Reassessing the biostratigraphy and the paleobathymetry of the Gonfolite Lombarda Group in the Como area (northern Italy)

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

Elisa Guasti
TNO - Geobiology team, Princetonlaan 6, NL-3584 CB Utrecht, The Netherlands.

Giancarlo Scardia*
Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano-Pavia, via Bassini 15, I-20133 Milano, Italy.

Cipriano Carcano
Burren Resources Petroleum, Kierran Cross 11 Strand, London WC2N 5HR, United Kingdom.

Sergio Rogledi
ENI E&P, via Emilia 1, I-20097 San Donato Milanese, Italy.

Dario Sciunnach
Regione Lombardia, via Rosellini 17, I-20124 Milano, Italy.

* Corresponding author. E-mail: scardia@mi.ingv.it

Key-words: Gonfolite Lombarda Group; biostratigraphy; calcareous nannofossils; foraminifers; Southern Alps; Cenozoic; Italy

Abstract

Calcareous nannofossil and foraminiferal analyses have been carried out on outcrops from the type-area of the Gonfolite Lombarda Group (Como, northern Italy). In these marine fine- to coarse-grained clastics, rapidly accumulating at the southern front of the uprising Alpine range during the Oligo-Miocene, a scarce, but reliable, sequence of calcareous nannofossil events has been observed, allowing to refine the previous age assignments. Planktonic foraminifera were found to be extremely rare and provided limited biostratigraphic information. The Villa Olmo Conglomerate and the Chiasso Formation contain the Last Occurrence (LO) of *Sphenolithus distentus* and the First Occurrence (FO) of *Triquetrorhabdulus carinatus*, which are characteristic of the nannofossil zones NP24 and NP25 (Chattian), respectively. The lower part of the Como Conglomerate was deposited during the zone NP25, whilst the upper part of the Como Conglomerate straddles the Chattian/Aquitanian boundary in zone NN1. The deposition of the Prestino Mudstones also occurred during zone NN1. However, the upper part of this formation has been dated as Burdigalian during nannofossil zone NN2. The deposition of the upper part of the Val Grande Sandstone has been assigned to the NN3 zone owing to the presence of the taxon *Sphenolithus belemnos*, which is restricted to NN3. The upper part of the investigated section is characterized by the deposition of the Lucino Conglomerate and its fine-grained members (Lucinasco and Lurate Caccivio Mudstones). The Lucinasco Mudstones have been dated as late Burdigalian corresponding to zone NN4, whilst the overlying Lurate Caccivio Mudstones were deposited during the Langhian part of the zone NN5, based on the presence of *S. heteromorphus* and the absence of *H. ampliaperta*. On the whole, the base and the top of the outcropping Gonfolite Lombarda Group result from our study to be younger than hitherto proposed, allowing to resolve certain previous conflicts with the few radiometric dates available for clasts from the Gonfolite Lombarda Group. The depth of deposition was upper bathyal during the Chattian and the Aquitanian and shallowed to neritic during the deposition of the Langhian Lurate Caccivio Mudstones.

Riassunto

Nell’area-tipo del Gruppo della Gonfolite Lombarda, in Provincia di Como, sono state eseguite analisi biostratigrafiche e paleobatimetriche per mezzo di foraminiferi e nannofossili calcarei. Nella successione clastica, caratterizzata da sedimenti da fini a grossolani accumulatisi al fronte meridionale della catena alpina nell'intervallo Oligocene-Miocene, è stata riconosciuta una serie di eventi biostratigrafici a nannofossili calcarei, che ha permesso di migliorare le precedenti datazioni biostratigrafiche. Al contrario, la scarsità di foraminiferi planctonici e bentonici nei campioni analizzati non ha fornito significativi elementi temporali. La Formazione di Chiasso e il Conglomerato di Villa Olmo contengono la prima e l'ultima comparsa di *Sphenolithus distentus* e *Triquetrorhabdulus carinatus*, rispettivamente, che indicano le zone a nannofossili NP24-NP25 nell'Oligocene superiore (Cattiano). La zona NP25 caratterizza anche la parte inferiore del Conglomerato di Como, mentre la parte superiore è stata datata come NN1, a cavallo del limite Oligocene/Miocene. Le sovrastanti Peliti di Prestino si sono depositate nelle zone a nannofossili NN1 e NN2. Un solo campione è stato analizzato dalle Arenarie di Val Grande e ha permesso di attribuirne la parte superiore alla zona a nannofossili NN3, per la presenza del marker zonale *Sphenolithus belemnos*. La datazione del Conglomerato di Lucino, è stata eseguita analizzandone i membri pelitici, di Lucinasco e di Lurate Caccivio, rispettivamente assegnati alle zone NN4 (Burdigaliano superiore) e NN5 (Langhiano). Complessivamente, la base e il tetto del Gruppo della Gonfolite Lombarda risultano avere, sulla base del nostro studio, un'età più giovane di quanto ritenuto, permettendo così di risolvere alcune incompatibilità esistenti con le poche datazioni radiometriche disponibili per i clasti della Gonfolite. Le associazioni a foraminiferi bentonici e planctonici hanno fornito alcune informazioni paleobatimetriche per le unità analizzate. I dati ottenuti suggeriscono che il Gruppo della Gonfolite Lombarda nell'area di Como si sia deposto prevalentemente in un ambiente batiale superiore, con una diminuzione della profondità nelle Peliti di Lurate Caccivio, depostesi in ambiente neritico.

Introduction

The study of syn-orogenic deposits from foreland basins commonly represents the most feasible way to recognize and date discrete stages of paroxysmal activity ("tectonic climaxes") in the related orogens. The Gonfolite Lombarda Group (GLG), clastic infilling of the Alpine retro-foreland basin during the Oligo-Miocene, has been traditionally a key-succession to constrain the post-collisional evolution of the Alps (e.g. Bernoulli et al. 1989; Castellarin et al. 1992; Bersezio et al. 1993; Schumacher et al. 1997). The importance of the GLG has led to several studies since the beginning of the XX century, mainly dealing with petrographic, biostratigraphic, and sedimentologic aspects (Cita 1957, and references therein). Two main Alpine tectonic phases (Schumacher et al., 1997) and at least three unconformity-bounded stratigraphic sequences (Gelati et al., 1988; 1991) are documented in the sediments of GLG, the precise age assignment of which is of remarkable importance to reconstruct their age and duration. However, in spite of the wealth of studies, some uncertainties in dating the GLG still persist as a result of the limited and poorly preserved paleontological material, also affected by significant reworking.

With this work, we contribute to the previous studies by providing new biostratigraphic and paleobathymetric constraints for the GLG in the Como province (northern Italy, Fig. 1), based on calcareous nannofossils and foraminifera.

Previous studies

The GLG occurs over a wide area along the southern margin of the Alps from Lake Maggiore to the Brianza area, south of Lake Como, reaching its maximum stratigraphic exposure in the Como area (Cita 1957). The first biostratigraphic studies were performed by using mainly planktonic foraminifera as a biostratigraphic tool in the Brianza area (Consonni 1953) and in the province of Como (Santini 1956) and Varese (Cita 1953; Villa 1955). Geologic mapping and extensive biostratigraphic ages for the whole GLG were summarized by Cita (1957) (Fig. 2) and, then, partially updated by Longo (1968). More recently, Gunzenhauser (1985), Napolitano (1985), and Gelati et al. (1988) investigated the area between Como and Varese with particular emphasis to the section of the Monte Olimpino railway tunnel (Italy-Switzerland border: Bernoulli et al. 1989, Gelati et al.1991). The sedimentological observations and and the new biostratigraphic data collected in the 80s were integrated into the lithostratigraphic framework of Gelati et al. (1988), still widely used without substantial modifications (Fig. 2).

The first biostratigraphic study carried out with calcareous nannoplankton was undertaken by Rögl et al. (1975). These authors analyzed a few sections between Chiasso (Switzerland) and Como and integrated planktonic foraminiferal, palynological, and calcareous nannofloral data (Fig. 2). Valdisturlo et al. (1998) dealt with the lowermost part of the GLG succession, mostly the Villa Olmo Conglomerate, providing also nannofossil determinations (Fig. 2). More recently, Sciunnach & Tremolada (2004) investigated several outcrops of the GLG in the Brianza area by means of calcareous nannofossils obtaining significantly younger ages than those proposed by Consonni (1953).

Radiometric datings and the Villa Olmo Conglomerate paradox

Biostratigraphic constraints obtained for the GLG were followed by radiometric datings between the late 80s and the early 90s. Giger & Hurford (1989) provided K-Ar and fission track ages of pebbles of intrusive rocks embedded in the GLG conglomerates, whilst Bernoulli et al. (1993) published $^{87}Sr/^{86}Sr$ ages of mollusk shells from the GLG. On the whole, the different radiometric measures provided numerical ages compatible with the available GLG biostratigraphic constraints, except for the Villa Olmo Conglomerate. A double K-Ar determination carried out by Giger & Hurford (1989) on a tonalite pebble referred to the Bergell pluton provided ages of 31.9 ± 0.4 and 31.7 ± 0.5 Ma, roughly identical with the available biostratigraphic constraints provided by Gelati et al. (1988). More recently, Valdisturlo et al. (1998) dated the Villa Olmo Conglomerate to the early Rupelian, corresponding to the interval between 33.9 and 33.0 Ma (Gradstein et al. 2005), which is consistently older than the K-Ar cooling ages provided by Giger & Hurford (1989). The Villa Olmo Conglomerate paradox was formerly discussed by Giger & Hurford (1989) and referred to a probably inadequate calibration of the time scales (Bernoulli et al. 1993). The necessity of more detailed biostratigraphic investigations was already highlighted by Giger & Hurford (1989) and Carrapa & Di Gliulio (2001). On the other hand, according to Di Giulio et al. (2001), the K-Ar radiometric dating by Giger & Hurford (1989) should be considered as questionable.

Material and methods

In the framework of the forthcoming Sheet 96 “Seregno” of the Geological Map of Italy at the 1: 50,000 scale (CARG Project) a detailed field mapping of the GLG was carried out leading to the discovery of new outcrops suitable for biostratigraphic analyses. The geological mapping focused on the Como area and extended laterally in order to cover the whole vertical stratigraphic succession and test the lateral continuity of lithostratigraphic boundaries and biostratigraphic ages.

A total of 55 samples obtained from marlstones and mudstones of the GLG was collected from several outcrops in the Como area and the precise location of each sample is listed in Table 1. In addition, 2 samples were analyzed from new outcrops of GLG deposits in the Brianza area, in order to improve the results obtained by Sciunnach & Tremolada (2004). These outcrops lie in a stratigraphic position respectively lower and upper with respect to the succession described in Sciunnach & Tremolada (2004) and their precise location is reported in Table 1. Calcareous nannofossil biostratigraphic and semiquantitative analyses were performed on 51 samples, whilst 18 samples were processed for foraminiferal investigations (Table 1). All samples for both nannoplankton and foraminifera were prepared in the Eni E&P laboratories of San Donato Milanese. Calcareous nannofossils were investigated by using standard smear slide techniques described by Bown & Young (1998) and standard light microscope methodologies under crossed polarizers and transmitted light at 1250x magnification. Calcareous nannofossils were identified at species level and the taxonomic schemes are those of Romein (1977), Aubry (1984; 1988, 1989, 1990), Perch-Nielsen (1985), de Kaenel & Villa (1996), Varol (1998), and Young (1998). The NP and NN biozonations of Martini (1971), with some modifications by Perch-Nielsen (1985), Young (1998), and Raffi et al. (2006) were adopted with the time scale of Gradstein et al. (2005). The categorization of Bown & Young (1998) was used to estimate the degree of etching (E index) and overgrowth (O index) of the calcareous nannofossils.

A quantitative analysis was tentatively performed on samples prepared for foraminiferal analyses, but the paucity of specimens and the extremely poor preservation prevented to reach a statistically significant number in most samples. Therefore, a qualitative analysis was preferred. Foraminifera were identified at species level, where possible, according to the *Foraminiferi Padani* atlas (AGIP 1982) and Iaccarino et al. (2005). The paleodepth limits follow those documented by van Morkhoven et al. (1986). Other microfossils, such as radiolaria, pyritized diatoms, ostracods and fragments of echinoids and sponges were also estimated.

Biostratigraphy and paleobathymetry

Calcareous nannofossils

Preservation and abundance of calcareous nannofossils vary significantly as a result of diagenetic overprint. In general, the preservation ranges from poor to good (E1 to E3; O1 to O3) and calcareous nannofossils are fairly abundant, although a few samples are barren (Tab. 1). Reworking of Eocene and Cretaceous taxa was observed in several samples (Tab. 1). The reworked Cretaceous assemblage consists of *Watznaueria barnesiae*, *Nannoconus* spp., *Cretarhabdus crenulatus*, *Prediscosphaera* spp., *Micula decussata* (*Micula staurophora* for several authors), and *Tranolithus orionatus*, whereas *Sphenolithus radians*, *Toweius*? *gammation*, and *Reticulofenestra dictyoda* are the components of the reworked Eocene nannofloral communities.

The concurrent presence of *Sphenolithus ciperoensis* (range NP24-NP25), *Cyclicargolithus abisectus* (NP24-NN1), *Sphenolithus dissimilis* (NP24-NN3), and

Sphenolithus distentus (NP23-NP24) indicates that the samples collected at the base of the Chiasso Formation (GLG 1–GLG 6) can be assigned to the Chattian NP24 nannofossil zone (Fig. 3). Abundant components of the calcareous nannofossil assemblage at the base of the succession are *Coccolithus pelagicus*, *Reticulofenestra bisecta* (*Reticulofenestra scissura* for several authors), *Cyclicargolithus floridanus*, *Reticulofenestra minuta*, *Sphenolithus moriformis*, *Sphenolithus dissimilis* and rare specimens of *Zyghrablithus bijugatus*, *Discoaster deflandrei,* and *Clausiccocus fenestratus*. The Last Occurrence (LO) of *S. distentus*, which indicates the base of NP25 zone, has been observed in the sample GLG 6. The identification of NP25 is confirmed by the First Occurrence (FO) of *Triquetrorhabdulus carinatus* (NP25-NN2) in the sample GLG 7 (Tab. 1; Fig. 3). The interval from sample GLG 7 up to GLG 30 is characterized by major changes in abundance of calcareous nannofossils, whereas the composition shows meaningless variations.

The lower part of the Como Conglomerate (sample GLG 24 to GLG 30) was deposited during the nannofossil zone NP25 owing to the presence of *S. ciperoensis*. In particular, the sample GLG 30 contains the LO of *S. ciperoensis*, which defines the base of NN1 (Tab. 1; Fig. 3). Calcareous nannofossils are extremely abundant in the sample GLG 30 and characterized by the lowest degree of diagenetic overprint (E1; O1). In general, this interval is characterized by a worldwide low-diversity assemblage (e.g., Fornaciari and Rio 1996; Young 1998). Sample GLG 32 contains the LO of *R. bisecta* (Tab.1; Fig. 3). The LO of *R. bisecta* is a useful event because it is close to the Oligocene/Miocene boundary (Fornaciari et al., 1996) and may represent a fairly good approximation of the boundary itself (e.g., Perch-Nielsen 1985; Berggren et al. 1995).

The Prestino Mudstones were deposited in the Neogene nannofossil zones NN1-NN2. Sample GLG 39 is characterized by the FO of *Helicosphaera carteri*, which represents the first evidence of Neogene age and it ranges from intra-NN1 to Recent (e.g. Young, 1998 and references therein). In addition, the sample GLG 40 contains the LO of *C. abisectus*, which suggests the upper part of nannofossil zone NN1 (e.g., Perch-Nielsen, 1985; Young, 1998). The sample GLG 41 is barren, but GLG 42 contains the FO of *Helicosphaera ampliaperta* (NN2-NN4). The concurrent presence of *H. ampliaperta* and *T. carinatus* (Tab. 1; Fig. 3) suggests zone NN2 for the upper part of the Prestino Mudstones. Calcareous nannofloral assemblages of this interval are dominated by *C. pelagicus*, *C. floridanus*, *R. minuta* group with low quantities of *T. carinatus*, *S. moriformis*, *S. dissimilis*, *Pontosphaera* spp., and *Helicosphaera* spp.

Only the sample GLG 43 was collected from the Val Grande Sandstone and it contains one specimen of the taxon *Sphenolithus belemnos*, whose occurrence indicates zone NN3 (Young, 1998).

The investigations of the Lucinasco Mudstones (samples GLG 44 to GLG 47) show a marked change in calcareous nannofloral composition. This interval is characterized by several reworked specimens of *S. ciperoensis*, *C. fenestratus*, *S. dissimilis*, *C. abisectus*, and *R. bisecta* and by the presence of *Sphenolithus heteromorphus* (NN4-NN5) and *Helicosphaera ampliaperta* (Tab. 1; Fig. 3). The co-occurrence of *S. heteromorphus* and *H. ampliaperta,* which LO defines the base of NN5, indicates the nannofossil zone NN4 for samples GLG 44 to GLG 47. However, it is unclear if the specimens of *H. ampliaperta* observed in this interval are *in situ* or reworked. In particular, a specimen of *Sphenolithus disbelemnos* (NN2-NN3) has been identified in the sample GLG 47 and may suggest reworking of sediments ascribable to nannofossil zones NN2 or NN3.

Calcareous nannofossils decrease drastically in abundance and show a poor preservation (E3; O3) at the top of the section in the Lurate Caccivio Mudstones. The calcareous nannofloral assemblages in samples GLG 48 and GLG 49 consist of dissolution-resistant taxa such as *S. moriformis*, *H. carteri*, *C. floridanus*, and *Reticulofenestra pseudoumbilica* <7μm. The presence of *S. heteromorphus* and the absence of *H. ampliaperta* suggests that these samples may be assigned to the Langhian part of the zone NN5 (Tab. 1; Fig. 3). The ordered stacking of calcareous nannoplankton biozones described above was not appreciably affected by tectonic deformation of the studied sedimentary succession.

The results obtained from the analysis of 2 samples collected in the Brianza area are shown in Table 1. The sample GLG B1 was collected in an outcrop ascribable to the Fornaci Marls (Fornaci lithozone in Sciunnach & Tremolada, 2004) on the basis of lithology, facies, and petrographic composition. Calcareous nannofossils are common and fairly well-preserved. The concurrent presence of *R. bisecta* (NP15-NN1), *H. recta* (NP24-NN1), *T. carinatus* (NP25-NN2), *C. abisectus* (NP24-NN1), and *C. fenestratus* (NP15-NN1) coupled with the absence of *S. ciperoensis* (NP24-NP25) and typical Neogene taxa such as *H. carteri* may suggest the Oligocene part of the nannofossil zone NN1. The sample GLG B2, collected in the uppermost beds of the Briosco Sandstone (Lambro lithozone in Sciunnach & Tremolada, 2004), is characterized by a poorly-preserved nannofloral assemblage. In particular, the presence of *C. floridanus* (NP12-NN6), *Helicosphaera californiana* (NN5-NN6) and *Reticulofenestra pseudoumbilica* >7μm (NN6-NN15; Young, 1998), and the absence of *S. heteromorphus* (NN4-NN5) may indicate the Serravallian nannofossil zone NN6.

Foraminifera

Foraminiferal assemblages show generally a fairly poor preservation and only a few samples contain a significant number of well-preserved specimens, although reworked forms are often present. The results are shown in Table 2.

The samples GLG 7, GLG 10, GLG 12 from the Villa Olmo Conglomerate and GLG 26 from the Como Conglomerate are very poor and no age-diagnostic planktonic foraminifera are present.

The samples GLG 38a, GLG 38b, GLG 40a, GLG 40b and GLG 42a from the Prestino Mudstones are characterized by variable richness and preservation of foraminifera. In sample GLG 38a, the assemblage is relatively rich, but poorly preserved and reworked specimens have been observed. For instance, in this sample the presence of the Oligocene foraminiferal taxon *Paragloborotalia opima nana* is interpreted as reworked since calcareous nannofossils clearly indicate a Miocene age. The taxon *Praeglobobulimina ovata* is dominant within the benthic foraminiferal assemblage. Sample GLG 38b contains Miocene benthic foraminifera such as *Gyroidinoides altiformis* and *Uvigerina* cf. *auberiana*. Preservation and species richness in the sample GLG 40a are higher. The benthic foraminiferal assemblage is characterized by *Uvigerina proboscidaea*, *Sphaeroidina bulloides*, *Osangularia* spp., *Hanzawaia boueana* and common *P. ovata*. The samples GLG 40b and GLG 42a are too poor to provide any biostratigraphic information. In addition, a few radiolaria have been identified in the sample GLG 40b.

The sample GLG 43 from the Val Grande Sandstone contains only a single specimen of *Gyroidina* sp. and an agglutinated foraminifer.

Foraminifera in the samples GLG 45, GLG 46 and GLG 47 from the Lucinasco Mudstones show a very poor preservation. A single occurrence of *Uvigerina mantaensis* is recorded in GLG 47 and a single pyritized diatom in GLG 46.

Samples from the Lurate Caccivio Mudstones (GLG 47a, GLG 48, GLG 48a and GLG 49) are generally poor and planktonic foraminifera are generally absent. The benthic foraminiferal assemblage varies significantly from the previous samples. In sample GLG 47a, typical shallow-water species such as *Elphidium* sp. and *Asterigerinata planorbis* are present. A foraminiferal assemblage with *S. bulloides*, *H. boueana*, and *Valvulineria* spp. characterizes sample GLG 48. A similar assemblage is present in samples GLG 48a and GLG 49 together with pyritized diatoms and radiolaria.

Paleobathymetry and depositional settings

The abundance and presence/absence of both planktonic and benthic foraminifera are symptomatic of variations in the water depth. The planktonic foraminifera occur sporadically along the section investigated, whilst benthic foraminiferal assemblages provide the only paleobathymetric information. Deposition during the late Oligocene–early Miocene occurred in an upper bathyal environment. The presence of *Sphaeroidina bulloides*, *Pullenia bulloides* and *Globocassidulina subglobosa* in samples from the Villa Olmo Conglomerate section (GLG 7 and GLG10) points to a depth range of 200–600 m (van Morkhoven et al. 1986) (Fig. 3). A similar upper bathyal setting is also suggested for the Prestino Mudstones (Fig. 3). A richer assemblage composed by a few planktonic foraminifera and benthic foraminifera, such as *Uvigerina proboscidaea*, *Hanzawaia boueana*, *S. bulloides*, *Osangularia* spp., *Valvulineria* spp., occurs from sample GLG38a to GLG40. Furthermore, the occasional dominance of *Praeglobobulimina ovata* in the same interval suggests episodes of decreasing sea-floor oxygenation. The samples collected in the Lucinasco Mudstones are very poor, preventing any paleobathimetric determination. In the Lurate Caccivio Mudstones the foraminiferal assemblage suggests a different scenario and a possible shallowing is seen in the sample GLG47a. Here, the occurrence of typical inner neritic benthic foraminifera such as *Elphidium* sp. and *Asterigerinata planorbis* together with the absence of planktonic foraminifera and the paucity of calcareous nannofossils suggest a shallowing toward inner-middle neritic conditions, possibly shallower than 100m (Fig. 3). However, we do not exclude that transport and dissolution may have affected the assemblage. The uppermost samples of the Lurate Caccivio Mudstones are composed by a mix of shallow-water specimens (e.g. *Elphidium* sp. and *Cancris* sp.) together with deeper-water specimens (e.g *Pullenia bulloides*). Therefore, indications of shallowing or deepening have to be carefully considered since reworking, transport and dissolution might have affected the assemblage. At this regard, the occurrence of terrestrial mammal remain in the upper Lucino Conglomerate (Sordelli 1896; Dal Piaz 1929) can be consistent with a shallow water environment. A shallowing trend in the Lurate Caccivio Mudstones was already suggested by Cita (1957), based on qualitative considerations. Conversely, Gelati et al. (1988) ascribed the Lurate Caccivio Mudstones to bathyal conditions (from 550-700m to 1000-1300m).

Bernoulli & Gunzenhauser (2001) described an event of diatom bloom in the Lucinasco Mudstones type-section (Montano member in Bernoulli & Gunzenhauser 2001) in response to an episode of intensified nutrient supply and high organic productivity. This level is also associated with traces of volcanic glass and pumice. According to these authors, recycling of silica by upwelling and input of windborne cineritic material and its alteration by seawater may be responsible for elevated concentrations of dissolved silica favoring diatom blooms in surface waters. The diatoms deposited in the Lurate Caccivio Mudstones could indicate a similar mechanism and pyritization could have occurred in a low-oxygen environment. However the foraminiferal assemblage is composed mainly by oxyc specimens, except for the occurrence of a dysoxic species *Cassidulinoides bradyi* in the sample GLG 49. Therefore pyritization might have occurred in sediments after burial.

Discussion

The biostratigraphic ages obtained from our analyses partially correlate with the previous investigations of Cita (1957) and Rögl et al. (1975). Conversely, our biostratigraphic ages are generally younger than those proposed by Gelati et al. (1988), especially concerning the biostratigraphy of the Villa Olmo Conglomerate, the Chiasso Formation, and the Lurate Caccivio Mudstones. Because of the paucity and poor preservation of planktonic foraminifera, our biostratigraphic interpretations are mainly based on the results from calcareous nannofloras.

The age assignment of the top of the Chiasso Formation/Villa Olmo Conglomerate has been under debate in the last four decades. Rögl et al. (1975) found the nannofossil zone NP24 and the foraminiferal zone *Globigerina opima opima*, which corresponds to the P21 zone, at the Rio Maiocca section. Similar results were obtained by Gelati et al. (1988) in the Brusata section, province of Varese. However, Gelati et al. (1988) documented foraminiferal assemblages indicating the P19/P20 zone, which correlates with the NP23 nannofossil zone, in the Monte Olimpino 2, Ponte Chiasso, and Villa Olmo sections. This discrepancy led Gelati et al. (1988; 1991) to suggest the presence of an erosional unconformity between the Chiasso Formation and the Como Conglomerate in the Monte Olimpino area. Our data partially correlate with the results obtained by Rögl et al. (1975) and imply that the Chiasso Formation and the Villa Olmo Conglomerate deposited during the same time interval in the nannofossil zones NP24-NP25 (Chattian). Rögl et al. (1975) identified all the age-diagnostic taxa observed in our study except *T. carinatus*, which allows us to assign the upper part of the Villa Olmo Conglomerate to the zone NP25, as well as the lower part of the Como Conglomerate. Some plausibly mistaken taxonomic identification at species level and/or the analysis of reworked material may explain the Rupelian age obtained by Gelati et al. (1988) in the Como area. The new biostratigraphic data obtained in this study do not support the important time-transgressive erosional contact between Chiasso Formation and Como

Conglomerate documented by Gelati et al. (1988; 1991). As a result, the erosional contact between the Como Conglomerate and the Chiasso Formation is constrained within the nannofossil zone NP25. The lack of an important time-transgressive erosional contact between Chiasso Formation and Como Conglomerate also suggests the inclusion of the Chiasso Formation in the GLG, in contrast with formal indications from the database of the Italian Stratigraphic Commission (Delfrati 2005). In addition, our new attribution of the Villa Olmo Conglomerate to the NP24-NP25 zones resolves the paradox stemming from the mismatch between the previous biostratigraphic datings (Gelati et al. 1988, 1991; Valdisturlo et al. 1998) and the K-Ar ages obtained from pebbles in the Villa Olmo Conglomerate (Giger & Hurford, 1989). Our new biostratigraphic determinations imply in fact a younger age for the Villa Olmo Conglomerate, straddling the NP24–NP25 boundary (27.3 Ma; Gradstein et al. 2005), well compatible with the cooling ages of 31.7 ± 0.5 and 31.9 ± 0.4 Ma provided by Giger & Hurford (1989) on a tonalite pebble included in the Villa Olmo Conglomerate.

The Como Conglomerate shows calcareous nannofossil assemblages suggesting a late Chattian to the earliest Aquitanian age (from nannofossil zones NP25 to NN1). Planktonic foraminifera have not provided reliable biostratigraphic results in this lithozone (Rögl et al., 1975; Gelati et al., 1988). The NN1 nannofossil zone assigned to the lower part of the Prestino Mudstones correlates entirely with the results obtained by Rögl et al. (1975, ENEL station section) and Gelati et al. (1988) indicating foraminiferal zones N4/basal N5.

The upper part of the Val Grande Sandstone have been dated as NN3, which matches the foraminiferal zones N5/N6 documented by Gelati et al. (1988) in the Monte Olimpino 2 tunnel section.

Santini (1956) documented a poor foraminiferal assemblage in the Lucinasco Mudstones containing *Catapsydrax dissimilis* and *Globoquadrina dehiscens*, which allowed Gelati et al. (1988) to assign this lithozone to foraminiferal zones N5/N6 (Aquitanian-Burdigalian). Also, Bernoulli & Gunzenhauser (2001) proposed a Burdigalian age based on palynological investigations. The calcareous nannofossil assemblages of this lithozone confirm the Burdigalian attribution, based on the NN4 assignment.

Finally, our biostratigraphic age assignment of the Lurate Caccivio Mudstones points to the Langhian NN5 zone, in agreement with the former interpretation of Cita (1957) and unpublished palynological results reported by Bernoulli et al. (1993), but in contrast with the late Burdigalian age proposed by Gelati et al. (1988).

In the Brianza area, the assignment of the Fornaci Marls lowermost beds to the latest Chattian NN1 zone seems to extend significantly the time interval materialized by the unit, but unfortunately the NN2 zone was never retrieved. As neither petrographic composition, nor lithologic changes have been observed between the outcropping lower and upper layers of the Fornaci Marls, we suppose that the lack of exposure of the NN2 zone should be mainly attributed to the soft lithology of the Fornaci Marls, in an area characterized by extensive Pleistocene glacial deposits. Conversely, it is confirmed by our study the attribution of the Briosco Sandstone uppermost beds to the Serravallian, already identified by Sciunnach & Tremolada (2004).

The occurrence of Chiasso Formation pebbles in the Lucino Conglomerate (Bernoulli et al. 1989) and the input of reworked Chattian nannofossil taxa in the Lucinasco Mudstones (*S. ciperoensis*, *C. fenestratus*, *S. dissimilis*, *C. abisectus*, and *R. bisecta)* suggest that the Chiasso Formation was exhumed during the late Burdigalian, likely due to the activity of the Monte Olimpino back-thrust. The deposition of the Lucino Conglomerate is commonly referred to the tectonic movement and uplift of the Southern Alps (Lombardic phase) (Bernoulli et al. 1989; Bersezio et al. 1993; Schumacher et al. 1997). As a consequence, with the onset of the Monte Olimpino back-thrusting the Como area of the GLG basin should be considered involved in the southward propagation of the Southern Alps thrusts, switching from a foredeep to a wedge-top depozone (*sensu* DeCelles & Giles 1996). The age of the switch can be likely constrained to the late Burdigalian (early? NN4), at the onset of the Lucino Conglomerate deposition. In this tectonic framework, the shallowing observed in the Lurate Caccivio Mudstones can be related to the involvement of the Como area in the wedge-top depozone of the GLG basin, with a decrease of the subsidence rates and the consequent filling of the remnant space.

Regional correlation

The biostratigraphic frame emerging from the present study allows to correlate the GLG units of the Como type-area with other sections exposed at the margin of the western Southern Alps.

In the Brianza area (Fig 1), north of Milan, a poorly exposed homocline displays a stratigraphic succession spanning the nannofossil zones NN1 (latest Chattian) to NN6 (Serravallian; Sciunnach & Tremolada 2004), with an important lack of exposure encompassing the zone NN2 (Fig. 4). The lower, more pelitic part of the succession (Fornaci lithozone of Sciunnach & Tremolada 2004; Fornaci Marls in the present study) is comprised between the nannofossil zones NN1 and the NN3 and thus correlates at least with the Como Conglomerate and Val Grande Sandstone in the Como area. A correlation with the Prestino

Mudstones can be presently only inferred. The overlying, coarser-grained succession (Bevera, Roggia Pissavacca, Roggia Riale-Cascina Guasto and Lambro lithozones of Sciunnach & Tremolada 2004; Briosco Sandstone in the present study) largely spans the nannofossil zones NN4 to NN6 and thus correlates with the Lucino Conglomerate (including the Lucinasco and the Lurate Caccivio Mudstones) of the Como type-area, where no unit younger than the nannofossil zone NN5 was found. Under this respect, the Lambro lithozone of the Briosco Sandstone in Brianza, ascribed to the nannofossil zone NN6 (Serravallian), remains as far as we know the youngest exposed unit within the GLG (Sciunnach & Tremolada, 2004).

South of Lake Iseo (Fig. 1), coarse-grained clastics, dominated by limestone and chert pebbles and deposited in shallow-marine fan-deltas (Monte Orfano Conglomerate), display in their upper part thin layers of chalky marls dated to nannofossil zone NN1 (Sciunnach et al., in press) (Fig. 4). The Monte Orfano Conglomerate correlates well with the Como Conglomerate as they both document a roughly synchronous stage of tectonic deformation and uplift involving large parts of the Alpine range (Sciunnach et al., in press). Therefore, the term “Gonfolite Bresciana” introduced by Cita (1957) for the Monte Orfano Conglomerate is correct in our view and well agrees with the traditional usage of including the Monte Orfano Conglomerate into the GLG of the Como-Varese area (Cita 1957; Gunzenhauser 1985; Bersezio et al. 1993; Schumacher et al. 1997; Sciunnach et al., in press).

In spite of the quite short distance between the respective outcrop areas (~15 km), a lithological correlation between the Como and Brianza areas should be carefully approached. Even sharing a likely common sediment provenance (Sciunnach & Tremolada 2004), the pelitic facies of the Fornaci Marls seems to persist for a long time interval encompassing several lithologic changes in the Como area, from the Como Conglomerate to the Val Grande Sandstone (Fig. 4). Conversely, a fair lithologic correlation can be observed between the overlying Briosco Sandstone in Brianza and the Lucino Conglomerate in the Como area, suggested by a common petrographic composition (Fiorentini Potenza, 1957; Sciunnach & Tremolada 2004) and by the occurrence of conglomeratic layers in the Briosco Sandstone. This evidence may be interpreted as facies lateral variations in presence of a single entry-point or heteropies within different turbidite systems fed by the uprising Southern Alps structural domain during the Lombardic phase.

The absence of comparable calcareous nannofossil biostratigraphic data hampers currently a precise correlation with the typical lithostratigraphic units of the Varese area, west of Como (Belforte and Rio dei Gioghi Mudstones, Malnate Sandstone).

Conclusions

A number of calcareous nannofossils events have been observed in the type-area of the Gonfolite Lombarda Group, whilst the paucity of planktonic foraminifera prevents a reliable biostratigraphy based on this fossil group. However, our nannofossil data alone permit to refine the age assignments of the Gonfolite Lombarda Group. Although the preservation and abundance of calcareous nannofossils vary considerably, several biostratigraphic markers show a fairly continuous occurrence. The Chiasso Formation and the Villa Olmo Conglomerate deposited during the Chattian nannofossil zones NP24-NP25, whilst the Como Conglomerate deposited during the late Chattian zone NP25 straddling the Oligocene/Miocene boundary, which is placed at the Last Occurrence of the taxon *R. bisecta* (Berggren et al, 1995). The Prestino Mudstones show a typical Neogene nannofloral assemblage assignable to nannofossil zones NN1 and NN2. The only sample collected from the Val Grande Sandstones is Burdigalian in age and indicates the nannofossil zone NN3, whilst the Lucinasco and the Lurate Caccivio Mudstones, members of the Lucino Conglomerate, were deposited during the late Burdigalian NN4 and the Langhian NN5 zones, respectively. The analysis of benthic and planktonic foraminiferal communities demonstrates that most of the investigated succession was deposited in an upper bathyal setting, characterized also by episodes of low-oxygenation on the sea-floor. A shallowing occurred during the Langhian and the deposition in a neritic environment is characteristic of the Lurate Caccivio Mudstones.

In our view, the observed shallowing of the GLG paleobathymetry reflects the structural evolution of the Gonfolite basin in the Como area, switching from a foredeep to a wedge-top depozone with the onset of the Monte Olimpino back-thrust. The depozone switch likely occurred during the late Burdigalian, in relation with the onset of the Lombardic phase and the strong southward propagation of the Southern Alps thrusts.

Acknowledgements

The field work of GS and biostratigraphic analyses by FT were carried out in the framework of the CARG project (Sheet 96 “Seregno) and supported by CNR-IDPA. EG thanks TNO for logistic support. The Authors want to thank A. Berlusconi, R. Bersezio, M. Ghielmi, T. Kouwenhoven, F. Livio, A. Michetti, A. Napolitano, G. Sileo, and G. Vezzoli for their collaboration and useful discussions. This paper benefited from reviews by I. Premoli Silva, R. Polino, D. Bernoulli, and Maurizio Gaetani.

References

AGIP (1982) - Foraminiferi Padani (Terziario e Quaternario), Atlante iconografico e distribuzione stratigrafica. 52 pls., AGIP, Milano.

Aubry M.-P. (1984) - Handbook of Cenozoic calcareous nannoplankton. Book 1: Ortholithae (Discoasters). 266 pp., Micropaleontology Press, New York.

Aubry M.-P. (1988) - Handbook of Cenozoic calcareous nannoplankton. Book 2: Ortholithae (Holococcoliths, Ceratoliths, Ortholiths and others). 279 pp., Micropaleontology Press, New York.

Aubry M.-P. (1989) - Handbook of Cenozoic calcareous nannoplankton. Book 3: Ortholithae (Pentaliths, and others), Heliolithae (Fasciculiths, Sphenoliths and others). 279 pp., Micropaleontology Press, New York.

Aubry M.-P. (1990) - Handbook of Cenozoic calcareous nannoplankton. Book 4: Heliolithae (Helicoliths, Cribriliths, Lopadoliths and others). 381 pp., Micropaleontology Press, New York.

Berggren W.A., Kent D.V., Swisher C.C. III & Aubry M.-P. (1995) - A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Aubry, M.-P. & Hardenbol, J. (eds.) - Geochronology, time scales, and global correlation. *SEPM Spec. Publ.*, 54: 129-212, Tulsa.

Bernoulli D. & Gunzenhauser B. (2001) - A dolomitized diatomite in an Oligocene-Miocene deep-sea fan succession, Gonfolite Lombarda Group, Northern Italy. *Sed. Geol.*, 139: 71-91, Amsterdam.

Bernoulli D., Bertotti, G., Zingg A. (1989) - Northward thrusting of the Gonfolite Lombarda (South-Alpine molasse) onto the Mesozoic sequence of the Lombardian Alps: Implications for the deformation history of the Southern Alps. *Eclogae Geol. Helv.*, 82: 841-856, Basel.

Bernoulli D., Giger M., Muller D.W. & Ziegler U.R.F. (1993) - Sr-isotope stratigraphy of the Gonfolite Group (“South-Alpine Molasse”, northern Italy) and radiometric constraints for its age of deposition. *Eclogae Geol. Helv.*, 86: 751-767, Basel.

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 Lombardian Southern Alps. *Géologie Alpine*, 69: 3-20, Grenoble.

Blow W.H. (1969) - Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. In: Brönnimann P. & Renz H.H. (eds.) - Proceedings of the First International Conference on Planktonic Microfossils. *E.J.Brill*, 1: 199-421. Leiden.

Bown P.R. & Young J.R. (1998) - Techniques. In: Bown, P. (Ed.) - Calcareous Nannofossil Biostratigraphy. 16-28 pp., Kluwer Academic Publishers, London.

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, Amsterdam.

Castellarin A., Cantelli L., Fesce A.M., Mercier J.L., Picotti V., Pini G.A., Prosser G. & Selli L. (1992) - Alpine compressional tectonics in the Southern Alps. Relationships with the N-Appenines. *Ann. Tectonicae*, 6: 62-94, Firenze.

Cita M.B. (1953) - Studi stratigrafici e micropaleontologici sulle formazioni comprese tra il Nummulitico ed il Pliocene nel territorio di Varese. *Boll. Serv. Geol.*, 75: 671-677, Roma.

Cita M.B. (1957) - Sintesi stratigrafica della “Gonfolite”. *Riv. It. Pal. Strat.*, 63: 79-117, Milano.

Consonni E. (1953) - La formazione gonfolitica della Brianza tra Romanò e Naresso. *Riv. It. Pal. Strat.*, 59: 173-194, Milano.

Dal Piaz GB. (1929) - Nuove osservazioni sull’Oligocene italiano. *Rend. R. Acc. Naz. Lincei, 9, serie 6*: 910-913, Roma.

DeCelles P.G. & Giles K.A. (1996) - Foreland basin systems. *Basin Res.* 8: 105-123.

de Kaenel E. & Villa G. (1996) - Oligocene-Miocene calcareous nannofossil biostratigraphy and paleoecology from the Iberia Abyssal Plan. In: Whitmarsh, R.B. & Sawyer, D.S. et al. (eds) - Scientific Results ODP Leg 149, 149: 79-145, College Station, TX.

Delfrati L. (2007) - Gruppo della Gonfolite Lombarda. In: Cita M.B., Abbate E., Balini M., Conti M.A., Falorni P., Germani D., Groppelli G., Manetti P. & Petti F.M. (eds.) - Carta Geologica d’Italia 1: 50.000, Catalogo delle Formazioni – unità tradizionali. *Quad. APAT*, Ser. III, 7/VII: 168-174, Roma.

Di Giulio A., Carrapa B., Fantoni R., Gorla L. & Valdisturlo A. (2001) - Middle Eocene-Early Miocene sedimentary evolution of the Western Lombardy South Alpine foredeep (Italy). *Int. J. Earth Sc.*, 90: 534-548, Kiel.

Fornaciari E. & Rio D. (1996) - Latest Oligocene to early Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology*, 42: 1-37, New York.

Fornaciari E., Di Stefano A., Rio D. & Negri A. (1996) - Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology*, 42: 38-64, New York.

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, Milano.

Gelati R., Napolitano A. & Valdisturlo A. (1991) - Results of studies on the Meso-Cenozoic succession in the Monte Olimpino 2 tunnel. The tectono-sedimentary significance of the "Gonfolite Lombarda". *Riv. Ital. Pal. Strat.*, 97: 565-598, Milano.

Giger M. & Hurford A.J. (1989) - Tertiary intrusives of the Central Alps: their Tertiary uplift, erosion, redeposition and burial in the south-alpine foreland. *Eclogae Geol. Helv.*, 82: 857-866, Basel.

Gradstein F., Ogg J., Smith A. (2005) - A geologic time scale 2004. 610 pp., Cambridge University Press, Cambridge.

Gunzenhauser B.A. (1985) - Zur Sedimentologie und Paläogeographie der oligo-miocaenen Gonfolite Lombarda zwischen Lago Maggiore und der Brianza (Südtessin, Lombardei). 114 pp., *Beitr. Geol. Karte Schweiz* N.F. 159, Bern.

Iaccarino S.M., Premoli Silva I., Biolzi M., Foresi L.M., Lirer F., Petrizzo M.R. (2005) - Practical Manual of Oligocene to Middle Miocene Planktonic foraminifera. International School on Planktonic Foraminifera, Perugia.

Longo V. (1968) - Geologie und Stratigraphie des Gebietes Zwischen Chiasso und Varese. 181 pp., PhD thesis, ETH Zürich.

Martini E. (1971) - Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (Ed.) - Proceedings of the II Planktonic conference: 739-785, Roma.

van Morkhoven F.P.C.M., Berggren W.A. & Edwards A.S. (1986) - Cenozoic cosmopolitan deep-water benthic foraminifera. 421 pp., Elf-Aquitaine, Pau.

Napolitano A. (1985) - Stratigrafia e sedimentolgia della "Gonfolite" nel settore di Como. *Rend. Soc. Geol. It*, 8: 69-72, Roma.

Okada H. & Bukry D. (1980) - Supplementary modifications and introduction to code numbers to the low latitude coccolith biostratigraphic zonation. *Mar. Micropaleont.*, 5: 321-325, Amsterdam.

Perch-Nielsen K. (1985) - Mesozoic calcareous nannofossils. *In* Bolli H.M., Saunders J.B. & Perch-Nielsen K. (eds.) - Plankton Stratigraphy, pp. 329-426, Cambridge University Press, Cambridge.

Raffi I., Backman J., Fornaciari E., Pälike H., Rio D., Lourens L., Hilgen F. (2006) - A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years. Quat. Sci. Rev., 25: 3113-3137, Amsterdam.

Rögl F., Cita M.B., Müller C. & Hochuli P. (1975) - Biochronology of conglomerate bearing molasse sediments near Como (Italy). *Riv. It. Pal. Strat.* 81: 57-88, Milano.

Romein A.J.T. (1977) - Calcareous nannofossils from the Cretaceous/Tertiary boundary interval in the Barranco del Gredero (Caravaca, Prov. Murcia, SE Spain). *II Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen*, 80: 269-279, Wetenschappen.

Roth P.H. (1978) - Cretaceous Nannoplankton Biostratigraphy and Oceanography of the Northwestern Atlantic Ocean. In: Benson W.E., Sheridan R.E. et al. (eds.) - Initial Report DSDP Leg 44, 44: 731-759, Washington D.C.

Santini L. (1956) - Studio stratigrafico e micropaleontologico delle formazioni marnoso-arenacee della Gonfolite di Como. *Riv. It. Pal. Strat.* 62: 239-264, Milano.

Schumacher M.E., Schönborn G., Bernoulli D. & Laubscher H.P. (1997) - Rifting and collision in the Southern Alps. In: Pfiffner O.A., Lehner P. et al. (eds.) - Deep structure of the Swiss Alps: Results of the National Research Program 20, Birkhäuser, 186-204, Basel.

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

Sciunnach D., Scardia G., Tremolada F. & Premoli Silva I. - The Monte Orfano Conglomerate revisited: stratigraphic constraints on Cenozoic tectonic uplift of the Southern Alps (Lombardy, northern Italy). *Int. J. Earth Sc.*, in press.

Sissingh W. (1977) - Biostratigraphy of Cretaceous calcareous nannoplankton. *Geol. Mijnb.*, 56: 37-65, Amsterdam.

Sordelli F. (1896) - Flora fossilis insubrica. Studi sulla vegetazione di Lombardia durante i tempi geologici. 289 pp., Tip. Cogliati, Milano.

Thierstein H.R. (1976) - Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Mar. Micropaleont.*, 1: 325-362, Amsterdam.

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, Bologna.

Varol O. (1998) - Paleogene. In: Bown, P. (Ed.) - Calcareous Nannofossil Biostratigraphy. Kluwer Academic Publishers, 201-224, London.

Villa F. (1955) - Gli affioramenti terziari a sud del Lago di Varese. *Riv. It. Pal. Strat. 61: 66-92.*

Young J.R. (1998) - Neogene. In: Bown, P. (Ed.) - Calcareous Nannofossil Biostratigraphy. Kluwer Academic Publishers, pp. 225-265, London.

Figure and tables captions

Fig. 1 - Geologic sketch map of the Southern Alps (modified from Schumacher et al. 1997), with the study area (box).

Fig. 2 - Synopsis of the GLG litho- and biostratigraphy according to selected studies across a 50-years time span. Open upward columns refer to studies only dealing with a partial sector of the GLG. VOC = Villa Olmo Conglomerate; Lu: Lucinasco Mudstones; LC: Lurate Caccivio Mudstones. Time scale is from Gradstein et al. (2005).

Fig. 3 - Composite stratigraphic section of the Gonfolite Lombarda Group with indication of, from left to right, lithostratigraphic units, calcareous nannofossil biostratigraphic events, radiometric data from Giger & Hurford (1989) and Bernoulli et al. (1993), chronostratigraphic interpretation, and paleobathymetry. Important mudstone levels intercalated in the Como Conglomerate are documented by samples GLG 24-25 (SP17), GLG 26–29 (Ca), and GLG 31–33 (Ba). VOC: Villa Olmo Conglomerate; Ca: Castello; Ba: Baradello; Lu: Lucinasco Mudstones; LC: Lurate Caccivio Mudstones. Cumulative stratigraphic thickness from Napolitano (1985) and new stratimetric calculations; nannofossil events and numerical ages from Berggren et al. (1995), Gradstein et al. (2005), and Raffi et al. (2006).

Fig. 4 - Correlation of the GLG units in Lombardy. The westernmost outcrop area of the GLG (Varese) was not considered, due to the absence of calcareous nannoplankton biostratigraphy. Time scale from Gradstein et al. (2005); nomenclature and timing of alpine tectonic “phases” after Schumacher et al. (1997).

Table 1 - Nannofossil distribution chart. Semiquantitative abundances are expressed as follows: A= Abundant; C= Common; F= Frequent; R= rare. The symbol (*) indicates reworked specimens. Preservation of samples investigated is also shown. Sampling site coordinates are expressed according to the Gauss-Boaga reference system.

Table 2 - Foraminifer distribution chart. Qualitative abundances: “X”= presence; “XX”= common. Sampling sites coordinates are expressed according to the Gauss-Boaga reference system.

Plate 1 - All calcareous nannofossils pictured under crossed nicols at 1250x magnification.

1) *Triquetrorhabdulus carinatus* – Sample GLG 11

2 & 3) *Sphenolithus distentus* (same specimen) – Sample GLG 1

4) *Sphenolithus ciperoensis* – Sample GLG 1

5) *Helicosphaera carteri* – Sample GLG 40

6) *Helicosphaera ampliaperta* – Sample GLG 44

7 & 8) *Sphenolithus heteromorphus* (same specimen) – Sample GLG 44

9) *Cyclicargolithus abisectus* – Sample GLG 30

10) *Cyclicargolithus abisectus* – Sample GLG 37

11 & 12) *Sphenolithus belemnos* and *Coccolithus pelagicus* (same microscope field of view) – Sample GLG 43

13) *Reticulofenestra lockeri* – Sample GLG 15

14) *Reticulofenestra bisecta* (*R. scissura*) – Sample GLG 27

15) *Reticulofenestra bisecta* (*R. scissura*) – Sample GLG 20

16) *Reticulofenestra pseudoumbilica* – Sample GLG 48

17) *Cyclicargolithus floridanus* – Sample GLG 28

18) *Cyclicargolithus floridanus* – Sample GLG 12

19) *Zyghrablithus bijugatus* – Sample GLG 9

20) *Clausicoccus fenestratus* – Sample GLG1

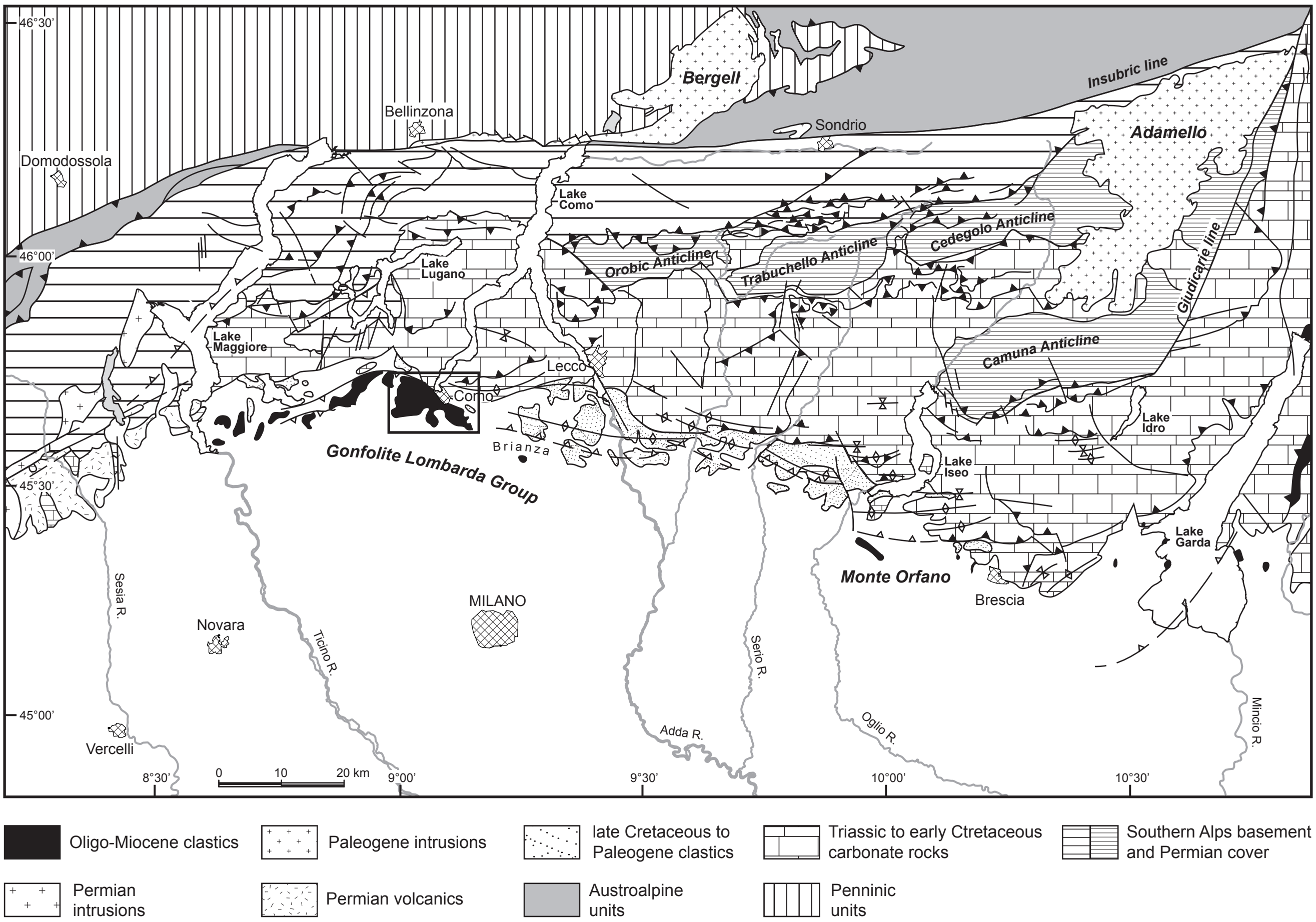

46°30'
Bergell
Insubric line
Bellinzona
Sondrio
Adamello
Domodossola
Lake Como
46°00'
Lake Lugano
Orobic Anticline
Trabuchello Anticline
Cedegolo Anticline
Giudicarie line
Lake Maggiore
Camuna Anticline
Lecco
Como
Lake Idro
Brianza
Lake Iseo
Gonfolite Lombarda Group
45°30'
Lake Garda
Monte Orfano
MILANO
Brescia
Novara
Sesia R.
Ticino R.
Serio R.
45°00'
Adda R.
Oglio R.
Mincio R.
Vercelli
8°30'
0
10
20 km
9°00'
9°30'
10°00'
10°30'
Oligo-Miocene clastics
Paleogene intrusions
late Cretaceous to Paleogene clastics
Triassic to early Ctretaceous carbonate rocks
Southern Alps basement and Permian cover
Permian intrusions
Permian volcanics
Austroalpine units
Penninic units

Figure 1

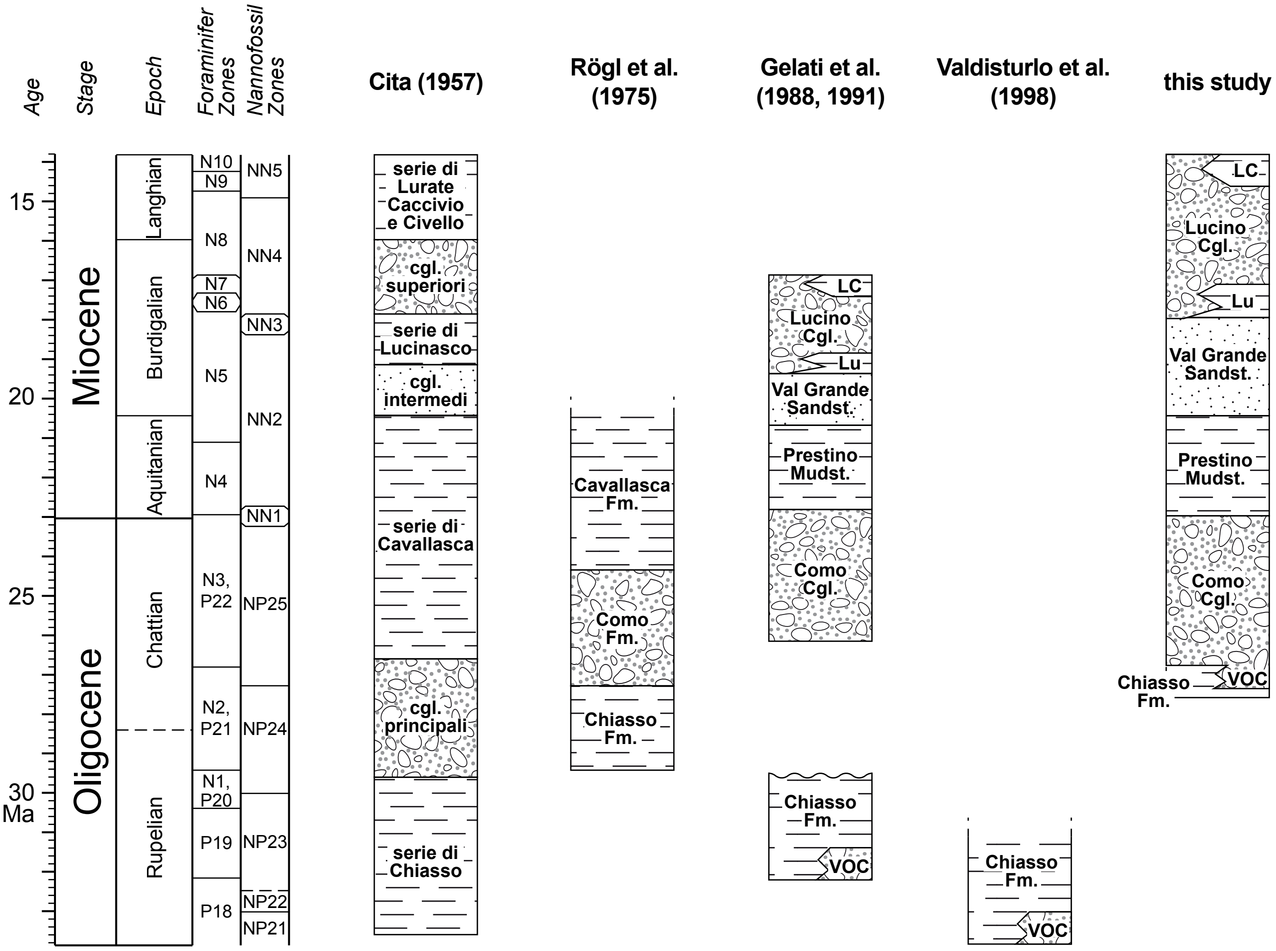

Age
Stage
Epoch
Foraminifer Zones
Nannofossil Zones
Cita (1957)
Rögl et al. (1975)
Gelati et al. (1988, 1991)
Valdisturlo et al. (1998)
this study
15
20
25
30
Ma
Miocene
Oligocene
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
N10
N9
N8
N7
N6
N5
N4
N3, P22
N2, P21
N1, P20
P19
P18
NN5
NN4
NN3
NN2
NN1
NP25
NP24
NP23
NP22
NP21
serie di Lurate Caccivio e Civello
cgl. superiori
serie di Lucinasco
cgl. intermedi
serie di Cavallasca
cgl. principali
serie di Chiasso
Cavallasca Fm.
Como Fm.
Chiasso Fm.
LC
Lucino Cgl.
Lu
Val Grande Sandst.
Prestino Mudst.
Como Cgl.
Chiasso Fm.
VOC
Chiasso Fm.
VOC
LC
Lucino Cgl.
Lu
Val Grande Sandst.
Prestino Mudst.
Como Cgl.
Chiasso Fm.
VOC

Figure 2

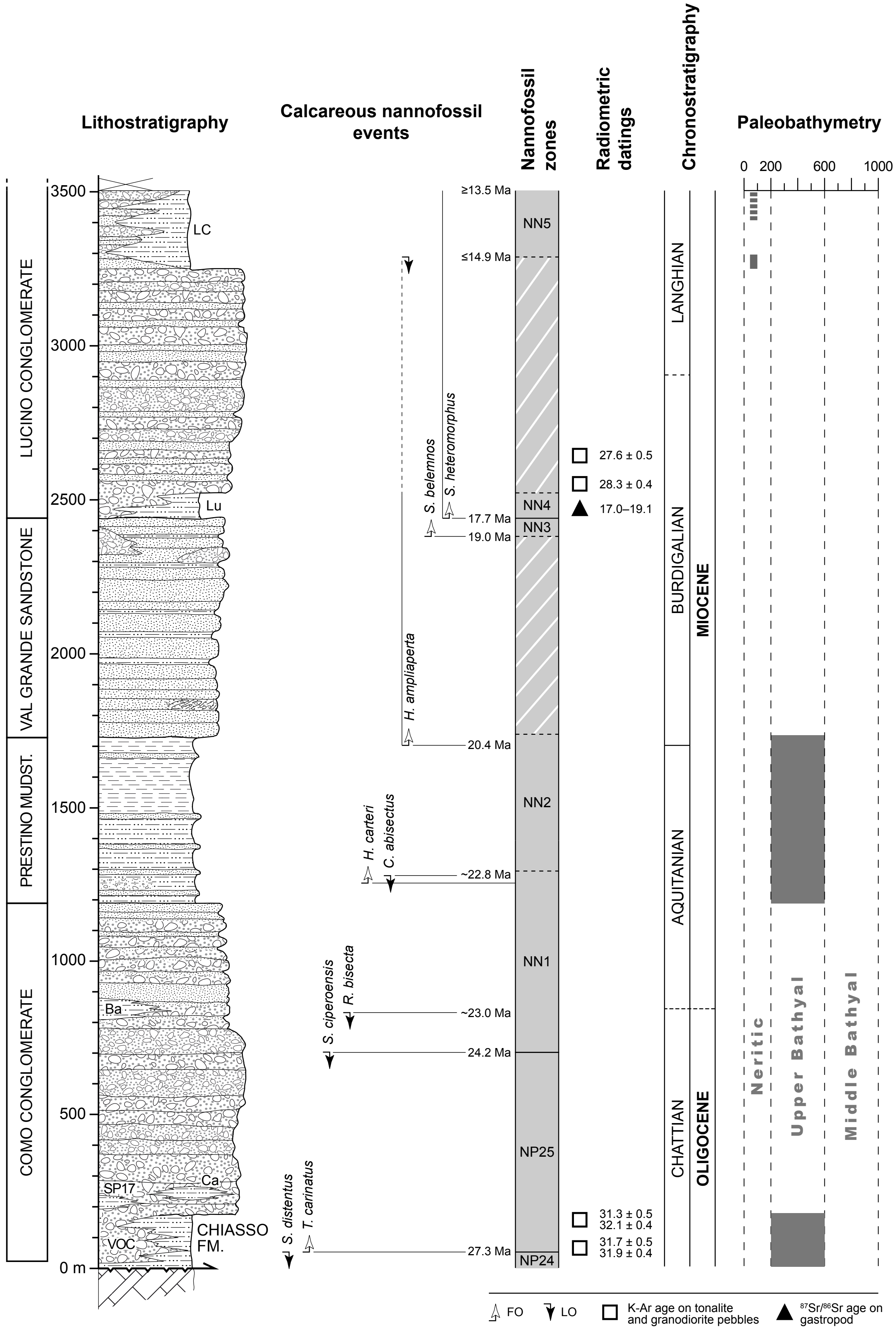

Lithostratigraphy
Calcareous nannofossil events
Nannofossil zones
Radiometric datings
Chronostratigraphy
Paleobathymetry
0 200 600 1000
3500
3000
2500
2000
1500
1000
500
0 m
LUCINO CONGLOMERATE
VAL GRANDE SANDSTONE
PRESTINO MUDST.
COMO CONGLOMERATE
LC
Lu
Ba
Ca
SP17
VOC
CHIASSO FM.
S. belemnos
S. heteromorphus
H. ampliaperta
H. carteri
C. abisectus
S. ciperoensis
R. bisecta
S. distentus
T. carinatus
≥13.5 Ma
≤14.9 Ma
17.7 Ma
19.0 Ma
20.4 Ma
~22.8 Ma
~23.0 Ma
24.2 Ma
27.3 Ma
NN5
NN4
NN3
NN2
NN1
NP25
NP24
☐ 27.6 ± 0.5
☐ 28.3 ± 0.4
▲ 17.0–19.1
☐ 31.3 ± 0.5
32.1 ± 0.4
☐ 31.7 ± 0.5
31.9 ± 0.4
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
MIOCENE
OLIGOCENE
Neritic
Upper Bathyal
Middle Bathyal
FO
LO
☐ K-Ar age on tonalite and granodiorite pebbles
▲ ⁸⁷Sr/⁸⁶Sr age on gastropod

Figure 3

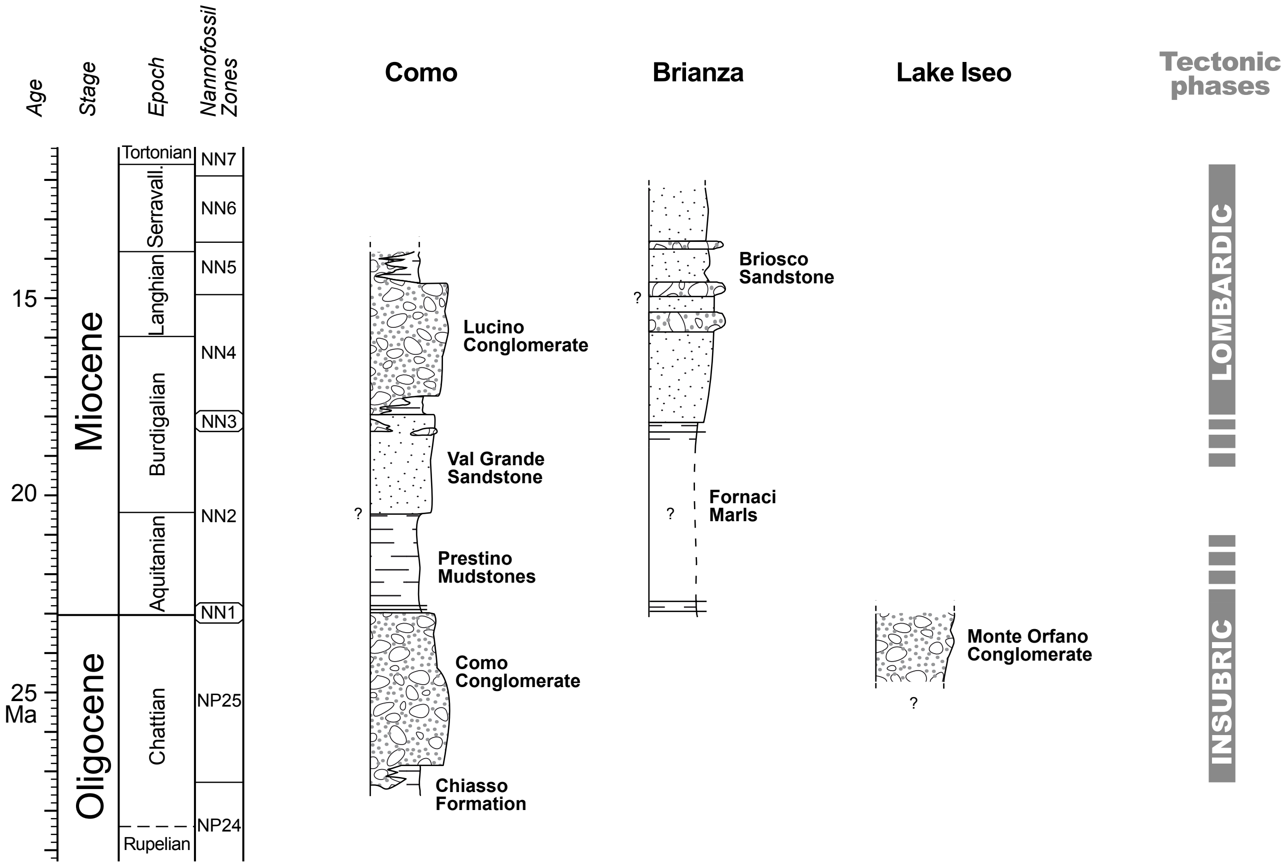

Age
Stage
Epoch
Nannofossil Zones
Como
Brianza
Lake Iseo
Tectonic phases
Tortonian
Serravall.
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Miocene
Oligocene
NN7
NN6
NN5
NN4
NN3
NN2
NN1
NP25
NP24
15
20
25
Ma
Lucino Conglomerate
Val Grande Sandstone
Prestino Mudstones
Como Conglomerate
Chiasso Formation
Briosco Sandstone
Fornaci Marls
Monte Orfano Conglomerate
?
LOMBARDIC
INSUBRIC

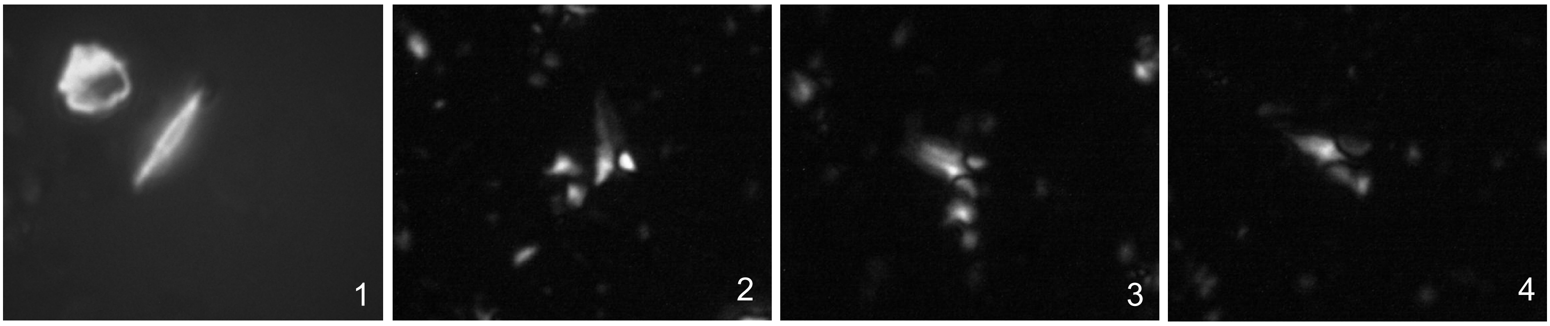
Figure 4

	Epoch	Stage	Nannofossil zone (Martini, 1971)	Group	Formations and members	sample (new label)	CALCAREOUS NANNOFOSSILS																																						SITES	
							abundance	etching	overgrowth	*Coccolithus pelagicus*	*Cyclicargolithus floridanus*	*Cyclicargolithus abisectus*	*Reticulofenestra minuta* group	*Sphenolithus moriformis*	*Sphenolithus ciperoensis*	*Sphenolithus dissimilis*	*Sphenolithus conicus*	*Sphenolithus distentus*	*Sphenolithus predistentus*	*Sphenolithus belemnos*	*Sphenolithus disbelemnos*	*Sphenolithus heteromorphus*	*Reticulofenestra bisecta* (*scissura*)	*Reticulofenestra lockeri*	*Reticulofenestra pseudoumbilica* <7μm	*Pontosphaera* spp.	*Helicosphaera intermedia*	*Helicosphaera bramlettei*	*Helicosphaera carteri*	*Helicosphaera recta*	*Helicosphaera euphratis*	*Helicosphaera ampliaperta*	*Helicosphaera californiana*	*Reticulofenestra pseudoumbilica* >7μm	*Discoaster deflandrei*	unidentifiable *Discoaster*	*Zyghrablithus bijugatus*	*Triquetrorhabdulus carinatus*	*Clausicoccus fenestratus*	*Hayaster perplexus*	reworked Cretaceous	reworked Paleogene	X	Y
COMO AREA	MIOCENE	Langhian	NN5	Gonfolite Lombarda Group	Lurate Caccivio Mudstones	GLG 49	R	E3	O3	F	R		R	R								R			R				R														1501476	5068755
						GLG 48a																																					1501476	5068755
						GLG 48	R	E3	O3	F	F		F									R			R	R			R														1501476	5068755
						GLG 47a																																					1500804	5069497
		Burdigalian	NN4		Lucinasco Mudstones	GLG 47	R	E3	O3	F	F		F	R							R*											R										R	1502192	5070905
						GLG 46	R	E2	O3	F	F	R*	F	R	R*	R*							R*	R*		R													R*		R	R	1502192	5070905
						GLG 45	BARREN																																				1502163	5070991
						GLG 44	F	E2	O2	F	C		F			R*						R	R*	R*	R	R	R		R			R									R		1502163	5070991
			NN3		Val Grande Sandstone	GLG 43	F	E3	O3	F	F		F	F						R			R*	R*		R			R							R					F		1503415	5070742
			NN2		Prestino Mudstones	GLG 42a																																					1503185	5072049
						GLG 42	C	E2	O2	C	C	R*	C	F																	R	R			F	R		R			F		1502356	5072964
		Aquitanian	NN1			GLG 41	BARREN																																				1502356	5072964
						GLG 40b																																					1503235	5072557
						GLG 40a	F	E2	O2	F	R	R	F	F										R		R			R									R			R		1503378	5072637
						GLG 39	F	E2	O2	R	R		F			R		R*						R					R		R				R						R		1503378	5072637
						GLG 38b																																					1504632	5071908
						GLG 38a																																					1504632	5071908
						GLG 38	F	E2	O2	F	F	R	F	R					R*							R												R			F	F	1507982	5068745
						GLG 37	F	E2	O2	F	F	F	C	R					R*					R		R		R									R				F	F	1507344	5069654
						GLG 36	F	E2	O2	F	F	R	F	R														R										R			F	F	1507880	5069349
					Como Conglomerate	GLG 35	F	E2	O2	F	F	R	F	R													R									R			R		R		1508506	5069481
						GLG 34	BARREN																																				1508506	5069481
						GLG 33	C	E2	O2	C	F	R	C	F										R		R											R	R				R	1506196	5071258
	OLIGOCENE	Chattian				GLG 32	F	E2	O2	F	R	R	F	R									R																				1506196	5071258
						GLG 31	F	E2	O2	F	F	R	F	R									R	R							R												1506196	5071258
			NP25			GLG 30	A	E1	O1	A	C	F	C	F	R	R	R						F	F		R	R	R		R	R				R	R	R	R	R		R	R	1506912	5071114
						GLG 29	F	E2	O1	R	F	R	F	R	R								R																			R	1506646	5071506
						GLG 28	C	E1	O2	C	C	R	C	R	R								F	R						R												R	1506646	5071506
						GLG 27	C	E1	O2	C	C	R	C	F	R	R							F			R	R								R				R		R	R	1506646	5071506
						GLG 26	C	E2	O2	C	C	R	F	F	R	R	R						R	R				R		R	R				R								1506646	5071506
						GLG 25	F	E2	O2	F	R	R	F	R		R							R	R							R				R							F	1504583	5073722
						GLG 24	R	E2	O2	R	R	R	R	R									R																				1504583	5073722
					Chiasso Formation	GLG 23	BARREN																																				1504287	5074107
						GLG 22	F	E2	O2	F	F	R	F	R	R												R											R					1504287	5074107
						GLG 21	F	E2	O2	F	F		F			R							R	R																			1504287	5074107
						GLG 20	R	E2	O2	R	R	R	R	R									R															R			R		1504287	5074107
						GLG 19	F	E3	O2	F	F	R	R		R	R							R																				1504287	5074107
						GLG 18	F	E2	O2	F	F	R	F			R							F	R											R				R	R			1504287	5074107
						GLG 17	F	E3	O2	F	F		R	R									R			R	R	R									R						1503893	5074335
						GLG 16	F	E2	O2	F	F	R	R		R	R							R	R														R				F	1503893	5074335
						GLG 15	F	E2	O2	F	F	R	R	R									R	R																	R	R	1503893	5074335
					Villa Olmo Conglomerate	GLG 14	C	E2	O2	C	F	F	F	F	R	R							F	R		R	R	R								R							1504969	5073593
						GLG 13	F	E2	O2	F	F	R	R	R									R	R		R	R										R					R	1504969	5073593
						GLG 12	F	E2	O2	F	F	R	R	R		R							R							R					R		R					R	1504969	5073593
						GLG 11	C	E1	O2	C	C	R	F		R	R	R						R	R		R		R										R					1504969	5073593
						GLG 10	F	E2	O2	F	F	R	F	F														R							R		R						1504969	5073593
						GLG 9	F	E2	O2	F	F	R	F	R									R	R		R					R				R		R		R			R	1504969	5073593
						GLG 8	C	E2	O2	C	F	R	F	F	R		R						F	R		R	R	R							R		R	R	R			R	1504969	5073593
						GLG 7	F	E2	O3	F	F	R	R	R									F	R			R			R								R					1504969	5073593
			NP24			GLG 6	F	E2	O2	F	F	R	R	R	R			R					R														R						1504969	5073593
						GLG 5	C	E1	O2	C	F	R	F	F	R	R		R					F	R			R	R							R	R			R				1504969	5073593
						GLG 4	C	E1	O1	F	C	R	R	F	R			R					R							R						R	R				R	R	1504950	5073681
						GLG 3	F	E1	O1	F	F	R	R	F									R	R				R							R				R			R	1504950	5073681
						GLG 2	C	E1	O2	F	F	R	F	R				R					R			R	R																1504950	5073681
						GLG 1	C	E1	O1	F	F	R	R	R	R	R		R					R	R				R		R					R		R		R		R		1504950	5073681
BRIANZA	MIOC.	Serrav.	NN6	GLG	Briosco Sandstone	GLG B2	R	E3	O3	F	R		R	R											R		R		R				R	R									1518282	5060656
	OLIG.	Chatt.	NN1		Fornaci Marls	GLG B1	C	E2	O1	C	C	F	F	F		R							F	R		R	R	R		R					R	R	R	R	R		F	R	1521215	5063278

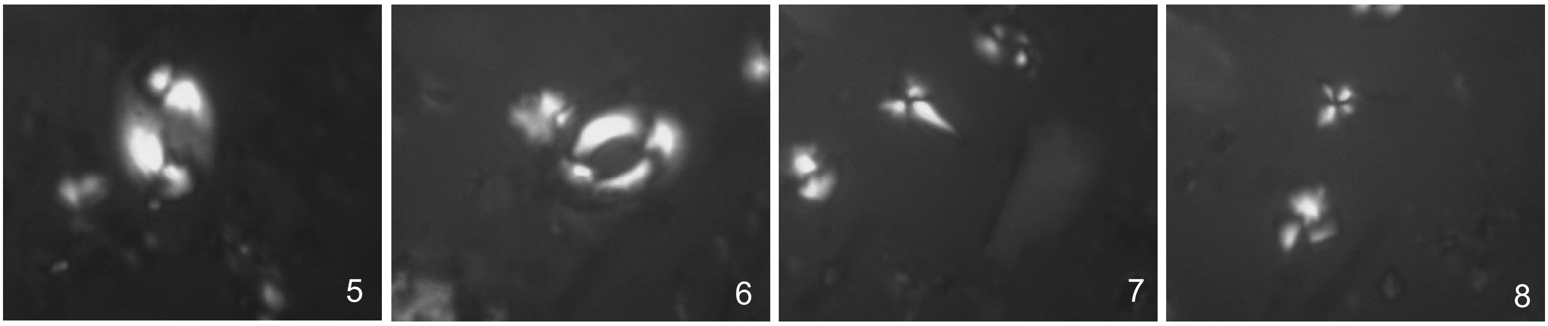
Table 1 (Tremolada et al.)

						PLANKTONIC AND BENTHIC FORAMINIFERA																																																						SITES	
Epoch	Stage	Nannofossil zone (Martini, 1971)	Group	Formations and members	sample (new label)	*Catapsydrax martini*	*Catapsydrax unicavus*	*Dentoglobigerina galavisi*	*Globigerina* spp.	*Globigerina* cf. *ciperoensis ciperoensis*	*Globorotaloides suteri*	"large Globigerinids"	*Paragloborotalia opima nana*	*Paragloborotalia opima opima*	*Globorotalia* spp.	*Cassigerinella* spp.	*Bolivina* spp.	*Alabamina* spp.	*Bulimina costata* gr.	*Cibicidoides/Anomalinoides* spp.	*Globocassidulina subglobosa*	*Oridosrsalis umbonatus*	*Osangularia* spp.	*Pleurostomella* spp.	*Praeglobobulimina ovata*	*Pullenia bulloides*	Nodosarids	*Gyroidina* spp.	*Valvulinera* spp.	*Sphaeroidina bulloides*	Miliolids	Lagenids	*Lenticulina* spp.	*Uvigerina* spp.	*Gyroidinoides altiformis*	*Uvigerina* cf. *auberiana*	*Bolivina* spp.	*Hanzawaia boueana*	*Uvigerina hispida*	*Uvigerina proboscidaea*	*Eponides* spp.	*Uvigerina mantaensis*	*Asterigerinata planorbis*	*Elphidium* spp.	*Melonis* spp.	*Cancris* spp.	*Cassidulinoides bradyi*	*Eggerella bradyi*	*Gaudryna* sp.	*Textularia* sp.	*Trochammina* sp.	*Haplophragmoides* sp.	*Rhizamminid* spp.	*Karreriella* spp.	*Recurvoides* spp.	*Spiroplectammina* spp.	Indet Agglutinated	Fish tooth	Ostracode	Echinoids	Radiolaria	Sponge	Diatoms (pyritized)	X	Y
MIOCENE	Langhian	NN5	Gonfolite Lombarda Group	Lurate Caccivio Mudstones	GLG 49				x								x			x			x			x			x	x			x													x	x						x							x	x	x	x	1501476	5068755
					GLG 48a															x										x														x		x															x	x	x	1501476	5068755
					GLG 48				x																	x			x	x								x							x												x			x	x	x	x	1501476	5068755
					GLG 47a																											x											x	x																x	x	x	x	1500804	5069497
	Burdigalian	NN4		Lucinasco Mudstones	GLG 47																						x														x	x																						1502192	5070905
					GLG 46																																																								x	1502192	5070905
					GLG 45																																																									1502163	5070991
					GLG 44																											x																									x			x		x		1502163	5070991
		NN3		Val Grande Sandstone	GLG 43																							x																													x							1503415	5070742
		NN2		Prestino Mudstones	GLG 42a	BARREN																																																								1503185	5072049
	Aquitanian				GLG 42																																																									1502356	5072964
		NN1			GLG 41																																																									1502356	5072964
					GLG 40b																											x																													x			1503235	5072557
					GLG 40a		x		x														xx		xx	x	x	x	x	x		x					x	x	x	x															x	x								1503378	5072637
					GLG 39																																																									1503378	5072637
					GLG 38b				x																	x			x			x			x	x																								x				1504632	5071908
					GLG 38a		x		x				x			x							x		xx			x			x	x	x	x																			x		x									1504632	5071908
					GLG 38																						x														x	x																						1507982	5068745
					GLG 37																																																									1507344	5069654
					GLG 36																																																									1507880	5069349
				Como Conglomerate	GLG 35																																																									1508506	5069481
					GLG 34																																																									1508506	5069481
					GLG 33																																																									1506196	5071258
OLIGOCENE	Chattian				GLG 32																																																									1506196	5071258
					GLG 31																																																									1506196	5071258
		NP25			GLG 30																																																									1506912	5071114
					GLG 29																																																									1506646	5071506
					GLG 28																																																									1506646	5071506
					GLG 27																																																									1506646	5071506
					GLG 26				x																			x				x																			x		x	x	x				x					1506646	5071506
					GLG 25																																																									1504583	5073722
					GLG 24																																																									1504583	5073722
				Chiasso Formation	GLG 23																																																									1504287	5074107
					GLG 22																																																									1504287	5074107
					GLG 21																																																									1504287	5074107
					GLG 20																																																									1504287	5074107
					GLG 19																																																									1504287	5074107
					GLG 18																																																									1504287	5074107
					GLG 17																																																									1503893	5074335
					GLG 16																																																									1503893	5074335
					GLG 15																																																									1503893	5074335
				Villa Olmo Conglomerate	GLG 14																																																									1504969	5073593
					GLG 13																																																									1504969	5073593
					GLG 12															x											x																																	1504969	5073593
					GLG 11																																																									1504969	5073593
					GLG 10															x	x						x	x		x																						x	x											1504969	5073593
					GLG 9																																																									1504969	5073593
					GLG 8																																																									1504969	5073593
					GLG 7				x						x												x	x	x																																			1504969	5073593
		NP24			GLG 6																																																									1504969	5073593
					GLG 5																																																									1504969	5073593
					GLG 4																																																									1504950	5073681
					GLG 3																																																									1504950	5073681
					GLG 2																																																									1504950	5073681
					GLG 1																																																									1504950	5073681

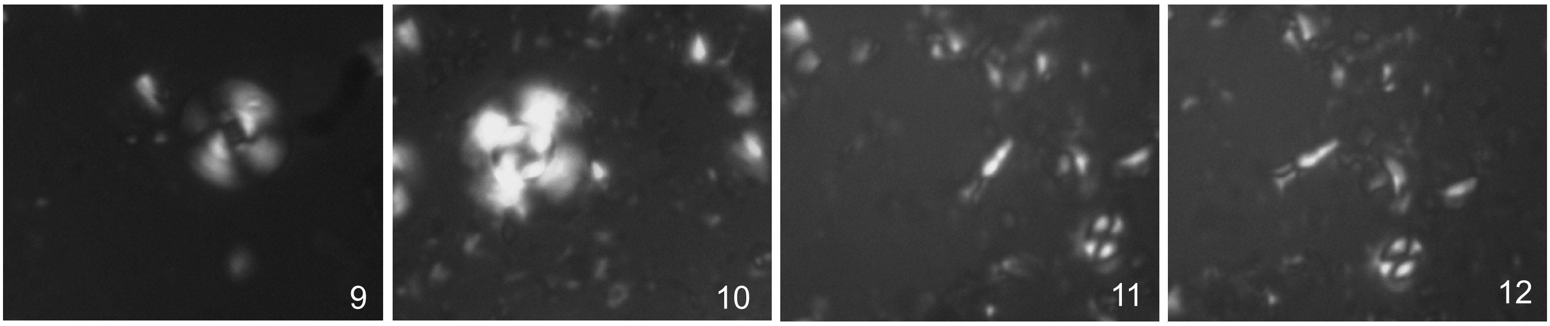
Table 2 (Tremolada et al.)



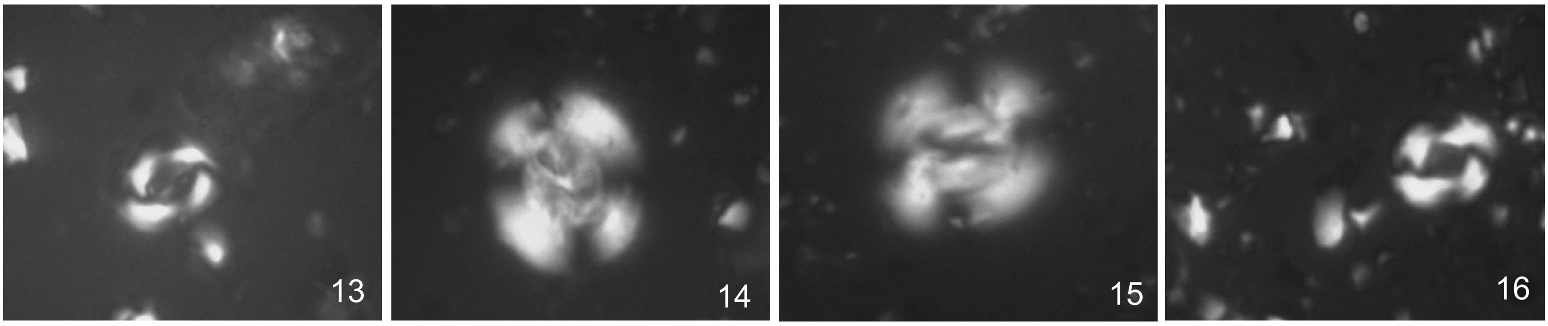
T. carinatus *S. distentus* *S. ciperoensis*



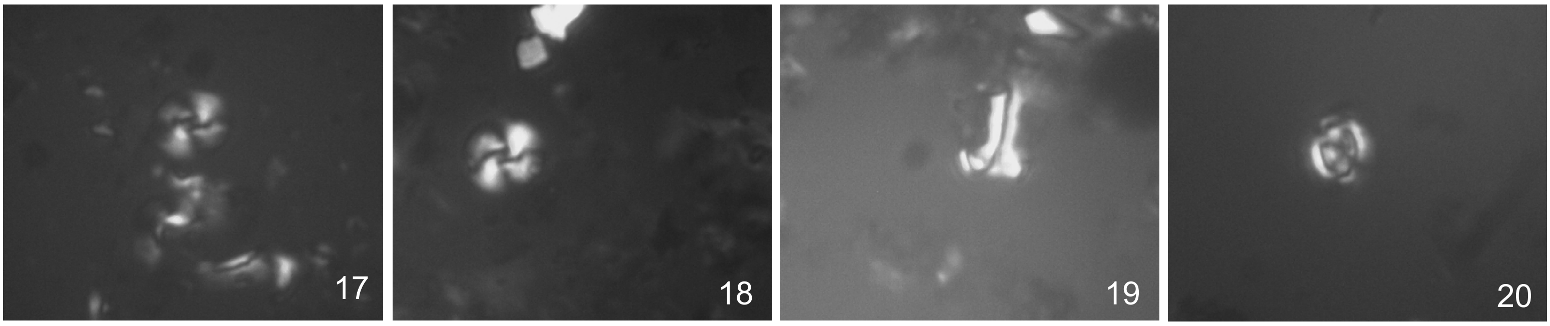
H. carteri *H. ampliaperta* *S. heteromorphus*



C. abisectus *S. belemnos* + *C. pelagicus*



R. lockeri *R. bisecta* (*R. scissura*) *R. pseudoumbilica*



C. floridanus *Z. bijugatus* *C. fenestratus*

10 microns

Plate 1 (tremolada et al.)