzanti E, Andò S, Vezzoli G (2006) The continental crust as a source of sand (Southern Alps Cross Section, Northern Italy). J Geol 114: 533-554

Gelati R, Napolitano A, Valdisturlo A (1988) La "Gonfolite Lombarda": stratigrafia e significato nell'evoluzione del margine sudalpino. Riv It Pal Strat 94: 285-332

Giger M, Hurford AJ (1988) Tertiary intrusives of the Central Alps: their Tertiary uplift, erosion, redeposition and burial in the south-alpine foreland. Ecl Geol Helv 82: 857-866

Gunzenhauser B (1985) Zur Sedimentologie und Paläogeographie der Oligo–Miozänen Gonfolite Lombarda zwischen Lago Maggiore und der Brianza (Südtessin Lombardei). Beitr Geol Karte Schweiz NF 159, 114 pp

Hagn H (1956) Geologische und paläontologische Untersuchungen im Tertiär des Monte Brione und seiner Umgebung (Gardasee, Ober-Italien). Paläontographica Abt A 107: 67-210

Harzhauser M, Kroh A, Mandic O, Piller WE, Golich U, Reuter M, Berning B (2007) Biogeographic responses to geodynamics: A key study all around the Oligo-Miocene Tethyan Seaway. Zool Anz 246: 241-256

Kleboth P (1982) Stratigraphie und Sedimentologie der Höheren Oberkreide und des Alttertiärs der Brianza (Provinz Como, Italien). Mem Sci Geol 35: 214-282

Luciani V (1989) Stratigrafia sequenziale del Terziario nella catena del Monte Baldo (Provincie di Verona e Trento). Mem Sci Geol 41: 263-351

Mandic O (2007) Pectinid Bivalve Zonation of the Central Paratethys. Joannea Geol Paläont 9: 59-60

Martini E (1971) Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci A (ed) Proceedings of the Second International Conference on Planktonic Microfossils, Roma (Tecnoscienza), pp 739-785

Massari F, Grandesso P, Stefani C, Zanferrari A (1986) The Oligo-Miocene molasse of the Veneto-Friuli region, Southern Alps. G Geol 48: 235-255

Miall AD (2006) The Geology of Fluvial Deposits. 4th ed Springer, Berlin, 582 pp

Mikes T, Baldi-Beke M, Kazmer M, Dunkl I, Von Eynatten H (2008) Calcareous nannofossil age constraints on Miocene flysch sedimentation in the Outer Dinarides (Slovenia, Croatia, Bosnia-Herzegovina and Montenegro). In: Siegesmund S, Fügenschuh B, Froitzheim N (eds) Tectonic aspects of the Alpine-Dinaride-Carpathian System. Geol Soc London Spec Publ 298: 335-363

Montrasio A (1990) Carta geologica della Lombardia. Serv Geol Naz, Roma

Nicolich R, Della Vedova B, Giustiniani M (2004) Carta del sottosuolo della pianura friulana – Note illustrative. Litografia Artistica Cartografica, Firenze, 32 pp

Okada H, and Bukry D (1980) Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation. Marine Micropaleont 5: 321-325

Perch-Nielsen K (1985) - Mesozoic calcareous nannofossils. In: Bolli HM, Saunders JB, Perch-Nielsen K (eds) Plankton Stratigraphy, Cambridge University press, Cambridge, pp 329-426

Picotti V, Prosser G, Castellarin A (1995) Structures and kinematics of the Giudicarie-Val Trompia fold and thrust belt (Central Southern Alps Northern Italy). Mem Sci Geol 47: 95-109

Picotti V, Casolari E, Castellarin A, Mosconi A, Cairo E, Pessina C, Sella M (1997) Structural evolution of the eastern Lombardian Prealps: Alpine inversion of a Mesozoic rifted margin. Agip S.p.A., San Donato Milanese, 102 pp

Pieri M, Groppi G (1981) Subsurface geological structure of the Po Plain (Italy). CNR Progetto Finalizzato Geodinamica, Pubbl 414 CNR, Roma, 13 pp

Ragazzoni G (1862) Cenni geologici sopra una parte dei terreni terziari della Provincia di Brescia. Commentari dell’Ateneo di Brescia per gli anni 1858-1961: 202-207

Retallack GJ (1990) Soils of the past: an introduction to paleopedology. 2nd edn. Unwin & Hyman, London, 520 pp

Salvador A (1994) International Stratigraphic Guide: A Guide to Stratigraphic Classification, Terminology, and Procedure. 2nd edn. IUGS and GSA, Boulder

Scardia G, Carcano C, Ghielmi M, Rogledi S, Sciunnach D, Tremolada F, Vezzoli G (2007) New stratigraphic data on the Neogene Southalpine foredeep: constraints for Neoalpine tectonics. VII Alpine Workshop, Davos, Abstract Volume: 68-69

Schaltegger U, Brack P (2007) Crustal scale magmatic systems during intra-continental strike-slip tectonics: U, Pb and Hf isotopic constraints for Permian magmatic rocks of the Southern Alps. Int J Earth Sci 96: 1131-1151

Schmid SM, Pfiffner OA, Froitzheim N, Schönborn G, Kissling E (1996) Geophysical-geological transect and tectonic evolution of the Swiss-Italian Alps. Tectonics 15: 1036-1064

Schönborn G (1992) Alpine tectonics and kinematic models of the central Southern Alps. Mem Sci Geol 44: 229-393

Schumacher ME, Schönborn G, Bernoulli D, Laubscher HP (1997) Rifting and collision in the Southern Alps. In Pfiffner OA, Lehner P, Heitzmann P, Müller S, Steck A (eds) Deep structure of the Swiss Alps: Results of the National Research Program 20. Birkhäuser, Basel, pp 186–204

Sciunnach D, Tremolada F (2004) The Lombardian Gonfolite Group in central Brianza (Como and Milano provinces): Calcareous nannofossil biostratigraphy and sedimentary record of neo-alpine tectonics. Ecl Geol Helv 97: 119-131

SenGupta S (1966) Studies on orientation and imbrication of pebbles with respect to cross-stratification. J Sed Petr 36: 362-369

Sige B, Aguilar J-P, Astruc JG, Marandat B, Riveline J, Villatte J (1995) Sur l'âge mammalogique (MP 30; Chattien terminal, Oligocene superieur) du "calcaire a Helix ramondi" de La Salle (Causse du Sud Quercy, Sud-Ouest de la France). N Jb Geol Palaeont. Monatsh 11: 697-710

Sordelli F (1882) Sui fossili e sull’età del deposito terziario della Badia presso Brescia. Atti Soc It Sci Nat 25: 85-93

Stefani C, Fellin MG, Zattin M, Zuffa GG, Dalmonte C, Mancin N, Zanferrari A, (2007) Provenance and paleogeographic evolution in a multi-source foreland: the Cenozoic Venetian-Friulian basin (NE Italy). J Sed Res 77: 867-887

Tremolada F, Sciunnach D, Scardia G , Premoli Silva I (2008) Maastrichtian to Eocene calcareous nannofossil biostratigraphy from the Tabiago section, Brianza area, northern Italy. Riv It Paleont Strat 114: 29-39.

Valdisturlo A, Castradori D, Fantoni R, Pessina C, Torricelli S (1998) Livelli clastici grossolani pre-Gonfolite (Oligocene inferiore) e loro significato nell’evoluzione del settore lombardo dell’avanfossa sudalpina. G Geol 60: 77-82

Vecchia O, Cita MB (1954) Studi stratigrafici sul Terziario Subalpino Lombardo: Nota III. Riv It Pal Strat 60: 1-15

Vezzoli G, Andò S, Bersani D, Garzanti E, Malusà M, Scardia G, Sciunnach D, Tremolada F, Vignola P (2007) Provenance of the Gonfolite Lombarda succession (Po Basin, Northern Italy). VII Alpine Workshop, Davos, Abstract Volume: 68-69

Willet S, Beaumont C, Fullsack P (1993) Mechanical model for the tectonics of doubly vergent compressional orogens. Geology 21: 371-374

Young JR (1998) Neogene. In: Bown PR (ed) Calcareous Nannofossil Biostratigraphy. Kluwer Acad Publishers, pp 225-265

Zinoni A (1951) L'Oligocene ed il Miocene dei dintorni di Manerba (Lago di Garda). Riv Ital Pal Strat 57: 1-12

Zuffa GG (1987) Unravelling hinterland and offshore paleogeography from deep-water arenites. In: Leggett JK, Zuffa GG (eds) Marine Clastic Sedimentology. Graham & Trotman, pp 39-61

Figure Captions

Fig. 1 Geological sketch map of the catchment area of the Monte Orfano Conglomerate (after Montrasio et al. 1990) and simplified stratigraphy of the MOC source rocks.

Fig. 2 Rose diagrams of paleocurrent trends and fractures from Badia. A) paleocurrent directions based on gravel imbrication; B) paleocurrent directions based on orientation of basal flow marks and of the major axis of elongated pebbles; C) strike of vertical fractures.

Fig. 3 Stratigraphic sections at Monte Orfano and Badia.

Fig. 4 Correlation of the MOC with adjacent units deposited in the Southalpine retro-foreland. Vertical timescale after Berggren et al. (1995). CM = Chiasso Formation (Marls); LL = Linfano Limestone; MBF = Monte Brione Fm.; MVF = "molassa" veneto-friulana; ODF = Outer Dinaride Flysch; VOC = Villa Olmo Conglomerate.

Fig. 5 Tentative paleotectonic scenario for the Chattian-early Aquitanian Monte Orfano Conglomerate.

Plate I Geological map of the Monte Orfano hill (after Corbari 2006; D. Corbari, P. Falletti, GS & DS, unpublished data collected in the framework of the CARG Project) and of the Badia-Sale hillos (insets). Topographic base: Carta Tecnica Regionale at the 1: 10 000 scale.

Plate II Lithofacies and sedimentary structures in the MOC. a) crudely-bedded orthoconglomerates (*Gh* facies) with iso-oriented platy pebbles and vague downstream imbrication (flow direction: right [NE] to left [SW]); b) strong differential relief between carbonate and chert clasts; c) imbricated pebbles and cobbles (flow direction: right [NE] to left [SW]); d) bedding surface displaying a thick-shelled and abraded, large pectinid valve (*Oopecten rotundatus* Lamarck); e) cross-bedded sandstones (*Sp* facies) intercalated between *Gh* beds; f) "chalky" mudrocks (lithofacies *Fm1*). All photos from Monte Orfano; photos a,b,f by D. Corbari – phots c,d,e by DS.

Plate III Petrography of MOC arenites and mudrocks from Monte Orfano. a) typical petrofacies (sedarenites/calclithites). Note subangular to subrounded carbonate and comparatively less abundant chert clasts. The largest carbonate clast is a calpionellid lime mudstone/wackestone that can be doubtlessly assigned to the Maiolica Fm.; b) sharply angular chert grains; c) oolitic grainstone fragment (*Conchodon* Dolomite?); d) sandstone fragment; e-f) single garnet grain; g) irregular honeycomb structure in mudrocks from facies *Fm1*. Photomicrographs a,b,c,e parallel nicols; photos d,f,g crossed nicols. Scale bar = 250 μm.

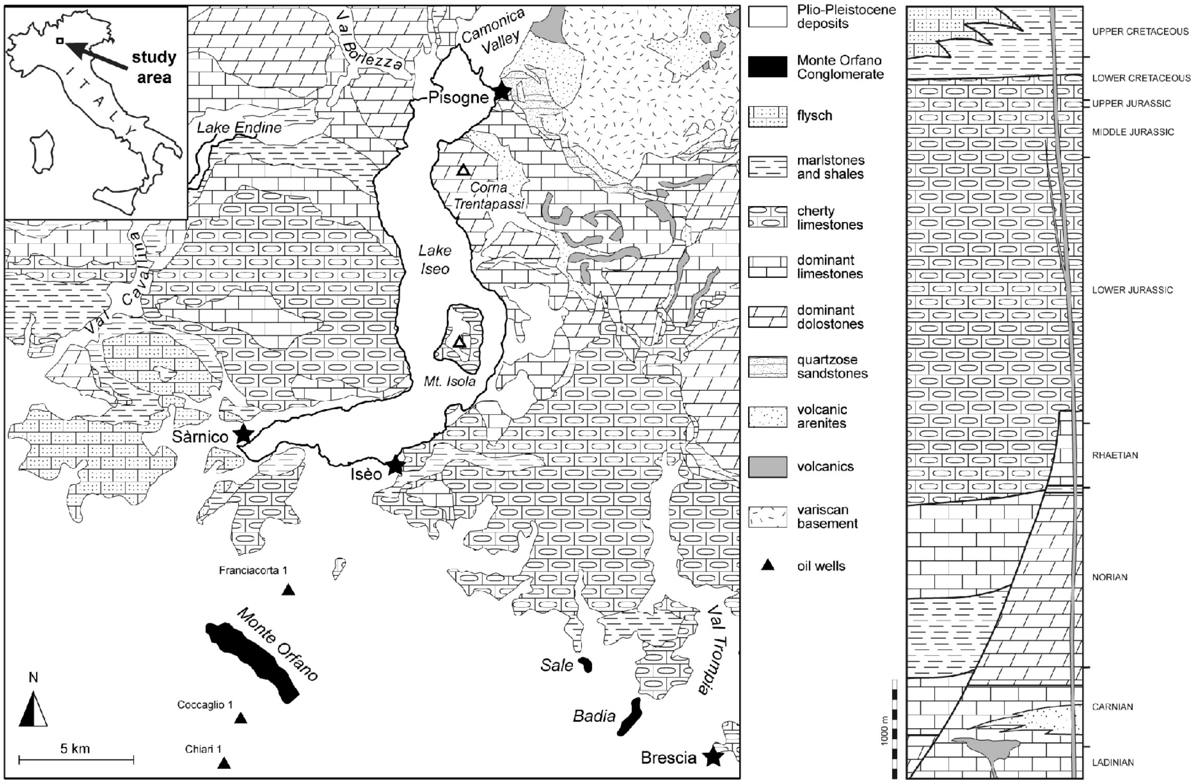
Plate IV Calcareous nannofossils from the MOC mudrocks. 1-2) *Reticulofenestra scissura (bisecta)* (crossed nicols; sample MO3); 3) *R. bisecta* (parallel nicols; sample MO3); 4) *Cyclicargolithus abisectus* (crossed nicols; sample MO5); 5-6) *Helicosphaera carteri* (crossed nicols; sample MO5); 7-8) *Cyclicargolithus floridanus* (crossed nicols; sample MO1); 9-10) *Discoaster deflandrei* (parallel nicols; sample MO1); 11-12) *Triquetrorhabdulus carinatus* (crossed nicols; sample MO1); 13) *Coccolithus pelagicus* (crossed nicols; sample MO5); 14-15; *Helicosphaera mediterranea* (crossed nicols; sample MO3); 16) *Helicosphaera recta* (crossed nicols; sample MO7); 17-18) *C. pelagicus* (crossed nicols; sample MO6); 19-20) *Zygrhablithus bijugatus* (crossed nicols; sample MO3).

Plate V Macrofossils from facies *Sp*, Monte Orfano. a) *Pecten* (*Amussiopecten*) *burdigalensis* Lamarck 1809, left valve; b) *Tellina* sp., left valve; c-g) cf. *Bolma* sp., various orientations. Scale bar = 2 cm. Determinations by E. Robba.

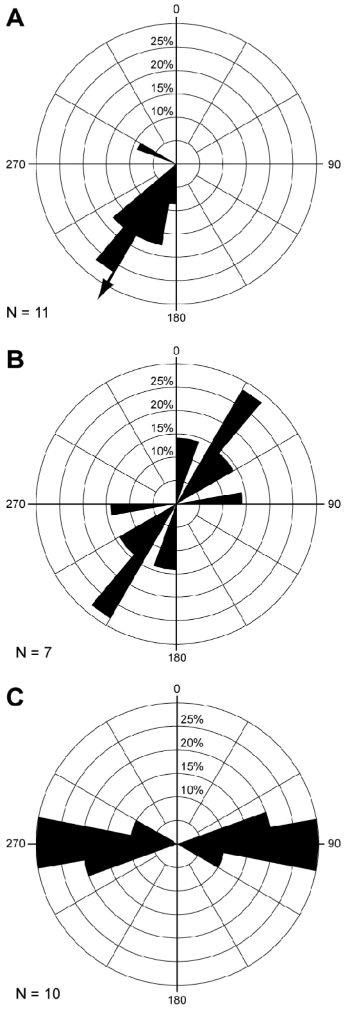
Tab.1 Petrography of the MOC arenites. Samples in alphabetical order. Qs = monocrystalline quartz; Qp = polycrystalline quartz; Af = alkalifeldspar; VRF = volcanic rock fragments. Carbonate extrabasinal grains (CE of Zuffa 1987) were subdivided into: CEM = lime mudstones (some of them displaying Calpionellid *loricae* and therefore reliably ascribed to the Maiolica Fm. - Tav. IIIa); CEW = wackestones, locally rich in radiolarians or, less commonly, containing Late Cretaceous globotruncanids; CEP = packstones; CEG = grainstones, commonly oolitic (Tav. IIIc); CEMIC = microsparites, a diagenetic facies that can originate from recrystallized micritic limestones; CEPSE = pseudosparites, a diagenetic facies that commonly originates from recrystallization of granular limestones such as packstones and grainstones, but that in principle can derive from any deeply-buried limestone type. Dolostone extrabasinal grains (DE) were subdivided into: DEMIC = microdolosparites, corresponding to dolomitized micritic limestones; DEPSE = pseudodolosparites, where the growth of large dolomite crystals has obliterated any original texture. Chert lithics were subdivided into: ChR = radiolarian chert; ChS = spicular chert; Chnn = unclassified chert. ARF = sandstone rock fragments (Tav. IIId); HM = heavy minerals; CI = carbonate intrabasinal grains; NCI = non-carbonate intrabasinal grains; mat = matrix, including recrystallized micrite; cem = calcite cement; aut = authigenic minerals; TOT = total. QFR modes after Folk (1974); C/Q, P/F, V/L ratios after Dickinson (1970); NCE-CE-NCI-CI modes after Zuffa (1987); GSZ = grain size in Φ scale.

Tab. 2 Descriptive characters (spatial coordinates and ages based on calcareous nannoplankton) for samples from Facies *Fm*$_1$. Biogenic and mineral content of washing residues was described for eight samples; the results of calcimetric and X-ray diffraction analysis are available only on four samples.

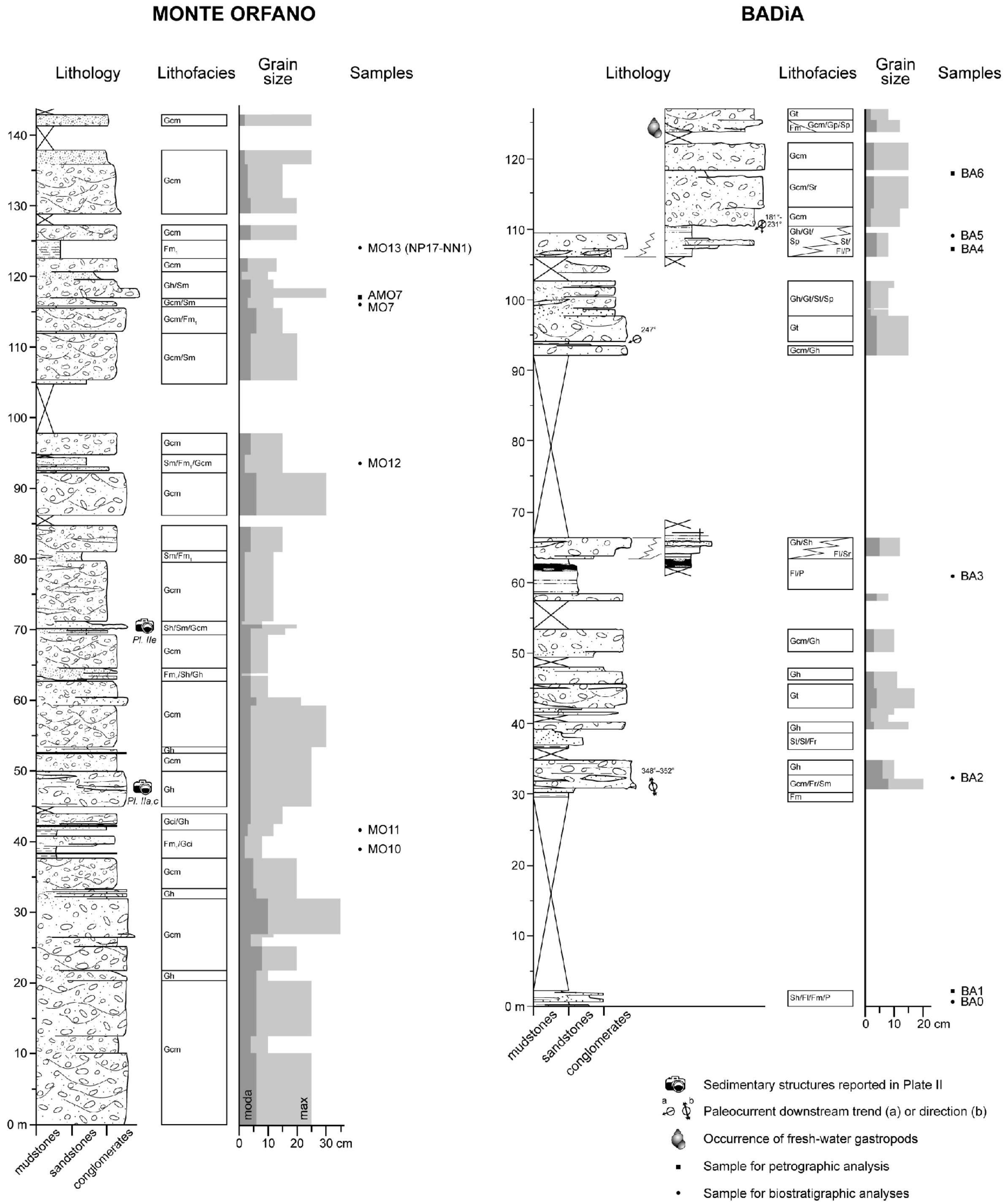
Sciunnach et al. Fig. 1



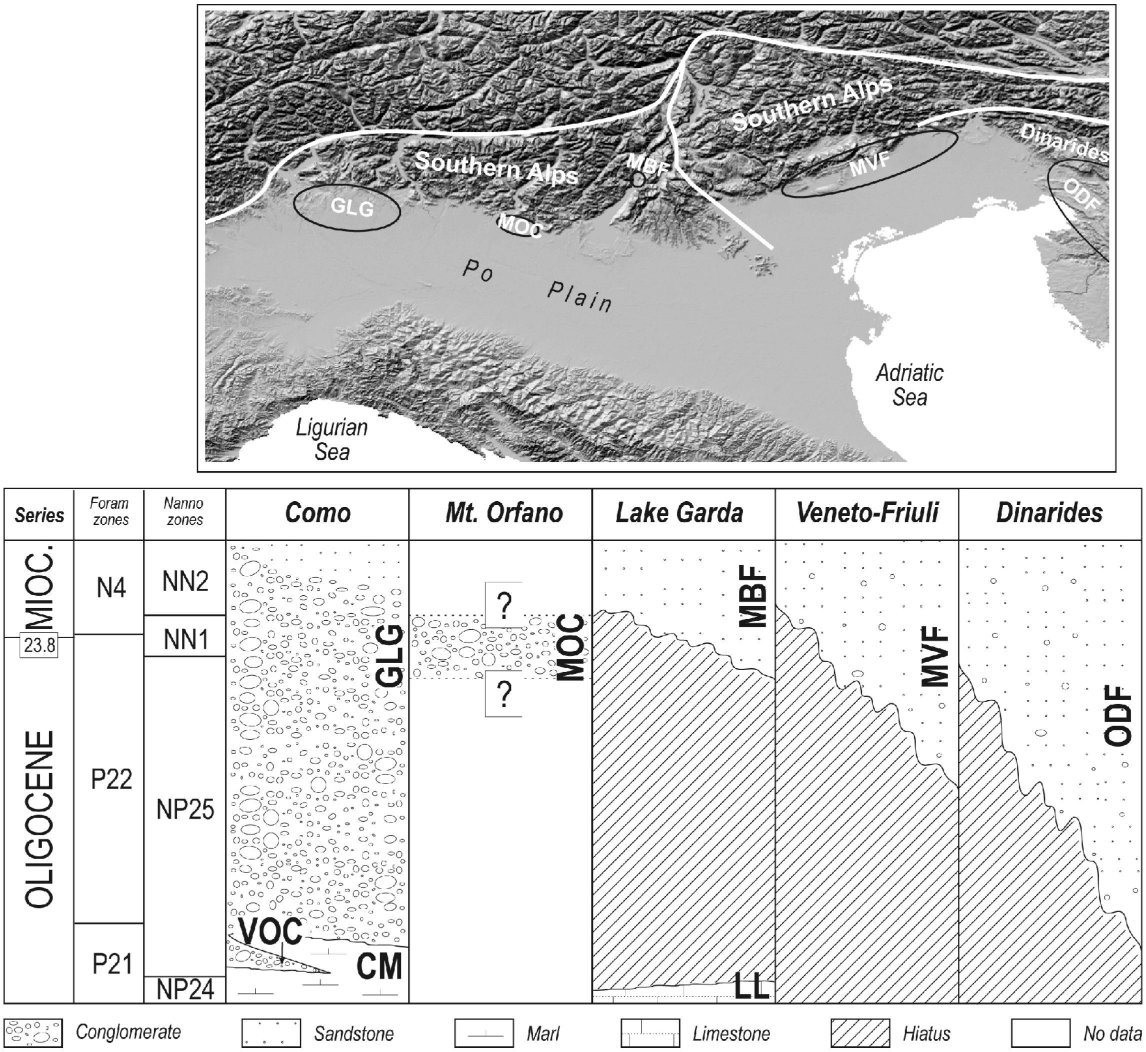
Sciunnach et al. Fig. 2



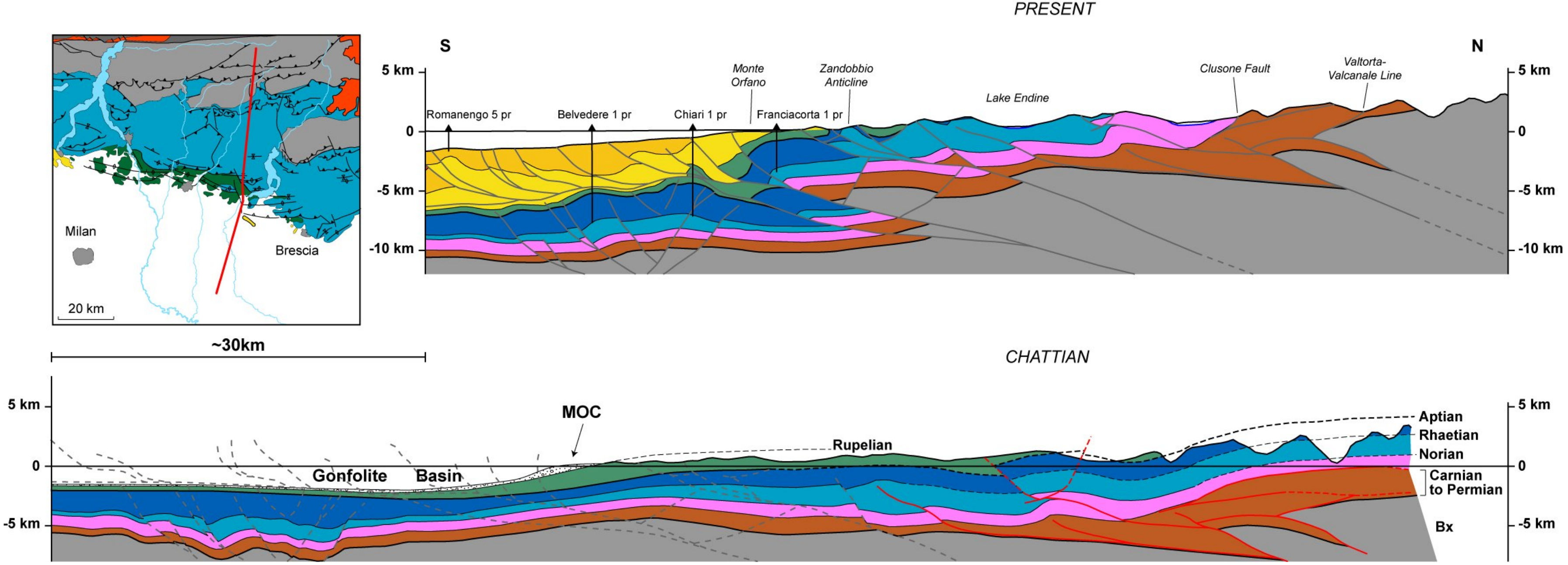
Sciunnach et al. Fig. 3



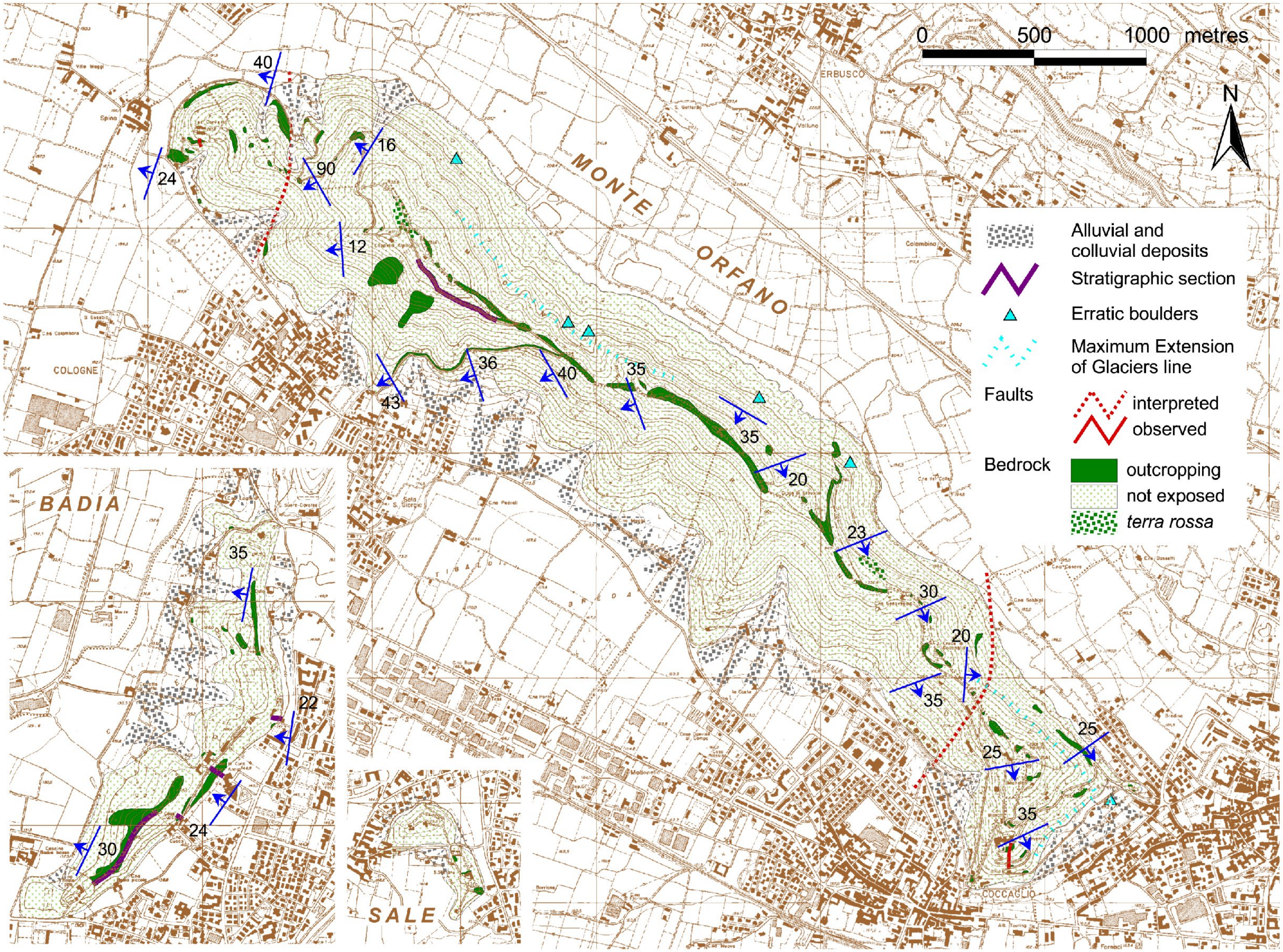
Sciunnach et al. Fig. 4

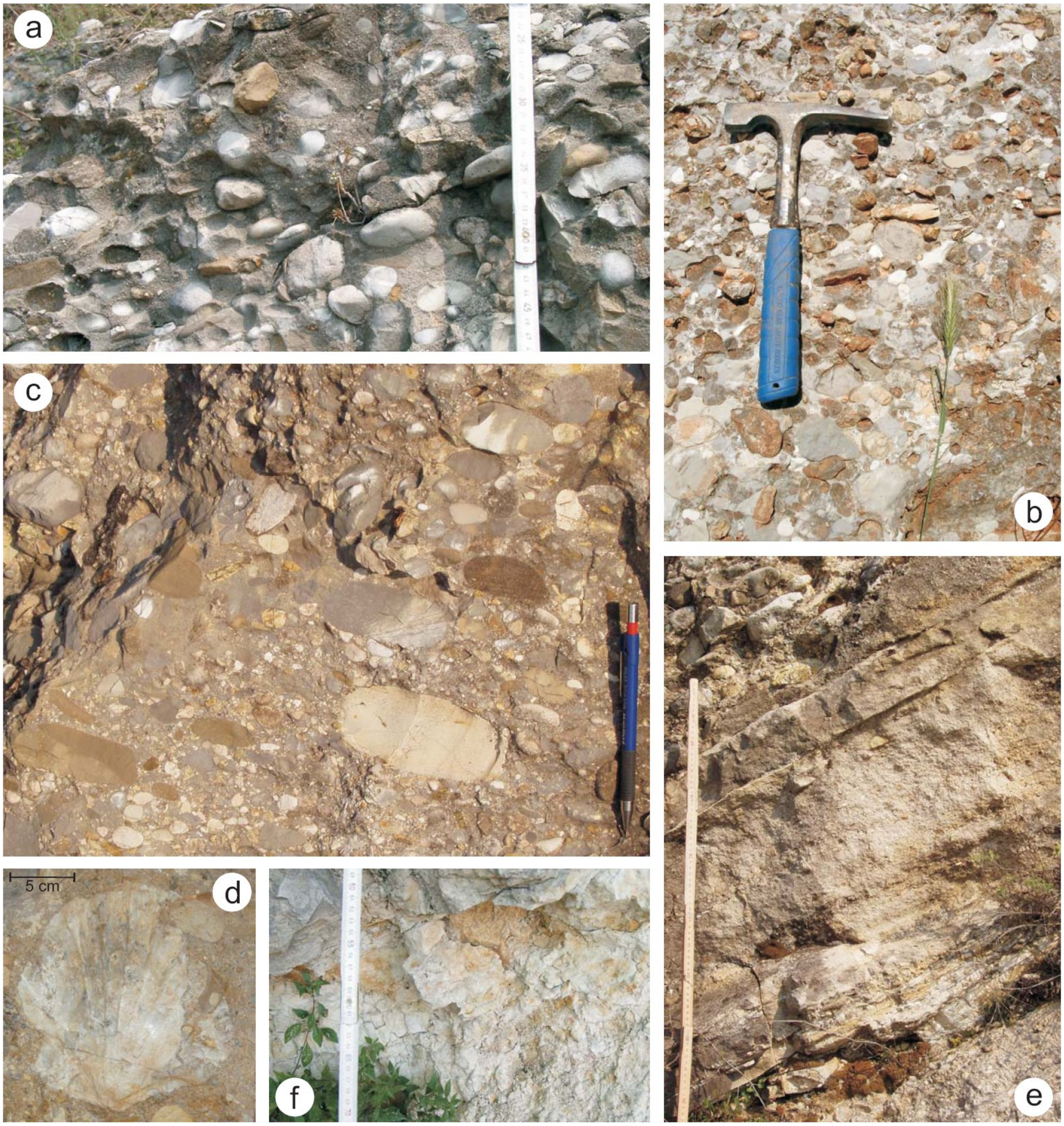


Sciunnach et al. Fig. 5



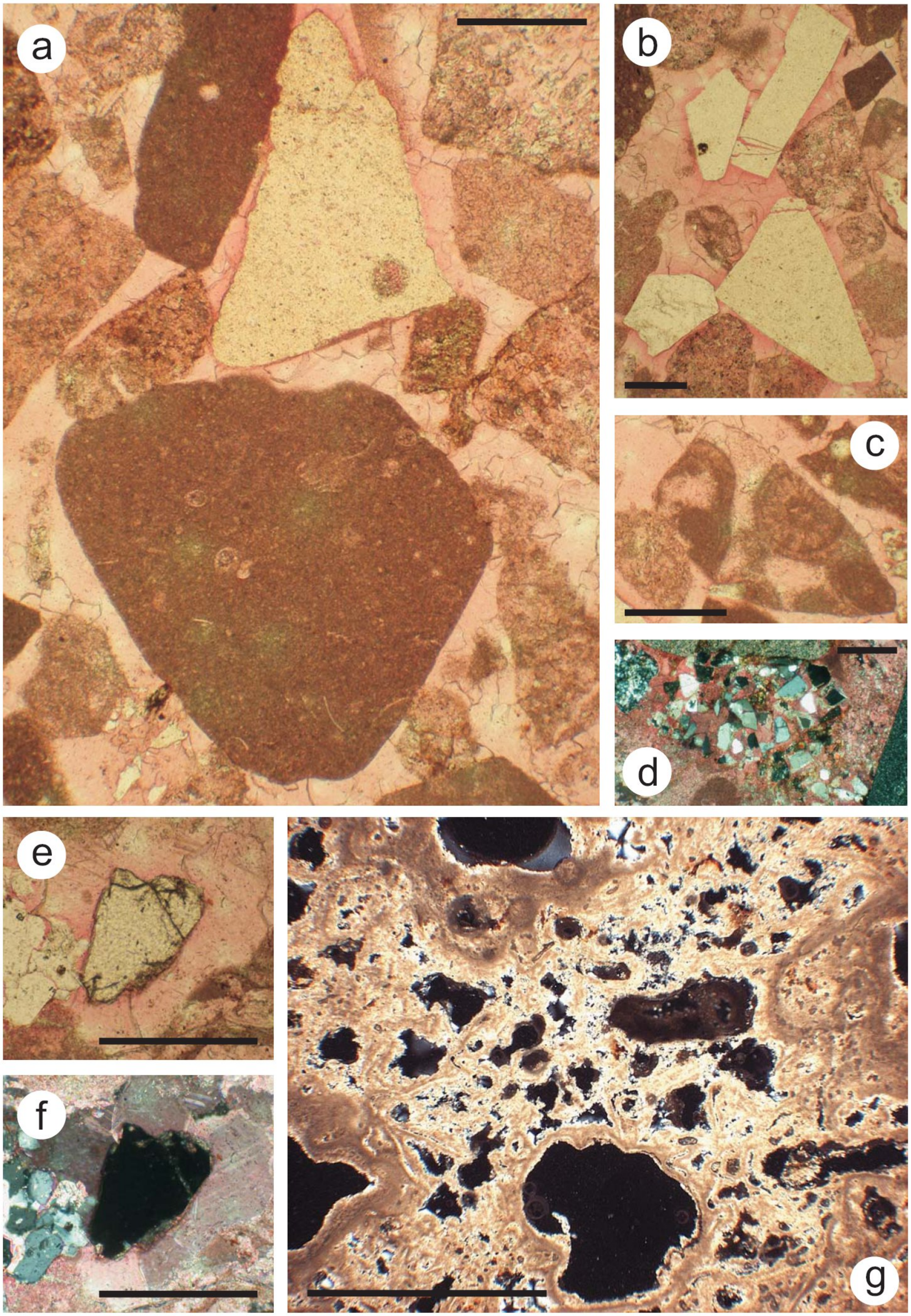
Sciunnach et al. Pl. 1



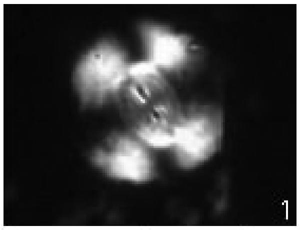


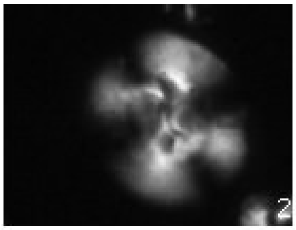
Sciunnach et al. Plate 2

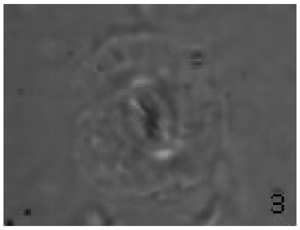
Sciunnach et al. Plate 3

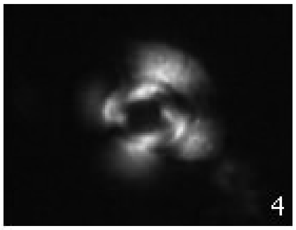


Sciunnach et al. Plate 4



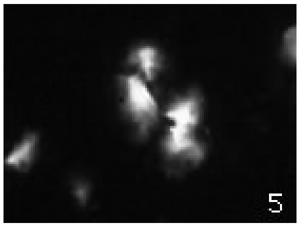


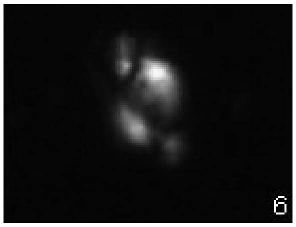


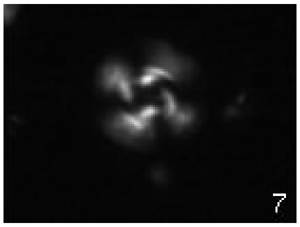


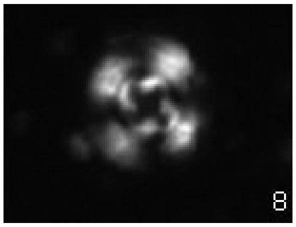
R. scissura (bisecta)

C. abisectus



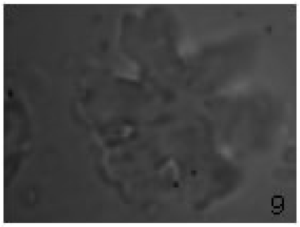


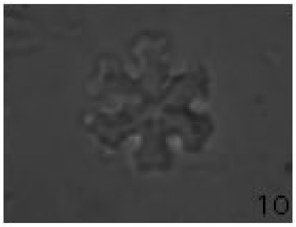


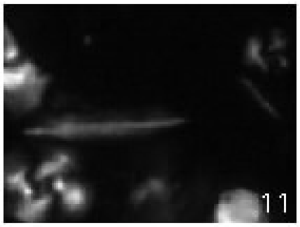


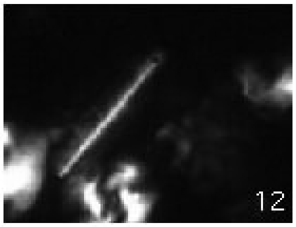
H. carteri

C. floridanus



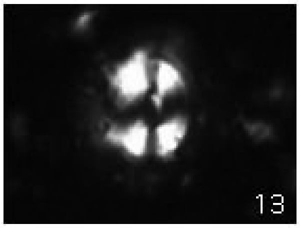


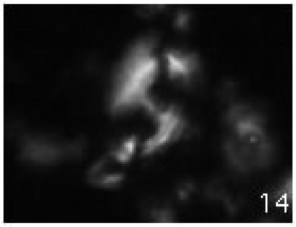


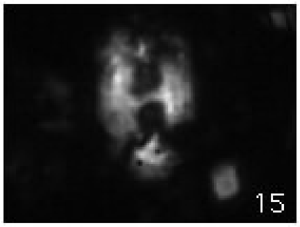


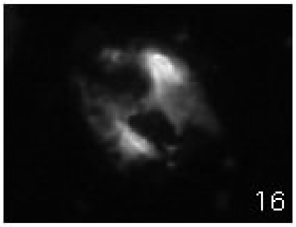
D. deflandrei

T. carinatus





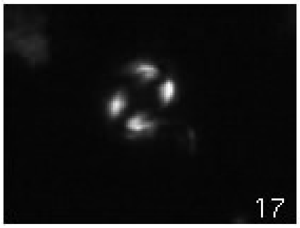


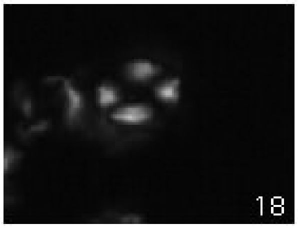


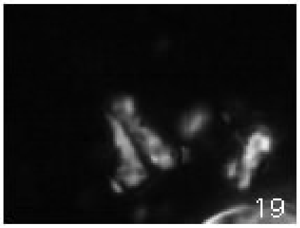
C. pelagicus

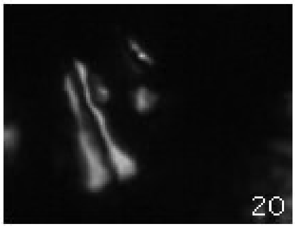
H. mediterranea

H. recta









C. pelagicus

Z. bijugatus

— — — — — — –
10 μm

Sciunnach et al. Plate 5

		Q		F	R																			
Locality	Sample	Qs	Qp	Af	VRF	CEM	CEW	CEP	CEG	CEMIC	CEPSE	DEMIC	DEPSE	ChR	ChS	Chnn	ARF	HM	CI	NCI	mat	cem	aut	TOT
Mt. Orfano	AMO2	tr.	0,0	0,0	0,0	23,0	6,0	1,3	0,3	15,3	10,7	1,3	0,0	3,0	0,3	9,0	1,0	0,3	1,0	0,0	2,0	25,0	0,3	100,0
	AMO3	1,0	0,0	tr.	0,0	16,0	2,3	2,0	3,7	24,3	8,3	1,3	0,0	3,0	1,7	5,7	0,0	0,0	3,0	0,0	0,7	27,0	0,0	100,0
	AMO4G	0,3	0,0	tr.	0,0	21,3	12,7	4,3	2,0	16,0	13,0	2,0	0,3	6,7	1,7	8,3	0,7	0,0	1,0	0,0	1,3	8,0	0,3	100,0
	AMO4F	0,3	0,0	0,0	0,0	17,3	8,0	3,7	4,0	11,3	9,3	0,3	1,0	6,0	2,0	8,3	0,3	0,0	1,0	0,3	10,3	16,3	0,0	100,0
	AMO5	1,3	0,3	tr.	0,0	15,7	1,0	0,3	0,3	26,3	10,0	1,3	22,3	1,7	0,7	3,3	0,0	tr.	1,3	0,0	0,7	12,7	0,7	100,0
	AMO6	1,0	0,0	0,0	0,3	3,3	1,0	1,0	1,7	29,0	7,7	0,7	6,3	1,7	0,3	3,7	0,0	tr.	2,7	0,0	6,0	33,7	0,0	100,0
	AMO7	1,0	0,0	0,0	0,7	21,7	6,3	1,3	2,3	10,0	21,7	1,7	0,3	6,7	0,3	10,0	1,0	0,0	0,3	0,3	6,0	8,3	0,0	100,0
Badia	BA4	0,3	0,0	0,0	1,0	18,7	1,3	1,7	1,3	29,3	5,3	0,7	5,0	2,3	0,3	5,0	0,0	0,0	0,0	0,0	12,0	15,7	0,0	100,0
	BA6	0,0	tr.	0,0	0,3	21,7	4,3	6,7	1,3	20,3	13,0	0,3	0,0	0,7	0,3	3,7	0,0	0,0	0,0	0,0	25,7	1,7	0,0	100,0
Sale	CIM	tr.	tr.	tr.	0,7	23,3	4,0	6,3	1,7	19,0	3,3	7,3	9,7	1,3	0,7	3,7	0,0	0,0	0,0	0,0	2,7	16,3	0,0	100,0
						CE						DE		Chert										

		Folk			Dickinson			Zuffa				
Locality	Sample	Q	F	R	C/Q	P/F	V/L	NCE	CE	NCI	CI	GSZ
Mt. Orfano	AMO2	0,0	0,0	100,0	0,00	-	0,00	18,4	80,2	0,0	1,4	0,25
	AMO3	1,4	0,0	98,6	0,00	0,00	0,00	15,7	80,2	0,0	4,1	1,25
	AMO4G	0,4	0,0	99,6	0,00	0,00	0,00	19,6	79,3	0,0	1,1	-0,25
	AMO4F	0,5	0,0	99,5	0,00	-	0,00	23,2	75,0	0,4	1,4	1,00
	AMO5	2,0	0,0	98,0	0,20	0,00	0,00	8,5	90,0	0,0	1,5	1,75
	AMO6	1,7	0,0	98,3	0,00	-	0,01	11,6	84,0	0,0	4,4	2,00
	AMO7	1,2	0,0	98,8	0,00	-	0,01	23,0	76,2	0,4	0,4	-0,50
Badia	BA4	0,5	0,0	99,5	0,00	-	0,01	13,7	86,3	0,0	0,0	1,75
	BA6	0,0	0,0	100,0	1,00	-	0,01	6,9	93,1	0,0	0,0	1,50
Sale	CIM	0,0	0,0	100,0	0,00	0,00	0,01	7,8	92,2	0,0	0,0	1,25
		"sedarenites"						"calclithites"				

Sciunnach et al. Tab. 1

sample	MO1	MO2	MO5	MO6	MO7	MO10	MO11	MO12	MO13	MO14
latitude (Gauss-Boaga W)	5 046 770	5 047 142	5 049 398	5 049 001	5 048 792	5 048 664	5 048 689	5 084 719	5 048 814	5 048 372
longitude (Gauss-Boaga W)	1 577 043	1 576 473	1 573 942	1 573 976	1 574 262	1 574 419	1 574 366	1 574 311	1 574 244	1 574 369
altitude (m a.s.l.)	224,0	304,0	359,5	392,0	419,0	385,0	390,0	405,0	421,0	250,0
calcimetry						81.93%		68.93%	68.18%	50.07%
mineralogy (from X-ray diffraction)						calcite		calcite, halloysite, quartz, smectite	calcite, quartz	calcite, dolomite, quartz
calcareous nannofossil assemblage	NN1	NN1	NN1	NN1	NN1	reworked	reworked	barren	NP17-NN1	barren
biogenic and mineral content of washing residues	benthic & planktonic forams, radiolarians, echinoid spines, mollusc fragments, tubular moulds of possible burrows					benthic forams, radiolarians, mollusc fragments, tubular moulds of possible burrows		benthic forams, radiolarians, mollusc fragments, tubular moulds of possible burrows	benthic forams, radiolarians, mollusc fragments, tubular moulds of possible burrows quartz	benthic forams, radiolarians, mollusc fragments, tubular moulds of possible burrows

Sciunnach et al. Tab. 2

Milano, November 19th 2008

Dear Prof. Dullo,

please find enclosed the revised version of manuscript

The Monte Orfano Conglomerate revisited: stratigraphic constraints on Cenozoic tectonic uplift of the Southern Alps (Lombardy, northern Italy)

by Sciunnach, Scardia, Tremolada and Premoli Silva.

We did our best to comply to the referee's requests, as far as both style and contents are concerned. The text has been thouroughly revised and not a single observation has been ignored. In particular:

A new paragraph concerning the structural evolution has been added to the "discussion" chapter, and a new image (Fig. 5) has been added to meet Prof. Bernoulli's request.

Fig. 1 has been modified by adding a stratigraphic column for the source rocks of the Monte Orfano Conglomerate, but the range of the map has not been extended (as requested by Prof. Bernoulli) because this would have lessened the detail on the formations decribed in the text. Rather, some information on the regional-scale geology has been added in the sketch map of Fig. 5 and by "dressing" Fig. 4 with the topography and ther major faults. We hope that this solution is satisfactory for you.

Fig. 3 has been improved as requested by both referees.

Fig. 4 now includes also the Dinaric foredeep. This has not been requested by the referees, but allowed us to update the paper to the most recent bibliography.

Plate I has been correceted as requested by both referees.

Plate V has been improved (unrequested graphic improvement).

We hope that the regional significance of the Monte Orfano Conglomerate is highlighted by the corrections, more than it was before. The quotations requested by Picotti were added only as far as Bertotti et al. is concerned, because we considered the paper by Garzanti & Malusà less relevant.

Although the letter arrives to you with 1-day delay, I hope that the paper (sent yesterday, but unsuccessfully, through the Editorial Manager) can be accepted as a revised paper and not as a new submission.

Best regards

Dario Sciunnach