

Micropalaeontological evidences of high productivity episodes in the Zanclean of Piedmont (Early Pliocene, Northwestern Italy)

Donata VIOLANTI, Maria Cristina BONCI, Stefania TRENKWALDER, Francesca LOZAR, Paola BECCARO, Francesco DELA PIERRE, Elisa BERNARDI & Paola BOANO

D. Violanti, Dipartimento di Scienze della Terra, Università di Torino and CNR IGG, U.O. di Torino, via Valperga Caluso 35, I-10125 Torino, Italy; donata.violanti@unito.it

M.C. Bonci, Dipartimento per lo studio del Territorio e delle sue Risorse, corso Europa 26, I-16132 Genova, Italy; bonci@dipteris.unige.it

S. Trenkwald, CNR IGG, U.O. di Torino, via Valperga Caluso 35, I-10125 Torino, Italy; s.trenkwald@csg.to.cnr.it

F. Lozar, Dipartimento di Scienze della Terra, Università di Torino, via Valperga Caluso 35, I-10125 Torino, Italy; francesca.lozar@unito.it

P. Beccaro, via A. Valazza 36, 28010 Boca (NO), Italy; paola.beccaro@alice.it

F. Dela Pierre, Dipartimento di Scienze della Terra, Università di Torino and CNR IGG, U.O. di Torino, via Valperga Caluso 35, I-10125 Torino, Italy; francesco.delapierre@unito.it

E. Bernardi, Dipartimento di Scienze della Terra, Università di Torino, via Valperga Caluso 35, I-10125 Torino, Italy; elisa.bernardi@unito.it

P. Boano, via Asti 13, I-14039 Tonco (AT), Italy; paola.boano@alice.it

KEY WORDS - Calcareous microfossils, siliceous microfossils, Zanclean, Piedmont, Northwestern Italy.

ABSTRACT - Quantitative and semiquantitative analyses carried out on calcareous (foraminifers, ostracods, calcareous nannofossils = CN) and siliceous (diatoms, radiolarians) microfossil associations preserved in diatomaceous silts and clays from Monferrato (Piedmont, Northwestern Italy), forming part of the Argille Azzurre (Blue Clay) Formation, document episodes of enhanced productivity during the Early Pliocene (Zanclean). This study represents the first documentation in Piedmont of Pliocene mixed calcareous and siliceous microfossil assemblages, generally reported from areas of upwelling and high productivity conditions. The assemblages collected from the sections of La Torretta, Castelcebro and Calliano allow a nearly coincident time interval to be proposed for their deposition, in the MPI 3 foraminiferal Zone (Globorotalia margaritae - Globorotalia puncticulata Zone), the MNN13 and/or MNN14-15 CN zones, the Nitzschia jouseae diatom Zone and RN11 (Stichocorys peregrina Zone) radiolarian Zone. High productivity in the water column is documented by the following: the frequent occurrence of diatoms, dominated by Chaetoceros RS, Thalassionema group and locally by Paralia sulcata, all related to upwelling conditions; the common to frequent presence of radiolarian; opportunistic phytophagous or dominantly phytophagous cool-water planktonic foraminifers (Globigerina bulloides, Neoglobobulimina acostaensis, Globigerinita glutinata and Turborotalita quinqueloba); benthic infaunal taxa, phytodetritus feeders or exploiting different trophic resources (Cassidulina carinata, Bulimina spp., Stainforthia complanata); the common ostracod Costa edwardsii and also by common Calcidiscus leptoporus, Helicosphaera carteri and H. sellii, also related to mesotrophic to eutrophic cool waters. The absence of the oligotrophic discoasterids may be another signal of high nutrient levels.

Productivity was rather high in comparison with that suggested for coeval assemblages in Piedmont, devoid of siliceous microfossils and generally characterized by more diversified foraminiferal and ostracod assemblages. Nevertheless, the rather low diatom numbers suggest a moderate productivity in comparison with recent oceanic upwelling areas.

The low Foraminiferal Number (FN) and benthic foraminifer and ostracod diversity may result from dilution of tests in the generally very abundant fine-grained terrigenous fraction, but could be influenced also by seasonal upwelling conditions. Similar very low FN characterized the MPI 3 assemblages in the deeper, epibathyal succession of Moncucco Torinese and suggest an increase of deposition rate, due to the warm, moist Early Pliocene climate. Seasonal successions of cool eutrophic (G. bulloides, N. acostaensis, T. quinqueloba) and warm oligotrophic taxa (Globigerinoides spp., Orbulina spp.) are suggested in the upper La Torretta section by their contemporary common occurrence.

RIASSUNTO - [Evidenze micropaleontologiche di episodi di alta produttività nello Zancleano (Pliocene Inferiore) dell'Italia nord-occidentale] - Le analisi quantitative e semiquantitative condotte su associazioni a microfossili calcarei (foraminiferi, ostracodi e nannofossili calcarei) e silicei (diatomee e radiolari) preservati in sedimenti (silts e argille) diatomitici del Monferrato (Piemonte, Italia nord-occidentale) documentano episodi di alta produttività durante lo Zancleano (Pliocene Inferiore). Questo studio rappresenta la prima documentazione per il Pliocene piemontese di associazioni micropaleontologiche contenenti anche microfossili silicei, che sono attualmente abbondanti in aree di risalita e di alta produttività primaria, finora segnalati solo in depositi miocenici della regione. Le associazioni campionate nelle sezioni di La Torretta, Castelcebro e Calliano (Asti) sono state tra loro correlate e riferite alla zona a foraminiferi MPI 3 (Zona a Globorotalia margaritae - Globorotalia puncticulata), alle zone MNN13 e/o MNN14-15 (CN), alla zona a diatomee Nitzschia jouseae e alla zona a radiolari RN11 (Zona a Stichocorys peregrina). Una produttività elevata nella colonna d'acqua è documentata dalle frequenti diatomee, dominate da Chaetoceros resting spores (RS), dal gruppo Thalassionema e localmente da Paralia sulcata, tutti taxa indicativi di condizioni di upwelling, e dai comuni e frequenti radiolari. I foraminiferi sono dominati da specie planctoniche di acque fresche ed eutrofiche, prevalentemente fitofaghe (Globigerina bulloides, Neoglobobulimina acostaensis, Globigerinita glutinata e Turborotalita quinqueloba), da taxa bentonici infaunali e opportunisti (Cassidulina carinata, Bulimina spp., Stainforthia complanata). L'ostracode Costa edwardsii è inoltre comune, come Calcidiscus leptoporus, Helicosphaera carteri e H. sellii, nannofossili calcarei generalmente correlati ad acque fresche mesotrofiche a eutrofiche. Anche l'assenza dei Discoasteridi, forme oligotrofiche, può essere dovuta a elevati livelli di nutrienti. La produttività era più elevata di quella ipotizzabile nelle associazioni coeve del Piemonte, contenenti esclusivamente microfossili calcarei e caratterizzate da una maggiore diversità specifica. Tuttavia, il numero relativamente basso di valve di diatomee, in confronto ai valori molto alti rilevati nelle attuali aree oceaniche di alta produttività, suggerisce una produttività primaria solo moderata. I bassi valori del Foraminiferal Number (FN) e della diversità specifica dei foraminiferi bentonici e degli ostracodi probabilmente derivano dalla diluizione dei gusci nell'abbondante materiale terrigeno fine, ma, almeno in parte, possono anche risultare dalle condizioni di alta produttività, come riscontrato in depositi oceanici attuali. Valori ugualmente bassi del FN sono stati riscontrati nell'intervallo attribuito alla Zona MPI 3 della successione epibatale di Moncucco Torinese e suggeriscono un aumento del tasso di sedimentazione durante il Pliocene Inferiore, caratterizzato da clima caldo e piovoso. La presenza

contemporanea di frequenti o comuni foraminiferi planctonici di acque fresche ed eutrofiche (*G. bulloides*, *N. acostaensis*, *T. quinqueloba*) e di acque calde, oligotrofiche (*Globigerinoides* spp., *Orbulina* spp.) nella parte superiore della sezione di La Torretta può indicare variazioni nella composizione faunistica legate a stagionalità.

INTRODUCTION

Geological survey and micropalaeontological analyses carried out for the 1:50.000 Geological Sheet 157 - Trino (Carg Project) (Dela Pierre et al., 2003) recovered diatomaceous silts pertaining to the Argille Azzurre (Blue Clay) Formation (Early Pliocene, Zanclean), cropping out in artificial and natural sections near the villages of La Torretta and Castelcebro (Montiglio Monferrato, Asti), and in the basal layer of clayey sandy silts in abandoned quarries at Calliano (Asti). Calcareous microfossils and subordinate sponge spicules, rare diatoms and radiolarians were recorded in the micropalaeontological samples locally collected in the about 40-45 km² surrounding area of Monferrato (Piedmont, Northwestern Italy) (Fig. 1).

This is the first documentation in Piedmont of Pliocene mixed calcareous and siliceous microfossil assemblages, generally reported from upwelling areas and high productivity conditions. Previously, in the region these assemblages were known only from Miocene diatomites and diatomaceous silts (Bonci et al., 1990, 1991). Pliocene calcareous microfossils consist of abundant to common foraminifers, calcareous nannofossils and ostracods. Rare to common molluscs, echinoids, fish fragments and vegetal debris, are also preserved in sediments pertaining to the Argille Azzurre (Blue Clay) and the Sabbie di Asti (Asti Sands) formations (Martinis, 1954; Casnedi, 1971; Violanti, 2005 with references). Recent data document in the region a Zanclean marine succession encompassing the MPI 1 to the MPI 4a foraminiferal zones and the MNN12 to MNN14-15 Calcareous Nannofossil (CN) zones. The most complete documentation of this succession crops out in the Moncucco Torinese quarry, in the Turin Hill, where the Messinian/Zanclean boundary is also preserved. At Moncucco T., calcareous microfossils document an open sea palaeoenvironment and the evolution from upper epibathyal depths during the MPI 1-MPI 2 zones to rather shallower bottoms, influenced by winnowing, in the younger MPI 3-MPI 4a zones (Trenkwalder et al., 2008; Violanti et al., 2011). The lower Zanclean (MPI 1-MPI 2 zones) is also known near Alba, from the Narzole borehole (Violanti et al., 2009) and in outcrops along the Tanaro river, where studies are in progress. Nevertheless, in Piedmont mainly MPI 3-MPI 4a calcareous microfossil assemblages can be recovered from patchy and often ephemeral outcrops of clays, silts and sands of Early Pliocene age (Violanti, 2005).

As yet, younger marine assemblages referable to the early Piacenzian MPI 4b Zone, have been recovered only from the northern side of the Eastern Monferrato, at the margin of the Po Plain (Violanti & Sassone, 2008). None of these assemblages yielded siliceous microfossils.

In the Pliocene of the Mediterranean area, sediments mainly contain calcareous microfossils and assemblages yielding also siliceous microfossils (diatoms, radiolarians, silicoflagellates) are scarce. Well-preserved and rich siliceous assemblages were described only from sapropels or sapropelitic layers, deposited during high productivity

intervals and characterized by high accumulation rates, favouring the preservation of biogenic opal. Zanclean to lower Piacenzian diatoms were studied from diatomite beds of Aghios Vlassios section (Crete, Greece) (Frydas, 1999; Frydas & Stefanopoulos, 2009) and from the Aegina Island (Greece) (Gaudant et al., 2010). Pliocene radiolarians have been described from few localities, e.g. the lower Zanclean of Capo Rossello (Sicily), referred to the MPI 2 Zone (Riedel et al., 1974), Neogene Mediterranean Sea sediments (Sanfilippo et al., 1978), a "Tabianian" (Lower Pliocene) sample at Tabiano Bagni (Emilia), where they were associated to other siliceous and calcareous microfossils (Sanfilippo et al., 1973) and the Bianco section (Calabria) (Sanfilippo, 1988; Rio et al., 1989). At Bianco, diatomites are interlayered to mudstones and record several upwelling episodes, the first occurring just before the *Globorotalia margaritae* LO, dating the MPI 3/MPI 4a boundary, the others more frequent in the lower Piacenzian upper part of the section (Rio et al., 1989).

More frequently, siliceous assemblages have been recovered from Pliocene to Pleistocene sapropels (Schrader & Materne, 1981; Björklund & De Ruiter, 1987; Danelian & Frydas, 1998; Negri et al., 2003; Frydas & Hemleben, 2007) as well as in bacterial mats (Erba, 1991) of the Eastern Mediterranean Sea.

The aims of the present work are: 1) the micropalaeontological description, biostratigraphical and palaeoenvironmental interpretation of La Torretta, Castelcebro and Calliano sections, unique in the Pliocene succession of Piedmont for their content in diatoms and radiolarians; 2) to propose their tentative correlation with biostratigraphically representative sections of Piedmont and with diatomaceous layers of the Mediterranean area.

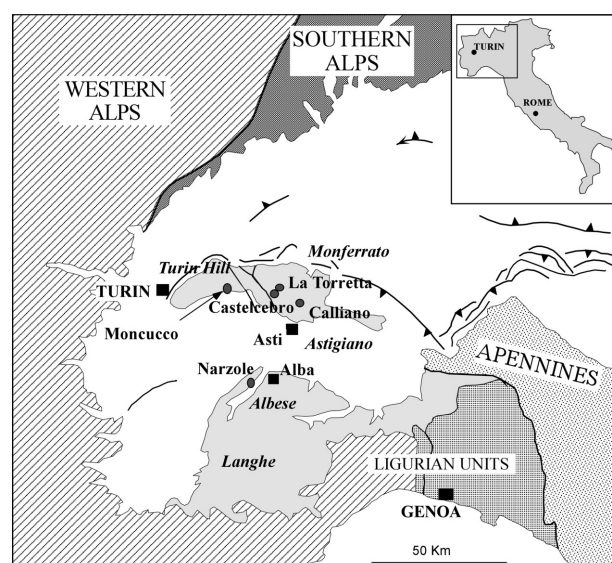


Fig. 1 - Geologic and structural map of Northwestern Italy, location of the studied successions and cited sections (modified from Bigi et al., 1990).

GEOLOGICAL SETTING

The hilly region of Monferrato corresponds to the NW termination of the Apennine thrust belt and is separated from the adjacent Torino Hill by the Rio Freddo deformation zone, a NW-SE transpressive shear zone that controlled the deposition of Oligo-Miocene sediments (Clari et al., 1995; Piana & Polino, 1995; Piana, 2000). To the north, the Monferrato is bounded by the most recent north-verging frontal Apenninic thrusts, buried under the Pliocene and Pleistocene sediments of the Po Plain foredeep (Bonsignore et al., 1969; Clari et al., 1995).

The Monferrato Cenozoic is represented by a thick succession of Eocene to Pliocene mainly clastic sediments that unconformably overlie Mesozoic Ligurian units. The lower part of the succession consists of Upper Eocene hemipelagites (Monte Piano Fm.) overlain by Oligocene shallow-water coarse-grained terrigenous sediments (Cardona Fm.) that grade upward to Aquitanian and Lower Burdigalian slope facies [Antognola and Marne a Pteropodi (Pteropods Marls) Fm.]. This succession is affected by important lateral changes in both facies and thickness, suggesting deposition on an articulated sea floor topography controlled by fault activity along NW-SE transpressive faults (Clari et al., 1995; Piana & Polino, 1995; Piana, 2000). Deposition of Middle to Upper Miocene sediments was controlled by N-verging compressional tectonics, coeval with the onset of the Po Plain foredeep to the north (Piana, 2000). These sediments are bounded at the base by an unconformity and consist of Langhian outer shelf carbonates and marls, followed by Serravallian to Tortonian-Lower Messinian outer shelf to slope facies, rich in marine calcareous microfossils, and by strongly deformed evaporites deposited during the Messinian salinity crisis. These sediments are unconformably overlain by a chaotic unit (the Valle Versa chaotic complex; Dela Pierre et al., 2002, 2003), made up of blocks of different size and composition (Ca-sulphate and a wide range of carbonate facies) floating in a fine grained matrix. Most of these sediments were deposited by large scale mass wasting, triggered in Late Messinian times by the outward migration of the Padane thrust fronts, causing the overthrusting of the Monferrato on the Po Plain foredeep (Dela Pierre et al., 2007).

The marine succession ends with Pliocene marls and sands, deposited after the Messinian salinity crisis. The Pliocene succession crops out along the southern edge of the Monferrato hills, north-east of the Astigian Basin (Fig. 1) (Dela Pierre et al., 2003; Festa et al., 2009). It starts with the Argille Azzurre (Blue Clay) Fm., previously reported as Argille di Lugagnano (Lugagnano Clays) Fm. (Bonsignore et al., 1969), grading upward and laterally to the Sabbie di Asti (Asti Sands) Fm. Stratigraphical and micropalaeontological analyses allowed correlation of the Argille Azzurre Fm. to the Early Pliocene (Zanclean) and their separation into three members: 1) the Silty-clayey Member, referable to the MPI 2-MPI 4a foraminiferal biozones (Cita, 1975; Rio et al., 1991) and deposited in epibathial to outer neritic-epibathial palaeoenvironment, 2) the Clayey Member and 3) the Silty-sandy Member, recognized only in the eastern sector of Monferrato (Dela Pierre et al., 2003); the latter two members are referable to the MPI 3-MPI 4a biozones and to outer neritic bottoms.

Interposed between the Silty-clayey Member or the Clayey Member and the basal layers of the Silty-sandy Member of the Argille Azzurre Fm., massive whitish silty-clayey to sandy silts, yielding mixed calcareous (foraminifers, ostracods, echinoid fragments) and siliceous (sponge spicules, diatoms and radiolarians) microfossil assemblages (the object of this paper) have been found in an area of about 40-45 km² in the south-eastern sector of the Sheet 157 - Trino (Dela Pierre et al., 2003).

Two members have been distinguished within the Sabbie di Asti Fm., both referable to the inner neritic/shallow outer neritic zone (Dela Pierre et al., 2003): 1) the Calcarenitic Member (AST1), cropping out at Moncalvo (Asti), deposited during the MPI 4a biozone and 2) the more widespread Sandy Member (AST2), deposited in the same time interval, often heteropic to the Argille Azzurre Fm., yielding often abundant macrofossils and shallow-water, long-ranging benthic foraminifers.

Pleistocene and Holocene fluvial and continental sediments form the valley plains.

MATERIAL AND METHODS

The studied samples were collected from diatomaceous clayey and sandy silts belonging to the Argille Azzurre Formation. Quantitative studies were carried out on the three sections: La Torretta, Castelcebro and Calliano, where the diatomaceous silts at the passage between the underlying Silty clayey or Clayey Member and the overlying Silty-sandy Member (Dela Pierre et al., 2003) are exposed.

The La Torretta and Castelcebro sections are located ca. 100 m NE and 300 m SE of the villages, respectively. At La Torretta, 1 m of sandy silts and about 0.8-1 m of diatomaceous silts, separated by a 5 m thick covered zone, are exposed. These sediments were sampled at intervals of about 5-50 cm.

At Castelcebro 10 m of homogeneous sandy to clayey silts have been sampled each 1-2 m.

At Calliano the succession is exposed in two abandoned quarries: section Calliano1 (about 15 m thick) is at 500 m SE of the village, section Calliano2 (about 13 m thick) is located NE of the village, near the SS 457 road. Sediments consist of a dm-thick layer of blue-grey homogeneous clays (cropping out only at the base of the Calliano2 section), and of yellowish massive silts passing upwards to poorly bedded sandy silts. Samples were collected at average intervals of about 1 m. The more complete section Calliano2, encompassing the basal blue-grey clays, is discussed here.

For foraminiferal and ostracod analyses 200-250 g of dry sediment were treated with a small quantity of hydrogen peroxide, gently washed, separated into grain size fractions greater than 250 µm, 125-250 µm and 125-63 µm and weighed.

Quantitative analysis of foraminiferal assemblages was carried out on total residues >125 µm, split into aliquots of at least 300-400 specimens. The number of foraminiferal specimens per gram of dry sediment (FN) and the P/(P+B) ratio were calculated. Following Van der Zwaan et al. (1990) and Van Hinsbergen et al. (2005), modified P/(P+B) ratios were considered, discarding from the total

tests the stress-tolerant forms (ST) (*Bulimina*, *Bolivina*, *Brizalina*, *Fursenkoina*, *Globobulimina*, *Stainforthia* and *Uvigerina*, that can proliferate within disoxic bottoms) and the inner neritic, shallow-water taxa (SW) (*Ammonia*, *Cibicides*, *Elphidium*, *Rosalina* that can be transported from shallower depths). High numbers of ST and SW specimens affect the abundance of planktonic tests, and thus the P/(P+B) ratio and the estimated palaeobathymetry. The benthic diversity was measured by two indices, using PAST ver. 1.77 (Hammer et al., 2008): 1) the benthic foraminifer (BF) taxa richness (S) as the total number of taxa for each sample; 2) the BF Fisher's diversity index (α) which takes into account the number of taxa as well as the number of specimens for each sample.

The adult ostracod valves were identified and counted for the >125 μ m residues following the Normalized Method (Mana & Trenkwalder, 2007). The number of minimum certain individuals was calculated as the sum of complete carapaces plus the highest number of valves (left or right). Two diversity indices, the ostracod (O) taxa richness (S) and the O Fisher's diversity index (α), were measured using PAST.

Calcareous nannofossil (CN) biostratigraphical analysis was based on light microscope observation of CN assemblages; samples were prepared according to standard methods (Bown & Young, 1998), and were studied under polarized light at 1250x magnification. Abundance data are based on counting of 500 specimens per sample on a predetermined area of the slide (9 mm²) following Backman & Shackleton (1983) and Rio et al. (1990).

For diatom analysis, 1 g of dry sediment for each sample was prepared according to the method of Barde (1981), increasing the decantation time to 12 hours. Diatom valves were counted on three total slides, 18x18 mm large, mounted in Naphrax medium, at a magnification of 1250x, according to the method of Schrader & Gersonde (1978). In the quantitative study, some taxa, strongly taxonomically related and with similar ecology, were counted as units at the generic level (i.e. *Actinopterychus* spp., *Cocconeis* spp., *Coscinodiscus* spp., *Grammatophora* spp.). *Thalassionema nitzschioides* and *Thalassiothrix longissima* valves were put together in the *Thalassionema* group (Mikkelsen, 1990). Diatom preservation is in general poor, in most samples strong fragmentation and dissolution were observed and loss of weakly silicified species can be inferred. As a consequence, the more robust forms (*Paralia sulcata*, *Actinopterychus* spp. and *Chaetoceros* resting spores, RS) could be over-represented. The very poor preservation and high fragmentation did not allow the evaluation of valve number/g.

Preliminary study of radiolarians was carried out on some samples of the La Torretta and Castelcebro sections. Sediments were treated with hydrochloric acid (HCl) at 4% for about one day, boiled with a diluted solution of soda and oxygen peroxide and then sieved over a 44 μ m mesh. Specimen's determination was carried out at the stereoscopic microscope and under the Scanning Electron Microscope (SEM). Methods of study and taxonomy follow Riedel & Sanfilippo (1971), Sanfilippo et al. (1973, 1985), Sanfilippo (1988), De Wever et al. (2001). Radiolarian taxonomic determination was hampered by differential preservation of taxa, high morphological

variability and discontinuous recovery, particularly affecting the Mediterranean record, where the standard zonation of tropical and subtropical regions (Sanfilippo et al., 1985) is of reduced validity due to the absence of many marker species.

Large diatom valves and radiolarians were collected in samples for foraminifer and ostracod analyses (LT5, CB1, CB4). The recovery can result from specimens concentration in the greater sediment amount (200-250 g) used for washing residues in comparison with the lower quantitative necessary for diatom slides (about 1 g).

SEM photographs were taken at the Paleontološki Institut Ivan Rakovec, Ljubljana (Slovenia) (radiolarians) and at the SEM Laboratory of Earth Sciences Department and Mineralogical and Petrological Sciences Department, Turin University. Diatom optical photographs were taken at DipTeRis, Genoa University.

MICROPALAEONTOLOGICAL DATA

1) La Torretta

RESIDUE COMPOSITION - Residues contain a common terrigenous fraction (quartz grains, mica flakes) more frequent in sample LT4, and yield frequent foraminifers, common siliceous sponge spicules and echinoid fragments, common to rare ostracods. Very rare diatom valves and radiolarians occur in most of the 125-250 μ m and 125-63 μ m fractions. Anellids (*Ditrupa*), bivalve and fish fragments are common in sample LT5. Percentages of the >63 μ m fraction (Fig. 2) are always less than 4% of the dry sediment.

FORAMINIFERS - Foraminifers are well preserved, dominated by benthic specimens. The FN is extremely low in the basal LT4 sample (22), reaches its maximum of 1575 in sample LT5, and ranges between about 230 and 700 in the upper samples. Values of the P/(P+B) ratio are also very low, less or about 10%. Even when corrected, i.e., discarding from the benthic forms the stress-tolerant infaunal taxa (ST) (*Bulimina*, *Bolivina*, *Brizalina*, *Fursenkoina*, *Gobobulimina*, *Stainforthia* and *Uvigerina*), (Van der Zwaan et al., 1990; Van Hinsbergen et al., 2005), the P/(P+B-ST) ratio remains below 15-20% (Max 18, sample LT5). A very small increase is measured discarding also the specimens of shallow-water benthic taxa (SW) (*Ammonia*, *Cibicides*, *Elphidium*, *Rosalina*, etc.), interpreted as winnowed from shallower bottoms [(P/(P+B-ST-SW) Max 21%, sample LT5].

Planktonic taxa are represented by a total of 16 species and eutrophic cold to temperate water taxa are dominant. *Globigerina bulloides* is always common to abundant and attains its maximum in sample LT (42%) (Fig. 2), its percentage variations are opposite to those of *Globigerinita glutinata*, which reaches values of about 20-30%. Also *Neoglobobulimina acostaensis* dextral and *Turborotalita quinqueloba* are common to frequent. Rare specimens of *Globorotalia scitula* occur only in sample LT5. The surficial oligotrophic warm-water genus *Globigerinoides* (*G. obliquus* and *G. extremus*) is common and increases in abundance in samples LT1 and LT2 (20-24%). *Orbulina universa*, an oligotrophic surficial to intermediate water taxon, occurs with high percentages

in samples LT and LT1, in positive correlation with the *Globigerinoides* spp. increase (Fig. 2). *Globoturborotalita apertura* is abundant (31%) only in the basal sample LT4.

Ninety-five benthic species have been recognized in the whole section, but only 18 species reach percentages higher than 2% and 9 species show >5% values in at least one sample (*Bolivina punctata*, *Brizalina spathulata*, *Bulimina gibba*, *B. minima*, *Cassidulina carinata*, *Florilus boueanum*, *Gavelinopsis praegeri*, *Stainforthia complanata* and *Textularia sagittula*). The benthic foraminiferal Taxa S and Fisher's α reach higher values in the lower LT4 and LT5 samples and decrease to a minimum in the uppermost sample LT3 (Fig. 3). The shallow infaunal *Cassidulina carinata* and the deep infaunal genus *Bulimina* are dominant (20-30% for each taxon), followed by the deep infaunal *Stainforthia complanata*, frequent in the upper layers and *Brizalina* spp., which attains 20% of the total only in sample LT5 (Fig. 3). Epifaunal taxa are poorly represented, by rather common *Gavelinopsis praegeri* (Max about 5%) and by rare *Cibicides lobatulus*, *Discorbis* spp., *Gyroidinoides umbonatus* and *Rosalina* spp. Outer neritic to bathyal taxa such as *Cibicidoides pseudoungerianus*, *Gyroidinoides neosoldanii*, *Melonis barleanum*, *Sigmoilopsis schlumbergeri*, *Sphaeroidina bulloides*, *Siphonina planoconvexa*, *Uvigerina* spp. and

nodosariids, widespread on upper epibathyal bottoms, are very rare and occur almost exclusively in sample LT5. No specimens of shelf forms as *Valvulineria bradyana*, common in recent prodelta facies (Frezza & Carboni, 2009, and references therein) as well as deeper taxa, common in bathyal Pliocene assemblages such as *Planulina ariminensis*, *Siphonina reticulata* and *Uvigerina rutila* (Wright, 1978; Violanti et al., 2011) have been recognized.

OSTRACODS - Ostracods are represented by a total of 28 species, mostly recognised in sample LT5. The number of species (Os Taxa S) and the Os Fisher's diversity index (α) throughout the succession (Fig. 3) show low values, except for sample LT5 in which 26 species occur and the Fisher alpha value is 24.70. *Costa edwardsii* is present in all samples and is common in samples LT4 and LT1 (Fig. 3). *Acantocythereis histrix* and *Occultocythereis dohrni*, which are warm-temperate water taxa (Montenegro et al., 1998), occur in sample LT5, together with taxa common in bathyal and outer-neritic Pliocene assemblages such as *Cytheropteron* spp., *Henryhowella asperima* and *Ruggeria tetraptera* (Dall'Antonia et al., 2001) and inner to outer neritic taxa such as *A. histrix*, *Carinivalva testudo*, *Cytherella* spp., *Pterygocythereis*

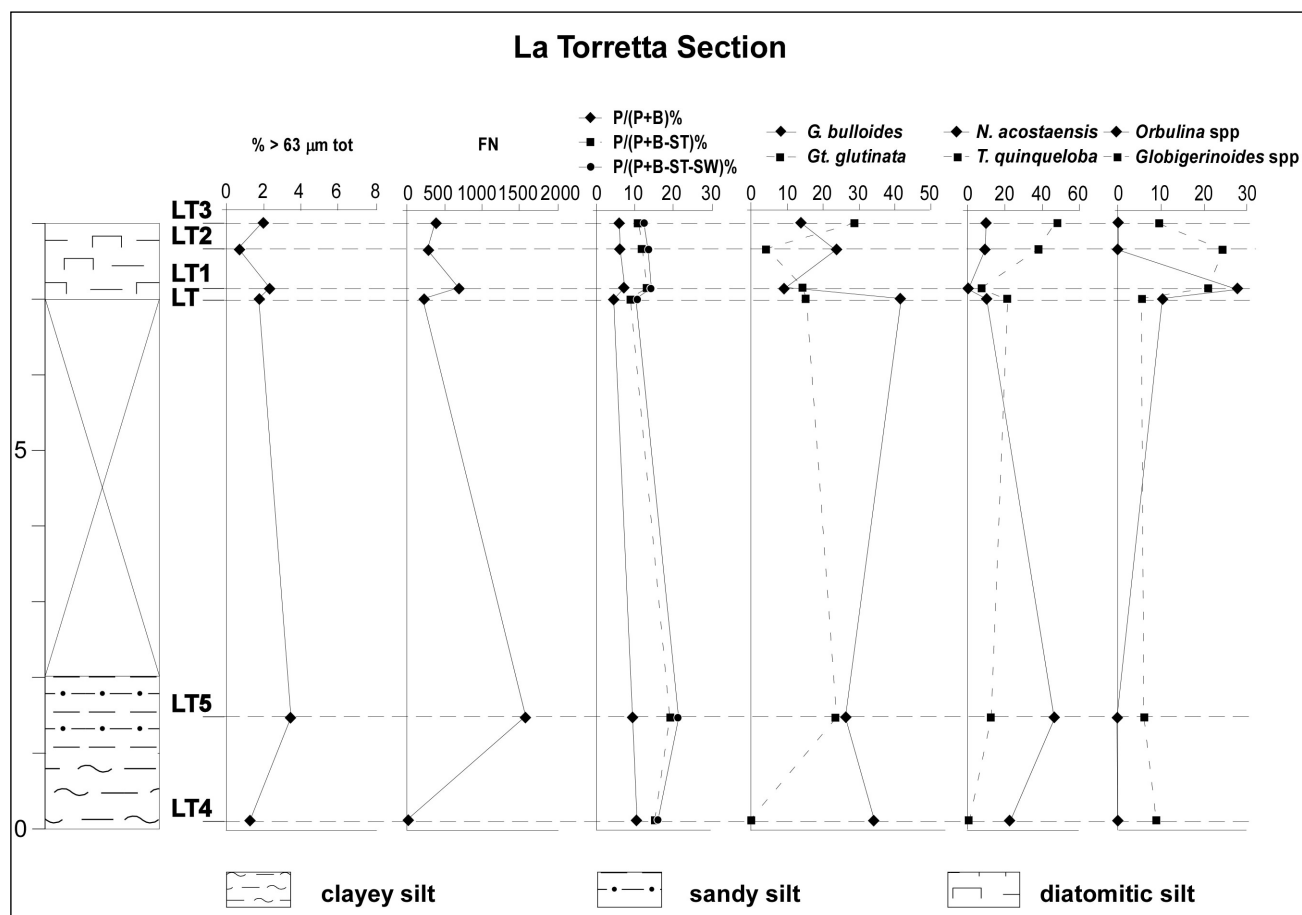


Fig. 2 - Lithological column, sample location, percentage variations of the grain size >63 µm residue, FN (number of foraminiferal tests per gram of dry sediment), P/(P+B) uncorrected and corrected ratio percentages (P = Plankton, B = Benthic, ST = Stress Tolerant, SW = Shallow water forms); percentage variations of planktonic foraminifers *G. bulloides*, *Gt. glutinata*, *N. acostaensis*, *T. quinqueloba*, *Orbulina* spp., and *Globigerinoides* spp. in the La Torretta section.

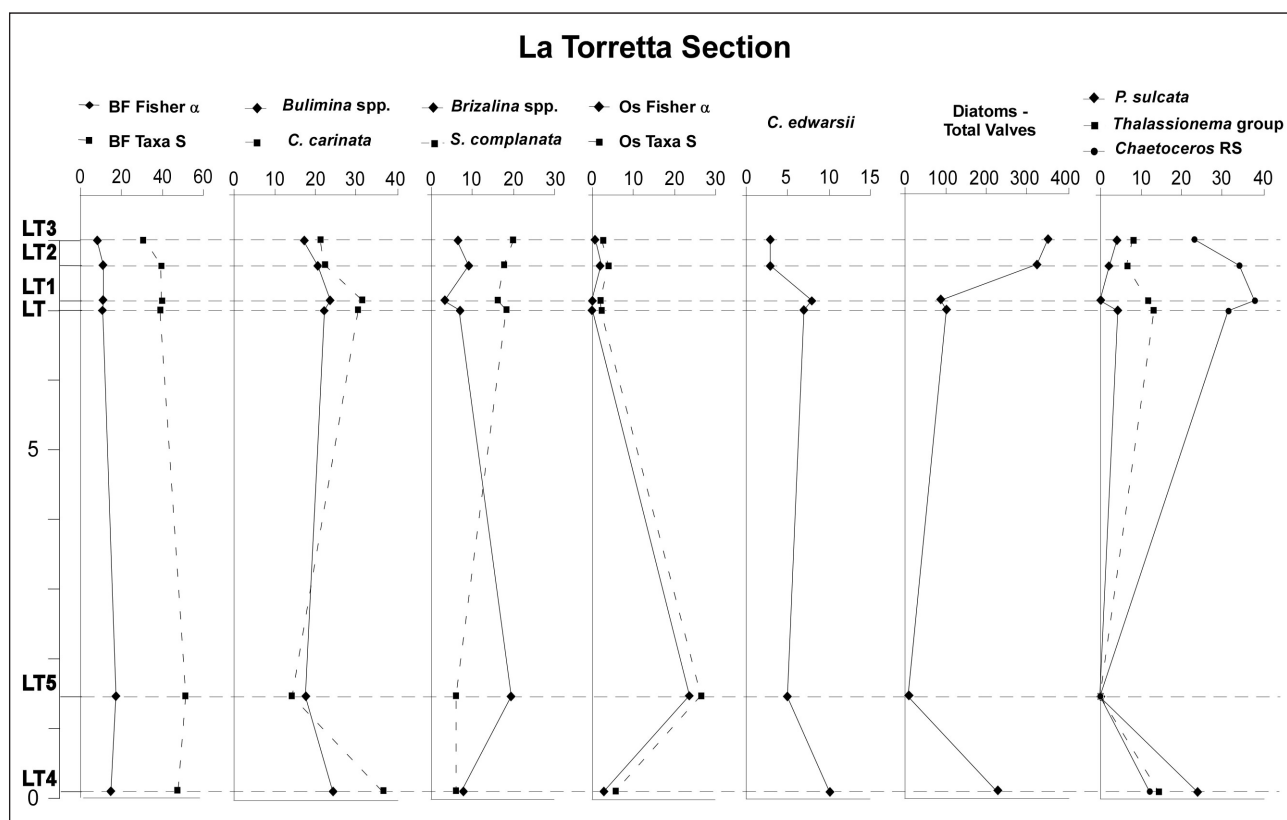


Fig. 3 - Percentage variations of the benthic foraminifer diversity (BF Fisher α and BF Taxa S, percentage variations of benthic foraminifer taxa *Bulimina* spp., *C. carinata*, *Brizalina* spp., and *S. complanata*; percentage variations of the ostracod diversity (Os Fisher α and Os Taxa S), percentage variations of the ostracod *C. edwardsii*, of diatom total valves and of diatom *P. sulcata*, *Thalassionema* group and *Chaetoceros* resting spores (RS) in the La Torretta section.

jonesi and *Xestoleberis communis* (Peypouquet, 1973; Ruiz & González-Regalado, 1996). The upper samples are characterized by dominant *C. edwardsii*, and rare inner to outer neritic taxa (*Aurila* sp., *L. mutabilis* and *Semicytherura inversa*).

CALCAREOUS NANNOFOSSILS - Calcareous nannofossils are common to abundant and their preservation is generally good in all samples. Assemblages contain abundant "small" *Reticulofenestra* (*R. haqi* and *R. minuta*). *Coccolithus pelagicus*, *Calcidiscus leptoporus*, *R. pseudoumbilica*, *Helicosphaera carteri* and *H. sellii* are also main component of the assemblages. On the contrary, assemblages are completely devoid of *Discoaster* spp. and *Sphenolithus* spp.

Calcareous nannofossil assemblages from La Torretta, as well as from the Castelcebro and Calliano sections, are characterized by reworked older specimens, mainly from Oligocene and Miocene sediments (*Zygrhablithus bijugatus*, *Reticulofenestra daviesii*, *Helicosphaera euphratis*), but also as old as Lower Cretaceous (*Biscutum constans*, *Eifellithus turriseifellii*, *Watznaueria britannica*).

DIATOMS - Diatoms are rather common in all samples, with the exception of sample LT5, in which rare large centric valves were observed only in the washing residue. A total of 74 species, plus the *Thalassionema* group

and *Chaetoceros* resting spores (RS), was recognized. Abundances, expressed as valve numbers/total slide, range between 224 total valves in the lowermost sample LT4 to nearly zero in sample LT5, show low values within sample LT and LT1 and increase to their maximum of 351 valves in the uppermost sample LT3 (Fig. 3). In the basal layer (LT4), *Paralia sulcata*, a meroplanktonic taxon indicative of high littoral production (Abrantes, 1988; Van Iperen et al., 1993; Bárcena et al., 2001), is dominant (Fig. 3). Also the *Thalassionema* gr. and *Chaetoceros* RS, both of which characterize upwelling areas and seasonal blooms (Sancetta, 1982; Frydas & Hemleben, 2007), are frequent. Upsection, a strong decrease of *P. sulcata* and, to a lesser extent, of the *Thalassionema* gr. is recorded, whereas *Chaetoceros* RS increase in abundances, with a peak in sample LT1. Other common taxa, ranging between about 3-8%, are meroplanktonic forms (*Actinocyclus octonarius*, *Thalassiosira eccentrica*) and benthic taxa such as *Diploneis* spp., *Grammatophora* spp., and *Rhaphoneis* spp. The holoplanktonic *Bacteriastrum* spp. and *Coscinodiscus* spp., generally represented by undeterminable fragments, are common only in the lowermost and upper samples, respectively. *Nitzschia jouseae*, *Thalassiosira oestrupii* and *Thalassiosira convexa aspinosa* are also present. Freshwater taxa are absent, only very rare *Rhopalodia gibba* and *Rh. musculus*, tolerant of brackish waters (Gersonde, 1980), randomly occur.

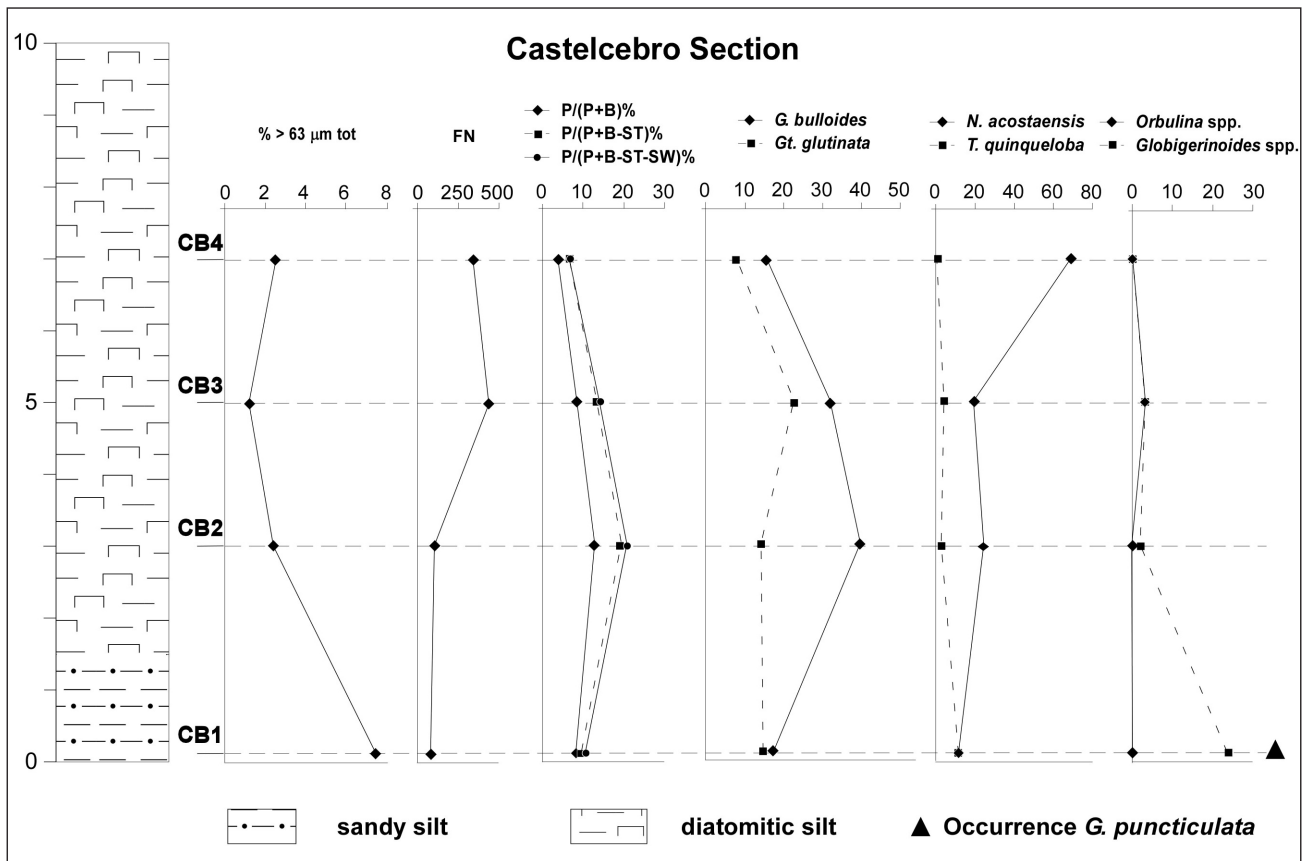


Fig. 4 - Lithological column, sample location, percentage variations of the grain size $>63 \mu\text{m}$ residue, FN (number of foraminiferal tests per gram of dry sediment), $P/(P+B)$ uncorrected and corrected ratio percentages (P = Plankton, B = Benthic, ST = Stress Tolerant, SW = Shallow water forms); percentage variations of planktonic foraminifers *G. bulloides*, *Gt. glutinata*, *N. acostaensis*, *T. quinqueloba*, *Orbulina* spp., and *Globigerinoides* spp. in the Castelcebro section.

RADIOLARIANS - Radiolarians are rare to frequent, well preserved in most samples of La Torretta section, except for samples LT5 and LT1. A total of 17 taxa was recognized, represented by Spumellaria (with abundant Spongodiscidae such as *Dictyocoryne profunda*, *Rhopalastrium zitteli*, frequent *Hexacontium* spp. and *Perychlamydiium limbatum*) and Nassellaria (with abundant Artostrobiidae, Eucyrtidae, Pterocorythidae and Ultraporidae). *Anthocyrtidium ophirensis*, *Eucyrtidium cienkowski*, *Theocorythium trachelium* cf. *dianae* and *Stichocorys peregrina* are frequent to abundant. Rare specimens of *Stichocorys delmontensis* also occur. Within the washing residues also specimens of *Actinomma* sp., *Amphirhopalum ypsilon*, *Euchitonia* spp., *Hexacontium* cf. *arachnoidale* were recovered.

2) Castelcebro

RESIDUE COMPOSITION - Residues yield common to abundant terrigenous aggregates, quartz grains and mica flakes, foraminifers, echinoid, and molluscs. Siliceous sponge spicules, ostracods and fish debris are common to rare. Diatom valves have been observed in the CB1 residue, radiolarians in the CB2 to CB4 residues. Percentages of the $>63 \mu\text{m}$ fraction are lower than 1% of the treated sediment, only slightly higher in the basal sample CB1 (Fig. 4).

FORAMINIFERS - Foraminiferal assemblages at Castelcebro show a very similar composition, but less diverse than that at La Torretta. The FN and the $P/(P+B)$ ratio are very low (Fig. 4): the FN has the maximum value of only 432 in sample CB3, percentages of the $P/(P+B)$ ratio (uncorrected) reach about 12% in sample CB2. The pattern of the modified $P/(P+B)$ curves [corrected discarding the stress tolerant (ST) and the shallow water (SW) forms] is similar to the previous uncorrected curve, with a more evident increase in sample CB2, in which the ST benthics contribute with about 7% to the total assemblage.

13 planktonic species and 87 benthic species, 19 of them reaching $\geq 2\%$ and 7 more than 5% in at least one sample, have been recognized in the counted fractions. Cool-water, eutrophic water taxa such as *G. bulloides*, *Gt. glutinata*, and *N. acostaensis* are dominant or constitute the entire planktonic assemblage (Fig. 4). *G. bulloides* is always common and is abundant in sample CB2 and CB3 (about 30-40%), *N. acostaensis* dextral becomes strongly dominant in the upper sample CB4 (about 70%). On the contrary, *T. quinqueloba* is rare. Warm-water, oligotrophic forms such as *Globigerinoides* spp. and *Orbulina* spp. are very rare and occur only in sample CB1. Very rare specimens of *Globorotalia puncticulata* occur in sample CB1.

Benthic diversity, expressed as BF Taxa S and Fisher α index, decreases from the bottom to the top and shows

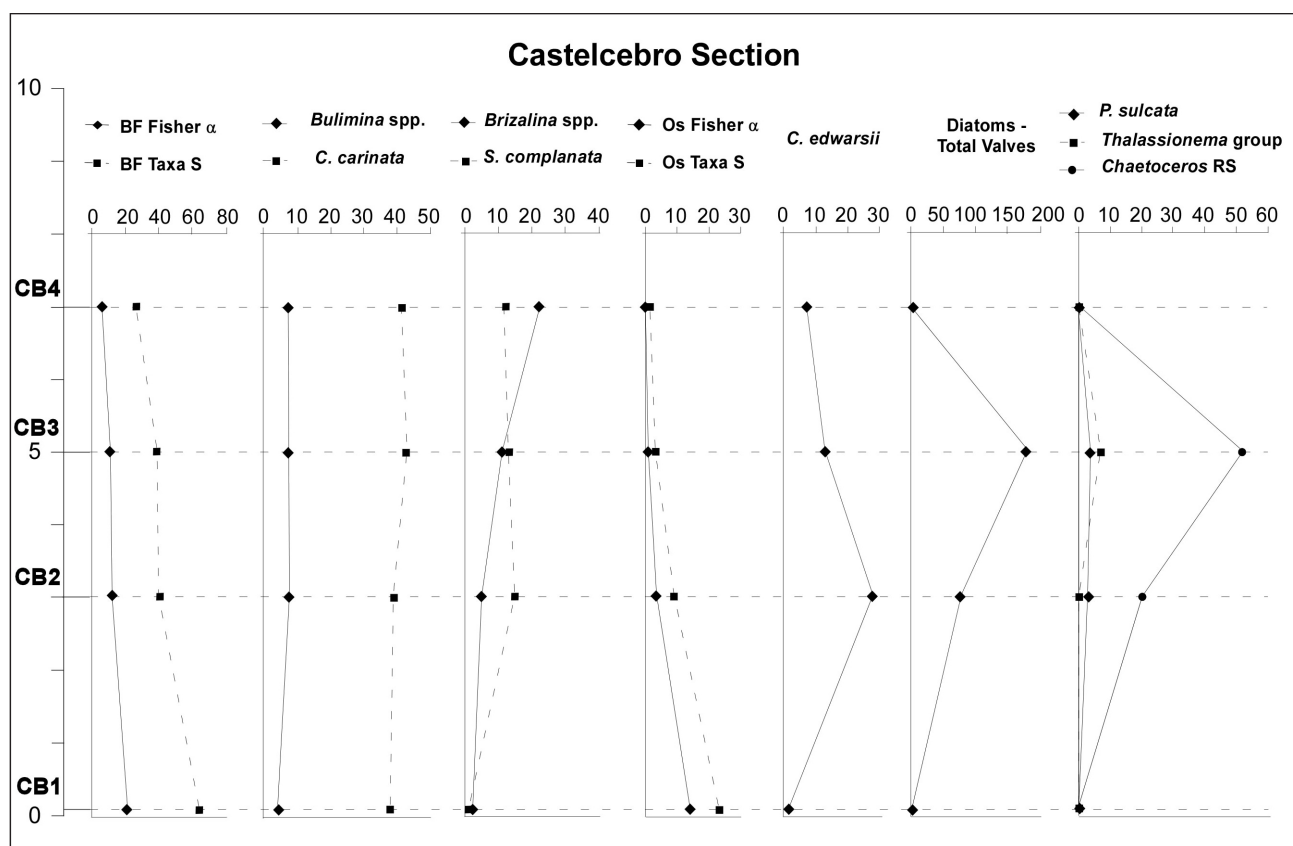


Fig. 5 - Percentage variations of the benthic foraminifer diversity (BF Fisher α and BF Taxa S, percentage variations of benthic foraminifer taxa *Bulimina* spp., *C. carinata*, *Brizalina* spp., and *S. complanata*; percentage variations of the ostracod diversity (Os Fisher α and Os Taxa S), percentage variations of the ostracod *C. edwardsii*, of diatom total valves and of diatom *P. sulcata*, *Thalassionema* group and *Chaetoceros* resting spores (RS) in the Castelcebro section.

low values (Fig. 5). Benthic assemblages are dominated by *C. carinata*, followed by the other infaunal, stress tolerant *Bulimina* spp. (*B. aculeata*, *B. gibba*, and *B. lappa*). The deep infaunal *Brizalina* spp. (*B. dilatata*, *B. spathulata*), *S. complanata* (Fig. 5), less common *B. punctata*, *F. schreibersiana* and the probably shallow infaunal *Florilus boueanum*, increase in abundance upwards. Epifaunal (*C. pseudoungerianus*) and deep outer neritic to bathyal taxa (*Gyroidinoides longispira*, *Melonis soldanii*, *S. schlumbergeri*, *S. bulloides*, *Spiroplectinella wrighti*, and *Uvigerina pygmaea*) are present only in sample CB1. In the same sample CB1 the inner neritic taxa *Ammonia beccarii* and *A. tepida* attain percentages between 1-3%. In the other samples shallow-water species (*Elphidium* spp., *Quinqueloculina seminulum*, and *Rosalina globularis*) are very rare or absent.

OSTRACODS - Ostracod assemblages, like foraminiferal assemblages, are similar to those described at la Torretta. A total of 26 ostracod species has been recognized. The number of Os Taxa S and the Os Fisher α diversity index (Fig. 5) show relatively low values, with the exception of sample CB1, in which 23 species occur, and the Fisher alpha value is 14.

A. histrix occurs only in sample CB1. The assemblage observed in sample CB1 is rather diversified and shows the dominance of inner neritic to outer neritic taxa

(*Echinocythereis scabra*, *R. tetraptera*, and *Sagmatocythere versicolor*) and typical outer neritic taxa (*A. histrix*, *Cytherella gibba*, *C. vulgatella*, *Cytheropteron rotundatum*, and *P. jonesi*). Outer neritic to bathyal taxa (*Argilloecia acuminata*, *A. minor*, *Bosquetina rhodiensis*, and *Krithe iniqua*) are present too. The other samples are characterized by the presence of the inner neritic to outer neritic *C. edwardsii*, accompanied in sample CB2 by rare outer neritic taxa (*C. testudo*, *C. rotundatum*, and *P. jonesi*) and in sample CB3 by *Callistocythere pallida* and *Sagmatocythere littoralis*. Sample CB4 only contains *C. edwardsii*.

CALCAREOUS NANNOFOSSILS - Calcareous nannofossils are badly etched by dissolution, poorly diversified and scarce. Sample CB1 contains recrystallized opal and its CN association is very poorly preserved; it is dominated by *C. pelagicus*, "small" *Reticulofenestra* and *Helicosphaera* spp. Very rare silicoflagellates (*Distephanus speculum*) were observed in samples CB2 and CB3. In general, CN assemblages (samples CB2, CB3, CB4) contain common to abundant *C. pelagicus* and *Cd. leptoporus*, together with "small" *Reticulofenestra*, *R. antarctica*, *R. pseudumbilica*, *H. carteri*, and *H. sellii*. *Discoaster* spp. and *Sphenolithus* spp. are absent.

DIATOMS - Diatom assemblages are poorer and less diverse than those of La Torretta. Samples CB1 and CB4

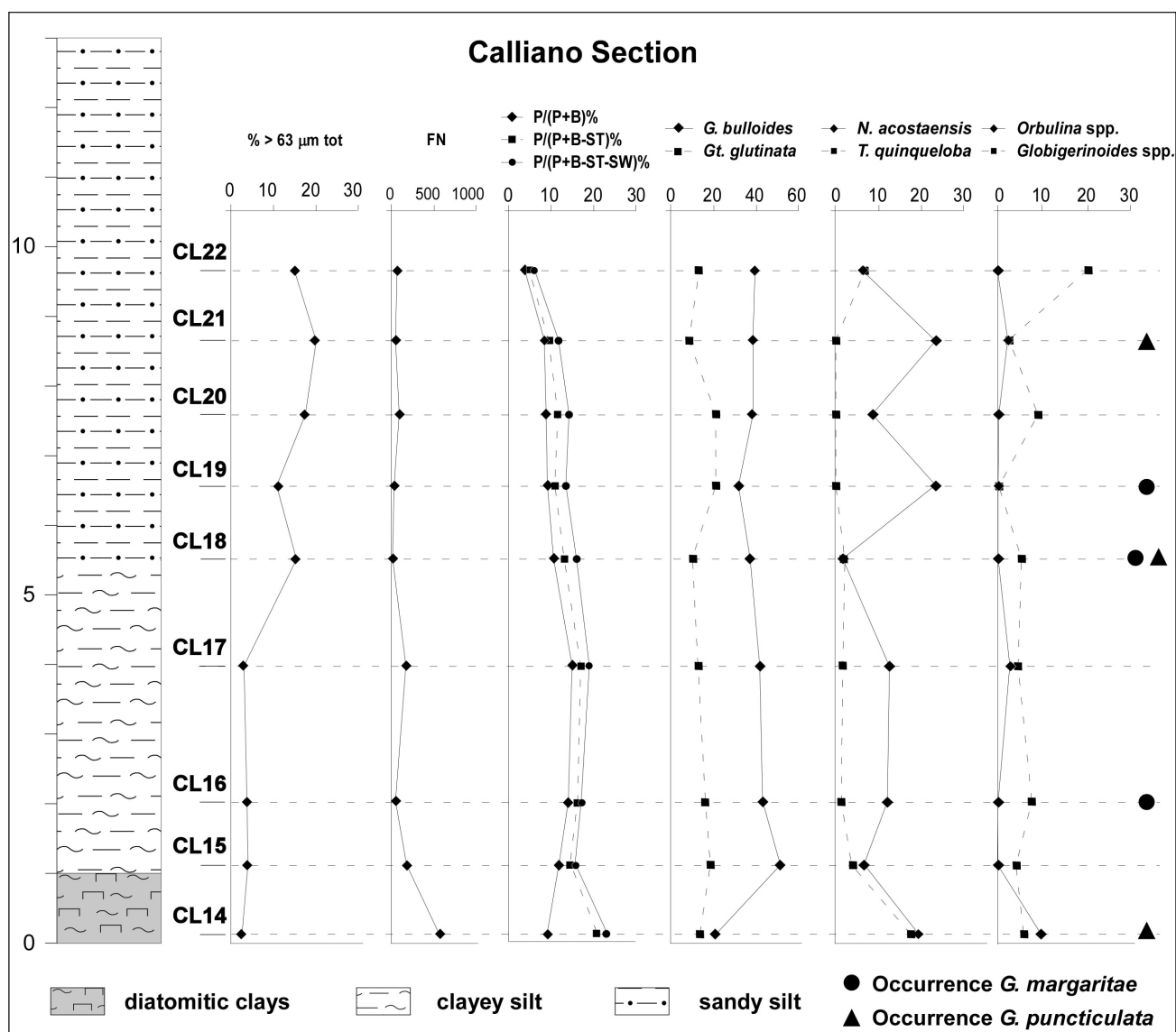


Fig. 6 - Lithological column, sample location, percentage variations of the grain size >63 µm residue, FN (number of foraminiferal tests per gram of dry sediment), P/(P+B) uncorrected and corrected ratio percentages (P = Plankton, B = Benthic, ST = Stress Tolerant, SW = Shallow Water forms); percentage variations of planktonic foraminifera *G. bulloides*, *Gt. glutinata*, *N. acostaensis*, *T. quinqueloba*, *Orbulina* spp., and *Globigerinoides* spp. in the Calliano section.

are barren of diatoms. Abundances are low in sample CB2 and reach 180 total valve/total slide in sample CB3 (Fig. 5). A total of 34 species, plus the *Thalassionema* group and *Chaetoceros* resting spores, was detected in samples CB2 and CB3. The benthic *Grammatophora* spp. are dominant in sample CB2 together with *Chaetoceros* RS, but also the benthic *Cocconeis* spp., *Diploneis* spp. and the meroplanktonic *Actinopterychus* spp. are common. In sample CB3, *Chaetoceros* RS contributed to the assemblage with 52%, the planktonic *Thalassionema* gr., the benthic *Grammatophora* spp., *Diploneis* spp. and *Rhaphoneis* cfr. *petropolitana* percentages range between 4-6%. *P. sulcata* shows low frequencies (Fig. 5). Benthic and meroplanktonic taxa (*Actinopterychus* spp., *Cocconeis* spp., *Dimeregramma* spp., and *Diploneis* spp.) are also frequent to common. Holoplanktonic taxa

(*Azpeitia nodulifera*, *Coscinodiscus oculus-iridis*, and *T. oestrupii*) are scarce. Fragments of large centrics are common.

RADIOLARIANS - Radiolarians are represented by a total of 16 taxa. Specimens are very rare, absent in sample CB1. Spumellaria are dominant, mainly represented by Spongodiscidae (*D. profunda*, *D. truncatum*, *R. zitteli*, *P. limbatum*, and *Hexacontium* spp.). Rare specimens of *Pseudocubus vema* occur in sample CB4. Nassellaria are scarcer, only *A. ophirens* and *Pterocanium trilobum* are common, *T. trachelium* cf. *dianae* is frequent in sample CB4. Rare specimens of *S. delmontensis* occur in sample CB2. In the washing residues also specimens of *Actinomma* sp., *Euchitonia* sp., *H. cf. arachnoidale*, and *S. peregrina* have been recovered.

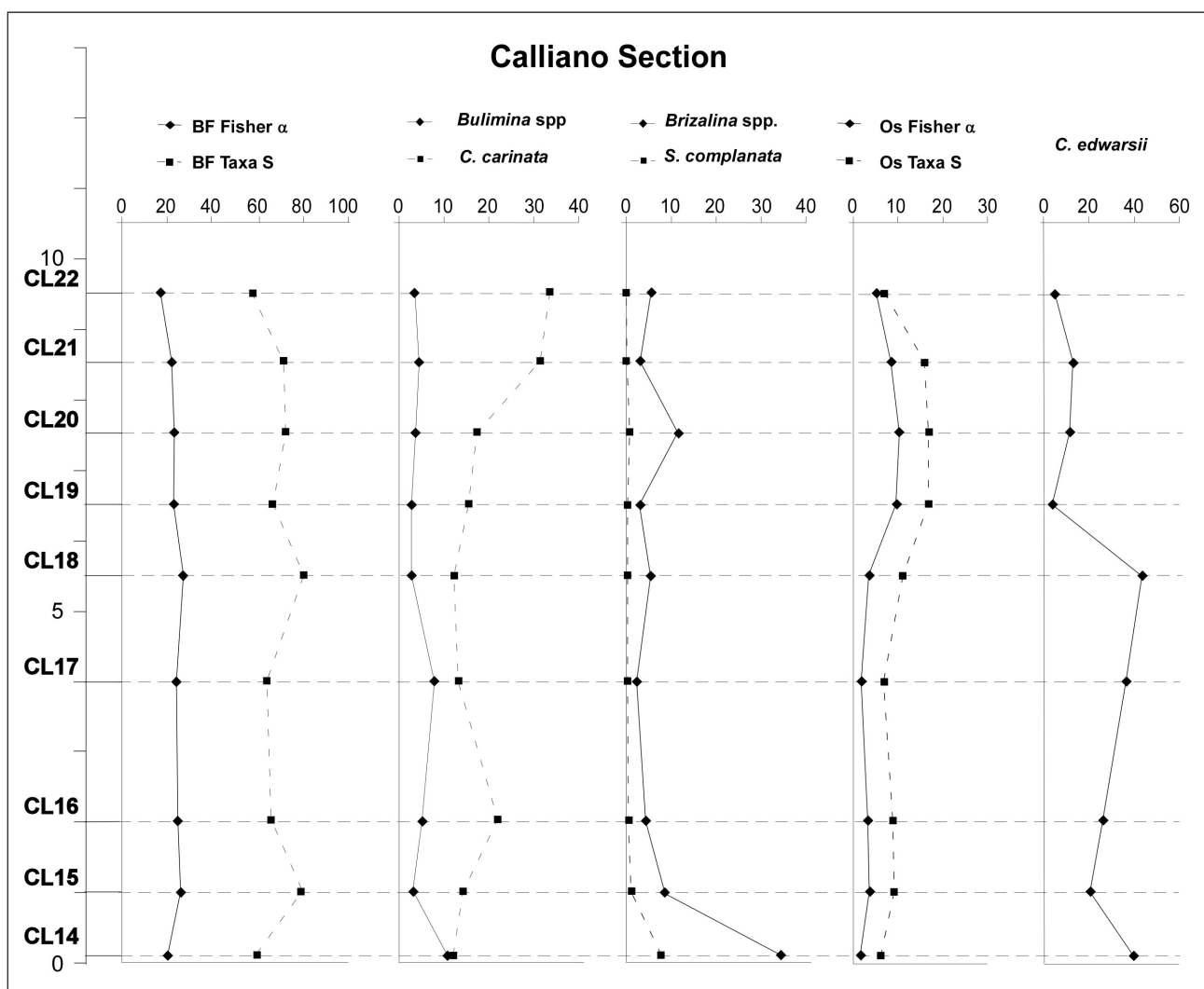


Fig. 7 - Percentage variations of the benthic foraminifer diversity (BF Fisher α and BF Taxa S, percentage variations of benthic foraminiferal taxa *Bulimina* spp., *C. carinata*, *Brizalina* spp., and *S. complanata*; percentage variations of the ostracod diversity (Os Fisher α and Os Taxa S), percentage variations of the ostracod *C. edwardsii* in the Calliano section.

3) Calliano2

RESIDUE COMPOSITION - Residues yield a common terrigenous fraction (quartz, micas, iron oxides aggregates) more frequent in the upper part of the section, from sample CL18 upwards. Foraminifers are abundant and rather diverse, anellids (*Ditrupa*), bivalves and echinoid fragments, ostracods and fish otoliths occur in most samples. Spicules of siliceous sponges are present in the lower layers, whereas rare diatom valves and radiolarians occur only in the basal sample CL14. Percentages of the total $>63 \mu\text{m}$ fraction are less than 5% in the lower samples and increase to 11-20% from CL18 to CL22 (Fig. 6).

FORAMINIFERS - Foraminifers are represented by a total of 15 planktonic and 133 benthic species. The FN reaches its maximum of 586 in the basal sample CL14, then decreases below 100 in the upper samples. The uncorrected P/(P+B) ratio is 10-15% in most samples and shows its minimum in the uppermost CL22. The two

curves of the modified P/(P+B-ST) and [(P/(P+B-ST-SW))] ratios differ very little from the previous one, with the exception of sample CL14, in which they register an increase of stress tolerant (ST) taxa (Fig. 6).

Also at Calliano, planktonics are dominated by eutrophic, cool to temperate water taxa. *G. bulloides* percentages range near 40% in most samples, with the exception of sample CL14 in which a minimum of about 20% is registered. *Gt. glutinata* and *N. acostaensis* dextral are common to frequent, whereas *T. quinqueloba* occurs with rather high percentages (17.31%) only in sample CL14. The surficial oligotrophic warm-water genus *Globigerinoides* (almost exclusively *G. obliquus*, sporadic *G. extremus*) occurs in most samples and increases in abundance in the uppermost CL22 (20%). The other oligotrophic species *O. universa* and *G. apertura* are rather common only in sample CL14 (Fig. 6). Rare *Globorotalia margaritae* and *G. puncticulata* co-occur in sample CL18 and are present also in other samples: *G. margaritae* in samples CL16 and CL19, *G. puncticulata* in samples CL14 and CL21.

Among benthic foraminifers, 22 species reach percentages >2% and 11 species show >5% values at least in one sample (*A. beccarii*, *B. spathulata*, *B. gibba*, *C. carinata*, *C. pseudoungerianus*, *Dorothia gibbosa*, *F. boueanum*, *M. soldanii*, *Oridorsalis stellatus*, *S. complanata*, and *U. pygmaea*). Many deep outer neritic to bathyal species occur with percentages of ca. 2% (*H. bellincionii*, *Melonis pompilioides*, *U. peregrina*) or ca. 1% (*Hoeglundina elegans*, *Planulina ariminensis*, *S. wrighti*).

The BF Taxa S ranges between 60-80 for each sample and the BF Fisher α Index shows a rather uniform pattern, with values near or equal to 20 (Fig. 7). *Brizalina* spp. (*B. spathulata*, *B. catanensis*, and *B. dilatata*) dominates the benthic foraminiferal assemblage of sample CL14 (33.86%), in which also the other stress tolerant *Bulimina* spp. and *S. complanata* are common. Their percentages are less than 10% in the other samples, whereas the shallow infaunal *C. carinata* increases to about 30% (Fig. 7).

OSTRACODS - Ostracods are represented by a total of 30 species. The Os Taxa S (Fig. 7) shows values comprised between 6 and 17, reaching the highest values in samples CL19, CL20 and CL21. The Fisher α index, whose values fluctuate between 1.84 and 10.63, reaches its highest values in the same samples. The warm-temperate *A. histrix* and *Carinocythereis withei* (Ingram, 1998; Montenegro et al., 1998) occur in most samples. *C. edwardsii* is always present, frequent to abundant in the lower samples (CL14-CL18), common or scarce in the upper section. Ostracod assemblages yield other outer-neritic taxa (*Buntonia subulata*, *C. testudo*, *C. vulgatella*, *E. scabra*, *Parakrithe dimorpha*, and *R. tetraptera*). From CL19 sample upward *H. asperrima* and some sporadic specimens of inner to outer neritic taxa (*Aurila* spp., *Carinocythereis withei*, *Costa punctatissima*, *Paracytheridea triquetra*, *Pontocythere turbida*, and *Xestoleberis* spp.) have been observed.

CALCAREOUS NANNOFOSSILS - Calcareous nannofossils are abundant, well preserved and rather diverse. Assemblages yield common to abundant *C. pelagicus*, *Cd. leptoporus*, *Cd. tropicus*, "small" *Reticulofenestra*, *R. antarctica*, *R. pseudumbilica*, *R. zancleana*, *H. carteri*, and *H. sellii*. In the upper samples, from CL19 upwards, reworking of Miocene specimens occurs (*Dictyococcites bisectus*, *Calcidiscus macintyreii* and *Calcidiscus premacintyreii*). *Discoaster* spp. and *Sphenolithus* spp. are absent in all samples.

DIATOMS - Diatoms are scarce, very poorly preserved, showing dissolution and breakage that frequently hampered taxonomic determination at the specific level and quantitative analysis. Valves occur only in the basal sample CL14 of the Calliano2 section. The assemblage is similar to those of La Torretta and Castelcebro samples, but poorer, yielding 24 species plus the *Thalassionema* group and *Chaetoceros* RS. Holoplanktonic large centrics (*Coscinodiscus* and *Thalassiosira*) and the *Thalassionema* gr. are dominant. On the contrary, *Chaetoceros* RS as well as benthic taxa are rare. Rare valves of *T. convexa aspinosa* were recovered.

RADIOLARIANS - Radiolarians are very rare, although well preserved, and were thus not analyzed quantitatively. Spumellarians (*Amphirhopalum* sp., *Euchitonia* sp., and *Hexacontium* sp.) and nassellarians (*Anthocyrtidium* sp., and *S. cf. peregrina*) were collected from the CL14 residue.

DISCUSSION

The silty sediments exposed in the two sections of La Torretta and Castelcebro and in the basal layer of Calliano2 section record for the first time the occurrence of mixed calcareous and siliceous assemblages in the Pliocene of Northwestern Italy. This study allows us to infer a palaeoenvironmental scenario more complex than previously known in the surrounding area, where only calcareous micropalaeontological assemblages were documented. Moreover, these data offer new material for correlation at regional and Mediterranean scale.

Micropalaeontological content and stratigraphical settings confirm the previous interpretation of the diatomaceous silts as a local member, interposed between the underlying silty clayey or clayey members and the overlying silty-sandy member of the Argille Azzurre Formation (Dela Pierre et al., 2003), dated to the Early Pliocene (Zanclean) and referable to upper epibathyal-outer neritic bottoms.

Biostratigraphy

The present study allows a detailed biostratigraphical correlation to the Mediterranean Zanclean biozonation. The calcareous and siliceous assemblages of La Torretta, Castelcebro and Calliano2 show a very similar composition, differing mainly in taxa percentages.

Foraminiferal biostratigraphical markers, represented by rare *G. puncticulata* at Castelcebro, are absent in the diatomaceous silts at La Torretta. The co-occurrence of *G. margaritae* and *G. puncticulata* at Calliano2, in layers above the diatomaceous clays, permits to assign this section to the MPI 3 foraminiferal Zone (Violanti et al., 2003).

High productivity conditions leading to development and preservation of siliceous microfossils, never before documented in other Pliocene successions of Piedmont, could have been nearly synchronous and suggest the correlation of the basal layer of Calliano2 with La Torretta and Castelcebro diatomaceous deposits, that, as a consequence, are referred to the MPI 3 Zone. The rareness of the oligotrophic globorotaliids is probably due to palaeoenvironmental factors, as suggested by the dominant opportunistic and eutrophic taxa.

The occurrence of *H. sellii* and *R. pseudumbilica* records the Zanclean MNN13 and/or MNN14-15 zones (Rio et al., 1990). The *Discoaster asymmetricus* FO (marking the lower boundary of Zone MNN14/15) was not recorded in the studied samples, since the assemblages are completely devoid of *Discoaster* spp. and *Sphenolithus* spp. Moreover, the occurrence of rare *N. jouseae* at La Torretta allows the correlation to the *Nitzschia jouseae* diatom Zone (upper Early Pliocene to Late Pliocene). The occurrence of *T. oestrupii* and *T. convexa aspinosa*

in all the three sections also supports a post-Miocene age. Among radiolarians, the occurrence of *S. peregrina* allows the correlation to the RN11 Zone (*Stichocorys peregrina* Zone) (Sanfilippo & Nigrini, 1998).

The occurrence of specimens close to *Theocorythium trachelium diana*, here indicated as *T. trachelium* cf. *diana* after the taxonomic revision of P. Dumitrica (pers. comm., 2011) is noteworthy. *T. trachelium diana* is a subspecies described from Recent to Holocene samples (Nigrini & Sanfilippo, 2001). The first appearance of *T. trachelium* and of *T. trachelium diana* is recorded at 2.5 My in the Indian Ocean, at 2.9 My in the Pacific Ocean and in the Bianco section (Sanfilippo, 1988 and references therein). The specimens from La Torretta and Castelcebro may suggest a taxon appearance older than previously known, during the MPI 3 foraminiferal zone (4.52-3.98 My).

Palaeoenvironment

THE SEDIMENT AND FN RECORD - The fine-grained sediment fraction (<63 µm) is very abundant in La Torretta and Castelcebro sections as well as in the lower part of the Calliano2 one, leading to percentages of the >63 µm residues comprised between 1-4% of the total. The upper part of the Calliano2 section differs for a more abundant silty and fine sandy fraction.

The high terrigenous influx is probably the main cause of the low values of the FN. With the exception of LT5 sample, in which the FN is rather high, the lowest FN values occur in coincidence with the highest benthic diversity (BF Taxa S and Fisher α Index). Moreover the FN curve is generally positively correlated with the P/(P+B) ratios (Figs 2-6).

The very high amount of silt and clay diluted the foraminiferal tests, thus causing low FN values. Low benthic FN are interpreted as linked to strong continental runoff in Pleistocene (Zarries & Mackensen, 2010) and Recent (Mojtahid et al., 2006) assemblages off West Africa. The studied succession was deposited in a marine basin surrounded by the emerged Alps, the source of large quantities of terrigenous debris and reaching very high elevations in the Zanclean. Fauquette et al. (1999) estimated a palaeoaltitude of almost 2000 m for the Mercantour Massif (Southern Alps, France) and a warmer and more humid than today climate in the North Mediterranean area during the earliest Pliocene, allowing the development of a subtropical to warm-temperate vegetation (Bertini & Martinetto, 2011). In the warm, humid Zanclean climate, rainfall was also intense; mean annual temperatures between 15-17.7°C, 1-4°C higher than today and rainfall between 1200-1500 mm, 500-800 mm higher than today have been proposed (Zheng & Cravatte, 1986). Moreover, other factors than terrestrial input can influence foraminiferal abundance. In the very productive waters of the tropical upwelling area off Oman (Arabian Sea) the lower total planktonic foraminiferal numbers are associated to high diatom numbers and abundant *G. bulloides* and *N. dutertrei* (Schiebel et al., 2004).

Low FN values were registered during the MPI 3 interval also in the Moncucco Torinese section (Turin Hill), where a nearly complete Zanclean epibathyal succession, from the Messinian/Zanclean boundary

up to the MPI 4a Zone, is preserved (Trenkwalder et al., 2008; Violanti et al., 2011). Biostratigraphical and palaeoenvironmental data allow the correlation between the La Torretta, Castelcebro, Calliano and Moncucco T. sections. Moreover, the diatomaceous sediments could be coeval of the middle part the MPI 3 interval of Moncucco T., characterized by the same low FN values calculated in the former sections (Fig. 8).

THE CALCAREOUS MICROFOSSIL RECORD - Percentages of the P/(P+B) ratio are below or near 20% in all the studied succession. The very low P/(P+B) ratio percentages could suggest a deposition in inner neritic zone, if compared with the Mediterranean bathymetrical zonation of Wright (1978). Nevertheless, the test dilution within the abundant fine terrigenous content as well as the microfossil composition and abundance, discussed below, suggest outer neritic bottoms and a strong influence of climatic and palaeoceanographic conditions.

In the three studied sections, the more frequent planktonic and benthic foraminiferal taxa are commonly reported from high productivity waters and bottoms rich in organic matter, respectively. Among planktonic foraminifers, *G. bulloides*, neogloboquadrinids, *Gt. glutinata*, and *T. quinqueloba* feed exclusively or preferentially on phytoplankton (Bè & Tolderlund, 1971; Hemleben et al., 1989; Pujol & Vergnaud Grazzini, 1995; Schiebel et al., 2001, 2004). In particular, *G. bulloides* is widespread in subtropical to subpolar waters, abundant in upwelling areas of the oceans (Bè & Tolderlund, 1971; Hemleben et al., 1989; Schiebel et al., 2001). In the Alboran Sea, *G. bulloides* shows a strong seasonal trend and is the main component of planktonic assemblages or co-dominant with *T. quinqueloba* when seasonal, wind-induced upwelling conditions are more intense (Bárcena et al., 2004; Hernández-Almeida et al., 2011). High numbers of *G. bulloides* occur with abundant neogloboquadrinids in Quaternary (Naidu & Malmgren, 1996) and Recent upwelling regions or during phytoplankton blooms (Giraudeau & Rogers, 1994; Pujol & Vergnaud Grazzini, 1995; Schiebel et al., 2004). It is also dominant in the foraminiferal assemblages of the Piacenzian-Gelasian Marecchia Valley section, in which Pliocene sapropels, sometimes yielding diatom frustules, are preserved (Rio et al., 1997).

The extinct *N. acostaensis* is assumed to have had oceanographic requirements similar to living neogloboquadrinids (*N. dutertrei*, *N. incompta*, *N. pachyderma*) (Thunell, 1979) that inhabit the water column close to or below the thermocline, and feed on phytoplankton, preferentially diatoms (Fairbanks et al., 1982; Hemleben et al., 1989; Watkins et al., 1996; Ivanova et al., 1998; Schiebel et al., 2004). Neogloboquadrinids are reported as dominant in temperate and low productivity waters or periods (Bárcena et al., 2001). *Neogloboquadrina dutertrei* and *G. bulloides* are abundant in the Eastern Mediterranean warm sapropel S5, the only Pleistocene sapropel in which siliceous microfossils have been recorded (Schrader & Matherne, 1981; Giunta et al., 2006). *G. bulloides* and *Neogloboquadrina* spp. are also abundant in the diatomites of the Pliocene Bianco section (Calabria, Rio et al., 1989), where radiolarians were also described

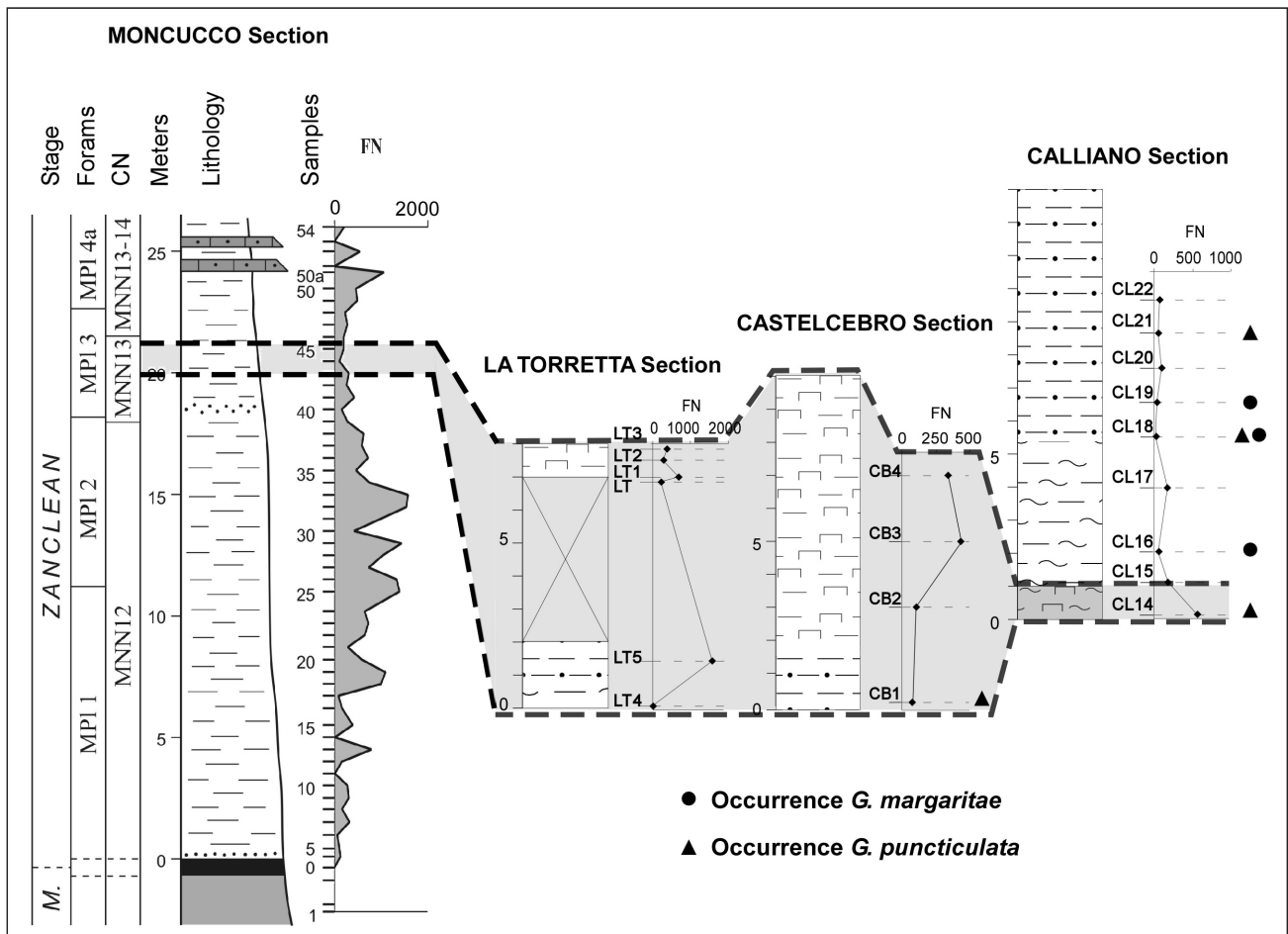


Fig. 8 - Proposed biostratigraphical correlation between the diatomaceous sediments of the middle outer shelf La Torretta, Castelcebro and Calliano sections with the upper epibathyal Moncucco T. section.

(Sanfilippo, 1988) and upwelling conditions have been proposed.

In the diatomaceous silts of La Torretta, Castelcebro as well throughout the Calliano2 succession, *G. bulloides* is generally the dominant taxon, often negatively correlated with *N. acostaensis*. Different trophic strategies and seasonal diffusion of the two taxa could explain this pattern.

In the studied samples, frequencies of the warm-water, low nutrient levels *Globigerinoides* spp. and *Orbulina* spp. (Bè & Tolderlund, 1971; Pujol & Vergnaud Grazzini, 1995), are low and show an opposite pattern than that of the upwelling assemblage (*G. bulloides*, *N. acostaensis*, *Gt. glutinata* and *T. quinqueloba*). At La Torretta, *Globigerinoides* spp. and *Orbulina* spp. are common to frequent only in the upper samples, in which *G. bulloides* and *N. acostaensis* are scarce. Warmer surficial waters can be inferred for the upper part of the La Torretta succession. Moreover, in sample LT2, the frequent *Globigerinoides* spp. co-occur with also frequent *G. bulloides* and *Gt. glutinata*, a diatom and chrysophytes grazing species (Hemleben et al., 1989; Schiebel et al., 2001) and with frequent diatoms, suggesting well stratified waters. A seasonal succession of planktonic taxa may also be inferred by comparison with data from the recent Mediterranean, where *Globigerinoides ruber* proliferates in summer and decreases under low fertility conditions

and warmer sea surface temperatures (Pujol & Vergnaud Grazzini, 1995; Bárcena et al., 2004).

The mesopelagic, oligotrophic genus *Globorotalia* is very rare in the diatomaceous layers of the three studied sections. Its diffusion could have been hampered by the high fertility levels suggested by the siliceous assemblages and by the dominance of eutrophic planktonic foraminifers. Taking into account the low P/(P+B) percentages, indicating a rather shallow palaeodepth, also a bathymetric control could be inferred.

Benthic foraminiferal assemblages are dominated by opportunistic, infaunal taxa, widespread in dysaerobic muddy bottoms with high content in organic matter, such as *C. carinata*, *Bulimina* spp., *Brizalina* spp., *S. complanata*, and less abundant *F. schreibersiana*.

C. carinata is the dominant benthic taxon in the three successions. The taxon is widespread in both normal marine environments and bottoms with moderate to high organic fluxes (Altenbach et al., 1999). In the Mediterranean it is common to frequent in recent outer neritic and bathyal bottoms (Blanc-Vernet, 1969; Sgarrella & Moncharmont Zei, 1993), and in the Holocene mud-belt of the Adriatic Sea (Morigi et al., 2005). *Cassidulina* spp. (*C. carinata*, *C. laevigata* and *C. neocarinata*, often used as synonyms) are frequently recorded as epifaunal/shallow infaunal deposit feeders (Corliss & Fois, 1990;

Murray, 2006; Zarries & Mackensen, 2010), indicative of intermediate organic carbon fluxes and high seasonality (Eberwein & Mackensen, 2008). *C. carinata* seems to respond fast to phytodetritus input from seasonal blooms (Duchemin et al., 2008).

The genus *Bulimina* is mainly represented by the poorly ornamented species *B. elongata*, *B. gibba* and *B. lappa*, typical of muddy shelf environment (Blanc-Vernet, 1969; Sgarrella & Moncharmont Zei, 1993). Living representatives of this opportunistic genus occur in a wide bathymetrical range and are proposed as indicative of high nutrient levels and/or dysoxia (Murray, 1991), of moderate to high productivity and low seasonality (Eberwein & Mackensen, 2008) as well as of eutrophication (Mojtahid et al., 2006). In the Rhone prodelta (NW Mediterranean) abundances of opportunistic species such as *B. aculeata*, *C. carinata*, and *Valvulineria bradyana* have been directly related to marine organic matter input (Goineau et al., 2011). *Bulimina* spp. and *C. neocarinata* (= *C. carinata*) are also among the dominant species of central Adriatic outer shelf assemblages, thriving under relatively high fresh phytodetritus fluxes (Morigi et al., 2005).

Bulimina spp. show percentages very close to those of *C. carinata* in most of samples from La Torretta, as well as in the basal diatomaceous layer of Calliano2. On the contrary it is less frequent at Castelcebro and in the sandy silts of Calliano2, confirming its preference for muddy bottoms.

B. spathulata and *B. dilatata*, deep infaunal taxa and among the most tolerant species of low-oxygen and high-nutrient levels (Murray, 1991), are common in most of the diatomaceous silts and reach frequencies about 20% in few samples of La Torretta and Castelcebro (LT5 and CB4, respectively), in which siliceous microfossils are absent or rare. *Brizalina* spp. is abundant (33.86%) in the basal sample CL14 (Calliano2 section), then decreases to percentage similar to those of the two other sections.

Another common species is *S. complanata*, frequent in the upper diatomaceous silts of La Torretta, very rare in the Calliano2 section, with the exception of the basal diatomaceous layer. *Stainforthia* species are reported

as shallow to deep infaunal forms, able to survive and proliferate under suboxic to anoxic conditions (Bernhard, 1992; Alve, 1994; Gooday & Alve, 2001). *S. fusiformis* has an opportunistic life strategy and strongly variable microhabitat, fastly increases its population in response to phytoplankton blooms but can also exploit different trophic resources and survive to absence of fresh phytodetritus (Alve, 2010). *S. complanata* is suggested to respond to different kinds of food and to be tolerant of lower inputs of phytodetritus (Smart et al., 2010). The *Brizalina* spp. and *S. complanata* curves are generally opposite to that of *C. carinata*, probably reflecting a different trophic behaviour.

Ostracod assemblages are very similar in the La Torretta and Castelcebro sections. In most samples ostracod assemblages are oligotypic, represented or dominated by *C. edwardsii*, a taxon related to highly stressed environments (Peypouquet, 1973). *C. edwardsii* is one of the most abundant ostracod species in surface muddy sediments with a hypoxic character from the continental shelf of the Bay of Biscay, associated to benthic foraminifers such as *B. spathulata*, *B. elongata/gibba*, *B. marginata*, *C. laevigata*, and *Uvigerina peregrina* (Pascual et al., 2008). In our samples percentage variations of *C. edwardsii* show a positive correlation with those of *Bulimina* spp. and *C. carinata* and confirm its opportunistic character.

Diverse ostracod assemblages characterize only samples LT5 at La Torretta and CB1 at Castelcebro, in which the warm-temperate outer neritic taxon *A. histrix* (Montenegro et al., 1998), followed by other outer neritic taxa (*O. dohrni*, *Cytherella* spp., *P. jonesi*) (Peypouquet, 1973; Ruiz & Gonzalez-Regalado, 1996) and outer neritic to bathyal taxa (*Cytheropteron* spp., *H. asperrima*, etc.) also occur. Inner neritic to outer neritic taxa (*E. scabra*, *R. tetraptera*, and *S. versicolor*) are more common at Castelcebro or in the upper samples from La Torretta. In the same samples LT5 and CB1 also more diversified foraminiferal assemblages occur and yield few specimens of the outer neritic to bathyal taxa recovered in the diatomaceous silts (*Melonis soldanii*, *S. schlumbergeri*, and *Uvigerina* spp.).

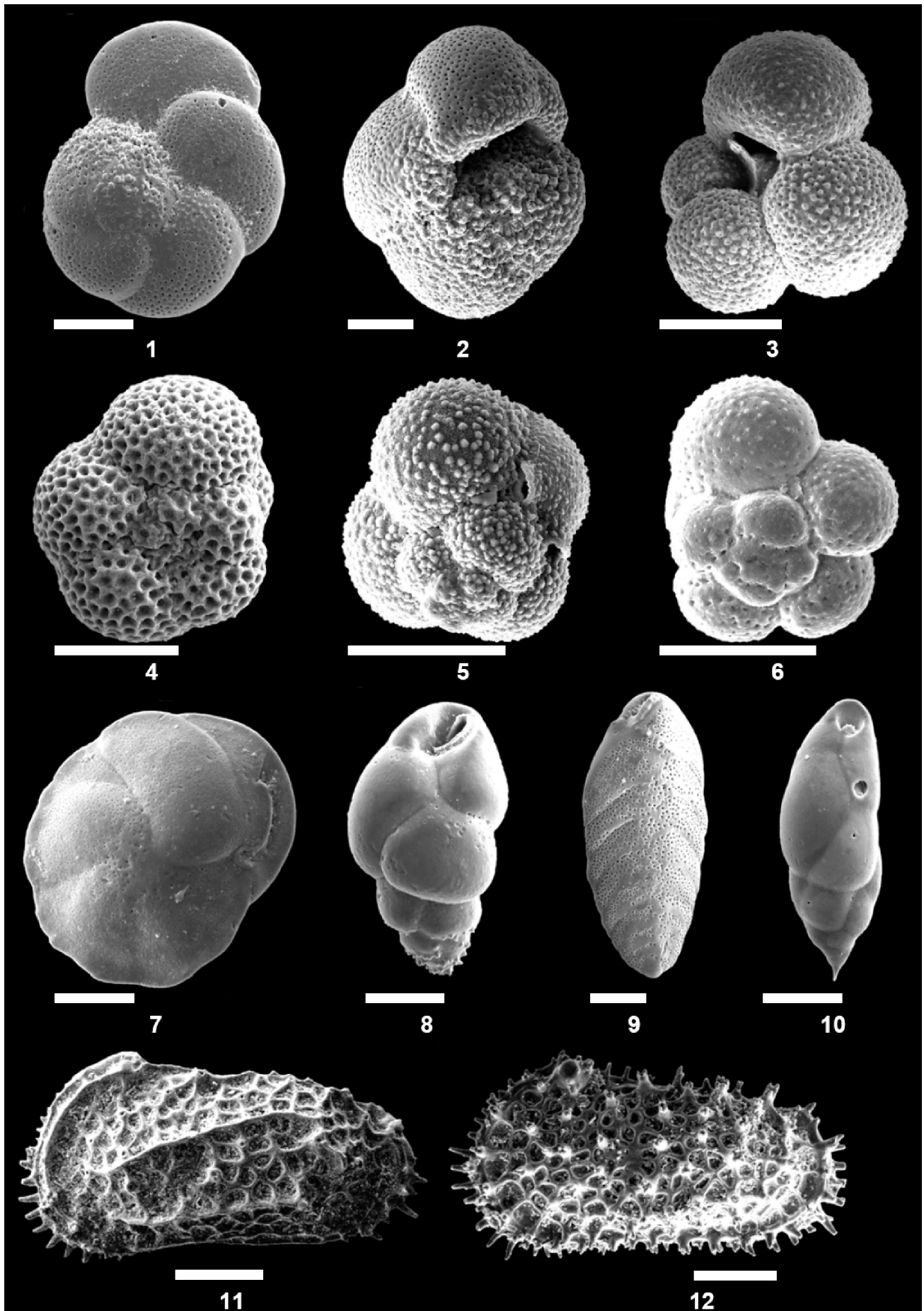
EXPLANATION OF PLATE 1

Foraminifers; scale bar = 100 µm.

- Fig. 1 - *Globorotalia margaritae* Bolli & Bermudez, spiral view, sample CL16;
- Fig. 2 - *Globorotalia puncticulata* (Deshayes), umbilical view, sample CL14;
- Fig. 3 - *Globigerina bulloides* d'Orbigny, umbilical view, sample LT;
- Fig. 4 - *Neoglobobulimina acostaensis* (Blow) dextral, spiral view, sample LT5;
- Fig. 5 - *Globigerinita glutinata* (Egger), spiral view, sample LT2;
- Fig. 6 - *Turborotalita quinqueloba* (Natland), spiral view, sample LT3;
- Fig. 7 - *Cassidulina carinata* Silvestri, umbilical view, sample CB4;
- Fig. 8 - *Bulimina lappa* Cushman & Parker, lateral view, sample LT4;
- Fig. 9 - *Brizalina dilatata* (Reuss), lateral view, sample LT4;
- Fig. 10 - *Stainforthia complanata* (Egger), lateral view, sample LT3.

Ostracods; scale bar = 200 µm.

- Fig. 11 - *Costa edwardsii* (Roemer), left valve, external view, sample LT4;
- Fig. 12 - *Acanocythereis histrix* (Reuss), left valve, external view, sample LT5.



Foraminiferal and ostracod assemblages are indicative of outer neritic bottoms, probably shallower at Castelcebro and in the upper part of La Torretta section. The more diverse assemblages could be related to depth variations, but more probably can be the response to less eutrophicated and more oxygenated bottoms and/or upwelled bottom waters. Only moderate transport from the inner shelf, documented by the scarce inner neritic forms (*A. beccarii*, *Elphidium* spp., and *Aurila* spp.) may be inferred for the three sections.

Rather similar foraminiferal and ostracod assemblages characterize the Calliano2 succession, also typical of an outer neritic palaeoenvironment. Nevertheless, in the lower part of the section, the slightly higher number of outer neritic to bathyal taxa (*H. elegans*, *M. pompilioides*, *P. ariminensis*, *U. peregrina* and *Cytheropteron* spp., and *H. asperrima*) as well as the occurrence of rare mesopelagic *G. margaritae* and *G. puncticulata*, suggest a deeper or more open palaeoenvironment than that inferred for La Torretta and Castelcebro. On the contrary, in the upper Calliano2 section, ostracod assemblages show more diversified inner to outer neritic species (*Aurila* spp., etc.) and the abundance decrease of *C. edwardsii*. Opportunistic *C. carinata* and the stress-tolerant *Brizalina* spp. and *Bulimina* spp. remain abundant or common, documenting still eutrophicated conditions. The more abundant fine sand fraction and the slightly more frequent displaced inner neritic taxa testify to changing palaeoenvironmental conditions.

Calcareous nannofossil assemblages yield common to frequent *Cd. leptoporus*, *C. pelagicus*, *H. carteri* and *H. sellii*. *Cd. leptoporus* is referred to mesotrophic and eutrophic open marine conditions (Ziveri et al., 2004). Three different morphotypes with specific water temperature preferences exist (Schiebel et al., 2004); the studied samples are dominated by intermediate size forms, thus suggesting temperate, mesotrophic to eutrophic surface waters at time of sediment deposition. In the

Alboran Sea (Western Mediterranean), characterized by seasonal high productivity, *Cd. leptoporus* and *H. carteri* show high fluxes during the upwelling intervals (Hernández-Almeida et al., 2011). *Discoaster* spp. and *Sphenolithus* spp., taxa that preferred oligotrophic waters and deep nutricline (Gibbs et al., 2004; Flores et al., 2005), were not recovered in the studied sections. Discoasterids occur, albeit rarely, in the open marine Zanclean Piedmont succession (Violanti et al., 2009, 2011). Their absence in the diatomaceous silts is thus probably linked to high nutrient availability in the upper water column and to a shallower nutricline.

The abundance in the Castelcebro assemblages of *C. pelagicus*, a taxon nowadays confined to high latitudes and interpreted as a cold water indicator (Roth, 1994; Ziveri et al., 2004), could be indicative of cold upwelled waters. Influxes of cooler, nutrient-rich bottom waters at Castelcebro and at La Torretta could be suggested also by the dominance of the opportunistic *C. carinata*, reported as preferential of cold-temperate waters (Murray, 1991).

THE SILICEOUS MICROFOSSIL RECORD - The fossil diatom record, inferred to be a proxy of surface high productivity, is dependent from the availability of nutrients and preservation during settling and sedimentation. In oligotrophic waters, siliceous microfossils, commonly collected from the surficial waters, can be dissolved during settling or in bottom sediments. Preservation is favoured by high sedimentation rates (Bárcena et al., 2001) and also by the deposition of large amount of siliceous tests, changing the geochemical conditions of the surrounding sediments. As a consequence, the siliceous microfossils record is sporadic and very probably under-represented. In the studied succession, its under-representation is suggested by the recovery of recrystallized opal in sample CB1 and of very rare specimens of diatoms and radiolarians in washing residues of otherwise barren samples.

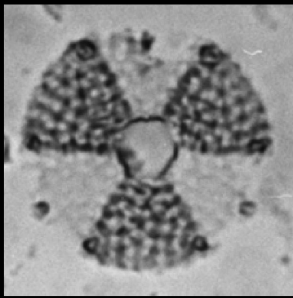
EXPLANATION OF PLATE 2

Diatoms.

- Fig. 1 - *Actinoptychus senarius* (Ehrenberg) Ehrenberg, sample LT3 - x 881;
- Fig. 2 - *Paralia sulcata* (Ehrenberg) Cleve, sample LT4 - x 1336;
- Fig. 3 - *Rhaphoneis* cf. *petropolitana* (Grunow) Pantocsek, sample LT4 - x 851;
- Fig. 4 - *Chaetoceros* RS, sample LT3 - x 1793;
- Fig. 5 - *Thalassiosira oestrupii* (Ostenfeld) Hasle, sample LT3 - x 1990;
- Fig. 6 - *Grammatophora angulosa* Ehrenberg, sample LT3 - x 1306;
- Fig. 7 - *Thalassiosira eccentrica* (Ehrenberg) Cleve, sample CB3 - x 688.

Radiolarians; scale bar = 50 µm.

- Fig. 8 - *Rhopalastrum zitteli* (Stöhr), sample LT4;
- Fig. 9 - *Euchitonia* sp., with *spatangum*, sample CB2;
- Fig. 10 - *Hexacontium* cf. *arachnoidale* Hollande & Enjume, sample LT4;
- Fig. 11 - *Hexacontium* sp., sample CB3;
- Fig. 12 - *Theocorythium trachelium* cf. *dianae* (Haeckel), sample LT5;
- Fig. 13 - *Stichocorys delmontensis* (Campbell & Clark), sample LT2;
- Fig. 14 - *Stichocorys peregrina* (Riedel), sample LT4;
- Fig. 15 - *Anthocyrtidium ophirensense* (Ehrenberg), sample LT4.



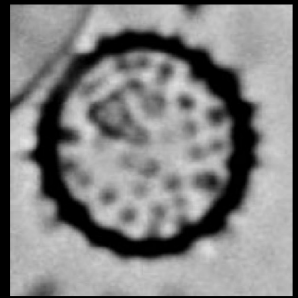
1



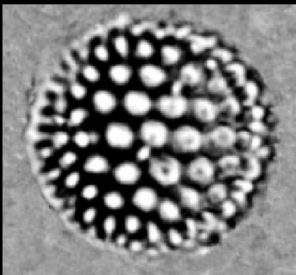
2



3



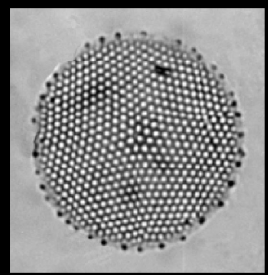
4



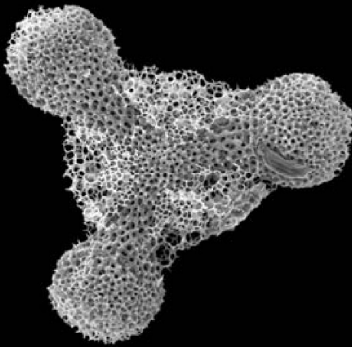
5



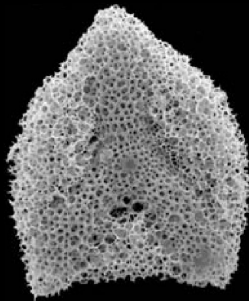
6



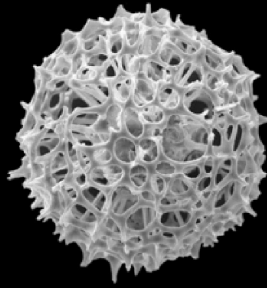
7



8



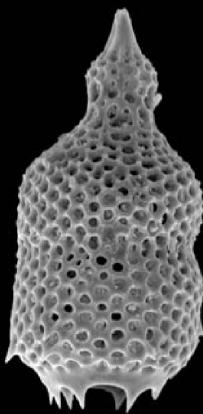
9



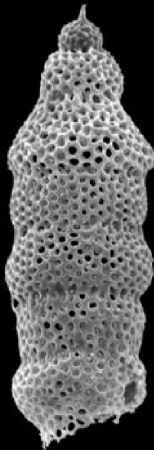
10



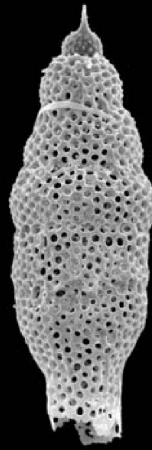
11



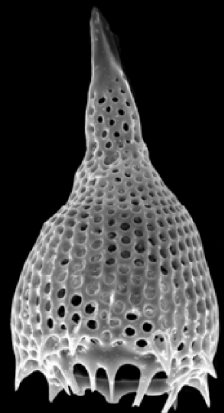
12



13



14



15

Diatom distribution and percentages and, to a lesser extent, radiolarians, that were only semiquantitatively studied, show generally opposite patterns to the calcareous microfossils. Siliceous microfossils are absent or very rare in the layers where foraminifers, ostracods and calcareous nannofossils are abundant and diverse (LT 5, CB1, CL14), and palaeoenvironmental indications are sometimes contrasting.

Diatom valve abundances are low and countings were necessarily carried out on the entire slide, not only on a slide portion, to reach even low numbers (max 351 valves in LT2). The assemblages are poorer than those described from strong upwelling oceanic areas, where countings are performed on a slide portion (Schiebel et al., 2001; Bárcena et al., 2004). Transport by water currents is probably the cause for high fragmentation of the valves, as well as of the dominance of resistant forms (*Chaetoceros* RS, *Thalassionema* group).

Diatom assemblages are richer and relatively diversified at La Torretta, in which two layers of high productivity can be inferred by higher diatom abundances in samples LT4 and LT2-LT3. Poorer diatom assemblages characterize Castelcebro and Calliano2. All diatom taxa are polyalibous forms, typical of normal marine salinities, only very rare *Rhopalodia gibba* and *R. musculus*, tolerant of brackish waters (Gersonde, 1980), randomly occur at La Torretta. At La Torretta, *P. sulcata* is abundant only at the section bottom. This meroplanktonic taxon, indicator of high littoral production or transport from the continental shelf (Sancetta et al., 1992), less frequent on the shelf margin (Sancetta, 1983), is also common in sediments of mid-latitude upwelling areas (Abrantes, 1988; Nave et al., 2001). *Chaetoceros* RS and the *Thalassionema* group, both characterizing upwelling areas and seasonal blooms (Sancetta, 1982; Frydas & Hemleben, 2007) are among the more frequent taxa, in particular *Chaetoceros* RS become strongly dominant in the upper interval (sample LT1-LT2). The meroplanktonic genus *Chaetoceros* is a fast blooming taxon, in both spring and summer blooms (Bernárdez et al., 2008). *Chaetoceros* RS represent high sea-surface productivity under coastal upwelling conditions (Bárcena et al., 2001, 2004; Nave et al., 2001; Schiebel et al., 2004). Hernández-Almeida et al. (2011) found an opposite distribution of the *Chaetoceros* RS and the marine planktonic group, mainly represented by *Thalassionema nitzschioides*, in Alboran Sea sediment traps; *Chaetoceros* RS were inferred to prefer persistent upwelling conditions, whilst *T. nitzschioides* prevailed in weaker upwelling episodes. A similar opposite trend of *Chaetoceros* RS and the *Thalassionema* group is shown in the upper layers of La Torretta and could reflect seasonal changes of hydrographic conditions and diatom populations.

As a whole diatom assemblages are dominated by meroplanktonic taxa (*Actinopteryx* spp., *A. octonarius*, *Chaetoceros* RS), mainly in the upper samples. They yield also common holoplanktonic forms (*A. nodulifera*, *T. oestrupii*, *Thalassionema* group and *Bacteriastrum* spp., *Coccosinodiscus* spp., frequently broken) and benthic genera (*Cocconeis*, *Diploneis*, *Grammatophora*, and *Rhaphoneis*). The assemblage is indicative of low to middle latitude warm waters: in particular the *Thalassionema* group and *T. oestrupii* are common components of tropical/subtropical

diatom floras, *Chaetoceros* RS generally are typical for diatom floras of mid-latitude coastal upwelling system (Romero & Hensen, 2002).

A middle outer shelf palaeoenvironment, influenced by coastal upwelling episodes under warm climatic conditions can be inferred from the diatom assemblages. Different percentages of the upwelling taxa *P. sulcata*, *Chaetoceros* RS and the *Thalassionema* group may reflect changes in the water circulation and nutrient content, with stronger coastal influxes or more productive bottom waters testified to by *P. sulcata* and a rather opener shelf or more stable upwelling conditions in the upper samples, suggested by the increase in *Chaetoceros* RS. An interval of higher productivity in the surficial water column and more eutrophicated bottoms in the upper La Torretta succession are also suggested by the higher diatom valves number, by the abundant *G. bulloides* and *T. quinqueloba*, by the decrease in benthic foraminiferal and ostracod diversity, as well as by the increase of the stress tolerant infaunal *S. complanata*.

Siliceous microfossils are nearly limited to the central part of Castelcebro section and weaker upwelling conditions than at La Torretta are inferred from the less diversified assemblages and the lower diatom valve numbers. Benthic diatoms (*Grammatophora* spp., *Cocconeis* spp.) are frequent in the lower part of this interval. Meroplanktonic taxa (mainly *Chaetoceros* RS) are also frequent and become strongly dominant. Planktonic taxa (*Thalassionema* group, fragments of large centrics) are also common. Diatom assemblages are rather similar to those of the upper part of La Torretta and can also be referred to a middle outer shelf palaeoenvironment, at a lesser extent influenced by coastal upwelling.

As suggested by foraminifers and ostracods, a slightly deeper or opener setting on the continental shelf can be inferred from the diatom assemblage of Calliano2, in which meroplanktonic and oloplanktonic (fragments of large centrics) taxa are dominant.

Further quantitative studies are needed for the palaeoenvironmental interpretation of radiolarian assemblages. Nevertheless, some indications could be given by the present preliminary analysis. Spumellarians and nassellarians are represented by similar taxa numbers and frequencies at La Torretta, documenting an open shelf palaeoenvironment. At Castelcebro spumellarians are dominant, both as taxa and specimen numbers and a rather shallower outer neritic bottom can be inferred. Spumellarians are more abundant than nassellarians in near-shore assemblages and ratios among nassellarian taxa versus the total taxa or among individual nassellarian and spumellarian species were used as palaeodepth indicators (Palmer, 1986; Casey, 1993).

Warm or warm-temperate waters are inferred by the occurrence of many tropical-subtropical species, such as *A. ophirensis*, abundant in low latitudes of the Indian Ocean and scarce in latitudes higher than 35° (Nigrini, 1967; Boltovskoy et al., 2010), as *D. profunda*, *D. truncatum* occurring, even less abundant, also in temperate waters (Boltovskoy et al., 2010) and *E. cienkowski*, *S. peregrina*, *S. delmontensis* (Sanfilippo et al., 1985). This climatic interpretation is in agreement with inferences based on diatom assemblages, which are also indicative of tropical-subtropical conditions. The abundance of cool-water

planktonic foraminifers and calcareous nannofossils, giving an apparently different climatic signal, can be linked to the presence of cold water upwelling, enhancing nutrient availability in the water column, primary productivity and influxes of zooplankton (*G. bulloides*, *N. acostaensis*, radiolarians) as well as of opportunistic benthic forms (*C. carinata*, *Bulimina* spp.).

Seasonal episodes of coastal upwelling and mixing of the water column, probably induced by high runoff and strong winds, could have supported rather rich siliceous assemblages on a middle outer shelf area, even if not so rich such as those of oceanic upwelling areas, in which siliceous protists are extremely abundant. Wind-induced upwelling and phytoplankton blooms, well-known in the Arabian Sea (Schiebel et al., 2004) and in the Alboran Sea (Bárcena et al., 2001, 2004; Hernández-Almeida et al., 2011) have been recorded also in the oligotrophic South Adriatic Sea in spring (Viličić et al., 1989) and winter (Batičić et al., 2011).

A similar strong influence of winter winds and downward transport of diatoms may be inferred for the studied assemblages. Strong rainfall and enhanced river discharge, transporting large amounts of sediments and nutrients to the coastal areas, could be, at least in part, at the origin of the very low numbers of foraminiferal tests, diluted in the dominant terrigenous supply, and of rather high productivity documented by calcareous and siliceous microfossils.

CONCLUSIONS

This study describes for the first time calcareous and siliceous microfossil assemblages from sediments of the Piedmont Pliocene. Our researches allow us to propose the following conclusions:

1) The similar composition of calcareous and siliceous assemblages preserved at La Torretta, Castelcebro and Calliano2 sections, as well as the rare occurrence of biostratigraphical markers (*G. margaritae*, *G. puncticulata*, *N. jouseae* and *S. peregrina*) allow us to propose that the diatomaceous silts and clays were deposited broadly in the same time interval; these sediments are correlated to the Zanclean (Early Pliocene) MPI 3 foraminiferal Zone, well documented in the upper, non diatomaceous silts of Calliano2 section. The Zanclean MNN13 and/or MNN14/15 CN zones, the *Nitzschia jouseae* diatom Zone (upper Early Pliocene to Late Pliocene) and RN11 (*Stichocorys peregrina* Zone) radiolarian zone were also recognized.

2) Enhanced productivity in the water column is documented by rather high frequencies of diatoms, dominated by *Chaetoceros* RS, *Thalassionema* group and locally by *Paralia sulcata*, all related to upwelling condition, by common to frequent radiolarians, by opportunistic phytophagous or dominantly phytophagous cool water planktonic foraminifers (*G. bulloides*, *N. acostaensis*, *Gt. glutinata* and *T. quinqueloba*), by benthic infaunal taxa, phytodetritus feeders or exploiting different trophic resources (*Cassidulina carinata*, *Bulimina* spp., *Stainforthia complanata*), by the common ostracod *C. edwardsii*, probably an opportunistic species too and also by calcareous nannofossils, characterized by common

Cd. leptoporus, *H. carteri* and *H. sellii*, also related to mesotrophic to eutrophic cool waters. The absence of the oligotrophic discoasterids may be another signal of high nutrient levels.

3) Productivity was rather high in comparison with that suggested for coeval assemblages of Piedmont, devoid of siliceous microfossils and characterized by more diversified foraminifer and ostracod assemblages (Violanti, 2005; Trenkwalder et al., 2008). Nevertheless, the rather low diatom numbers suggest an only moderate productivity in comparison with recent oceanic upwelling areas, where millions of valves/g occur (Nave et al., 2001).

4) The recorded low foraminiferal numbers (FN) and the low benthic foraminiferal and ostracod diversity may result from dilution of tests in the fine-grained terrigenous fraction, generally very abundant, but almost in part could be influenced by upwelling conditions and enhanced productivity, as registered in the Arabian Sea (Schiebel et al., 2004). Similar very low FN characterized the MPI 3 assemblages in the deeper, epibathyal succession of Moncucco, and suggest an increase of deposition rate, under the warm, moisty Early Pliocene climate and enhanced productivity both on the shelf and in the open sea. Seasonal upwelling episodes and phytoplankton blooms locally characterized the shelf. Seasonal successions of eutrophic (*G. bulloides*, *N. acostaensis*, *T. quinqueloba*, etc.) and oligotrophic taxa (*Globigerinoides* spp., *Orbulina* spp.) are suggested in the upper La Torretta section by their contemporary common occurrence.

5) The Piedmont diatomaceous succession here described is younger than the radiolarian-bearing level recovered in the Trubi of Capo Rossello, dated to the *G. margaritae margaritae* Zone (i.e. MPI 2 Zone) (Riedel et al., 1974). A tentative correlation is proposed with coeval MPI 3 layers yielding abundant calcareous and siliceous microfossil, such as the lowermost diatomite recorded in the Bianco section (Calabria, South Italy), deposited before the *G. margaritae* LO (Sanfilippo, 1988; Rio et al., 1989), the diatomitic beds of Aghios Vlassios section, Crete (Greece) (Spaak, 1983; Frydas, 1999), yielding both *G. margaritae* and *G. puncticulata*, and also with the diatomitic marls of the Aegina Island (Greece), yielding *G. margaritae* but intercalated between marls in which *G. puncticulata* occurs (Gaudant et al., 2010).

ACKNOWLEDGEMENTS

The authors wish to thank Dr Paulian Dumitrica (University of Lausanne, Switzerland) for his help in taxonomic determination and useful suggestions. Many thanks are due to Maria Bianca Cita, Caterina Morigi and Johannes Pignatti for their critical revision of the manuscript. The authors sincerely wish to thank also Annalisa Ferretti and Carlo Corradini for their help in the manuscript preparation. The research was supported by MIUR and CNR IGG Torino grants.

REFERENCES

- Abrantes F. (1988). Diatom productivity peak and increased circulation during latest Quaternary: Alboran Basin (Western Mediterranean). *Marine Micropaleontology*, 13: 79-96.
- Alve E. (1994). Opportunistic features of the foraminifer *Stainforthia fusiformis* (Williamson): evidence from the Frierfjord, Norway. *Journal of Micropalaeontology*, 13: 24.

- Alve E. (2010). Benthic foraminiferal responses to absence of fresh phytodetritus: A two-year experiment. *Marine Micropaleontology*, 76: 67-75.
- Altenbach A.V., Plafmann U. & Schiebel R. (1999). Scaling percentages and distributional patterns of benthic foraminifera with flux rates of organic carbon. *Journal of Foraminiferal Research*, 29 (3): 173-185.
- Baker C. (1983). Evolution and hybridization in the radiolarian genera *Theocorythum* and *Lamprocyclus*. *Paleobiology*, 9: 341-354.
- Backman J. & Shackleton N.J. (1983). Quantitative biochronology of Pliocene and early Pleistocene calcareous nannoplankton from the Atlantic, Indian and Pacific Oceans. *Marine Micropaleontology*, 8: 141-170.
- Bárcena M.A., Cacho I., Abrantes F., Sierro F.J., Grimalt J.O. & Flores J.A. (2001). Paleoproductivity variations related to climatic conditions in the Alboran Sea (Western Mediterranean) during the last glacial-interglacial transition: the diatom record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 167: 337-357.
- Bárcena M.A., Flores J.A., Sierro F.J., Pérez-Folgado M., Fabres J., Calafat A. & Canals M. (2004). Planktonic response to main environmental changes in the Alboran Sea (Western Mediterranean) as documented in sediment traps and surface sediments. *Marine Micropaleontology*, 53: 423-445.
- Barde M.F. (1981). Les Diatomées des sédiments actuels et du Quaternaire supérieur de l'Atlantique nord-oriental. Intérêt hydrologique et climatique. *Institut Géologique du Bassin d'Aquitaine*, 29: 85-111.
- Batistić M., Jasprica N., Carić M., Čalić M., Kovačević V., Garić R., Njire J., Mikuš J. & Bobanović-Čolić S. (2011). Biological evidence of a winter convection event in the South Adriatic: A phytoplankton maximum in the aphotic zone. *Continental Shelf Research*, doi: 10.1016/j.csr.2011.01.004.
- Bé A.W. & Tolderlund D.S. (1971). Distribution and ecology of living planktonic foraminifera in surface waters of the Atlantic and Indian Oceans. *In* Funnell B.M. & Riedel W.R. (eds), *Micropaleontology of Oceans*, Cambridge University Press: 105-149, Cambridge.
- Bernárdez P., Prego R., Varela M. & Francés G. (2008). Diatom thanatocoenoses in a middle Galician Ría: Spatial patterns and their relationship to the seasonal diatom cycle in the water column and hydrographic conditions. *Continental Shelf Research*, 28: 2496-2508.
- Bernhard J.M. (1992). Benthic Foraminiferal distribution and biomass related to pore-water oxygen content: central California continental slope and rise. *Deep Sea Research Part A. Oceanic Research Papers*, 39 (3-4): 585-605.
- Bertini A. & Martinetto E. (2011). Reconstruction of vegetation transects for the Messinian-Piacenzian of Italy by means of comparative analysis of pollen, leaf and carpological records. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 304: 230-246.
- Bigi G., Cosentino D., Parotto M., Sartori R. & Scandone P. (1990). Structural model of Italy. Geodynamic project, C.N.R., Firenze, S.E.L.C.A. scale 1:500.000, Sheet 1.
- Björklund K.R. & De Ruiter R. (1987). Radiolarian preservation in Eastern Mediterranean anoxic sediments. *Marine Geology*, 75: 271-281.
- Blanc-Vernet L. (1969). Contribution à l'étude des foraminifères de la Méditerranée. *Travaux Station Marine d'Endoume*, 64 (48): 315 pp.
- Boltovskoy D., Kling S.A., Takahashi K. & Björklund K. (2010). World atlas of distribution of recent Polycystina (Radiolaria). *Palaeontologia Electronica*, 13 (3): 230 pp. http://palaeo-electronica.org/2010_3/215/index.html.
- Bonci C., Clari P., Ferrero Mortara E., Ghibaud G., Pirini C., Ricci B., Valleri G. & Violanti D. (1990). The diatomites of Marmorito (Western Monferrato, northern Italy). *Memorie di Scienze Geologiche*, 67: 189-226.
- Bonci C., Fanucci F., Pirini Radrizzani C., Rizzi A. & Tedeschi D. (1991). I livelli diatomitici della successione miocenica di Cappella Monte (area di Serravalle Scrivia, Bacino di Alessandria). *Bollettino della Società Paleontologica Italiana*, 30(3): 381-301.
- Bonsignore G., Bortolami G.C., Elter G., Montrasio A., Petrucci F., Ragni U., Sacchi R., Sturani C. & Zanella E. (1969). Note illustrative della Carta Geologica d'Italia alla scala 1:100.000, Fogli 56 e 57 Torino - Vercelli, II^a ed., *Servizio Geologico Italiano*, Roma, 96 pp.
- Bown P.R. & Young J.R. (1998). Techniques. *In* Bown P.R. (ed.), *Calcareous Nannofossils Biostratigraphy*, Kluwer Academic Publication: 16-28, Dordrecht.
- Casey R.E. (1993). Radiolaria. *In* Lipps J.H. (ed.), *Fossil Prokaryotes and Protists*. Blackwell Scientific Publications: 249-284, Boston.
- Casnedi R. (1971). Contributo alle conoscenze del Pliocene del Bacino Terziario Piemontese: *Atti dell'Istituto Geologico dell'Università di Pavia*, 22: 110-120.
- Cita M.B. (1975). Planktonic foraminiferal biozonation of the Mediterranean Pliocene deep-sea record. A revision. *Rivista Italiana di Paleontologia e Stratigrafia*, 81: 527-544.
- Clari P., Dela Pierre F., Novaretti A. & Timpanelli M. (1995). Late Oligocene-Miocene sedimentary evolution of the critical Alps/Apennines junction: the Monferrato area, Northwestern Italy. *Terra Nova*, 7: 144-152.
- Corliss B.H. & Fois E. (1990). Morphotype analysis of deep-sea benthic foraminifera from the northwest Gulf of Mexico. *Palaios*, 5: 589-605.
- Dall'Antonia B., Di Stefano A. & Foresi L.M. (2001). Integrated micropaleontological study (ostracods and calcareous plankton) of the Langhian western Hyblean successions (Sicily, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 176: 59-80.
- Danelian T. & Frydas D. (1998). Late Quaternary polycystine radiolarians and silicoflagellates of a diatomaceous sapropel from the Eastern Mediterranean, Sites 969 and 971. *In* Robertson A.H.F., Emeis K-C., Richter C. & Camerlenghi A. (eds), *Proceedings of the Ocean Drilling Program, Scientific Results*, 160: 137-154.
- Dela Pierre F., Balestro G., Bicchi E., Boano P., Clari P., De Luca D., D'Atri A., Fioraso G., Forno M.G., Morelli M., Piana F., Ruffini R. & Violanti D. (2003). Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 157 Trino. APAT Dipartimento di Difesa del Suolo, Tipografia Geda: 147 pp. Nichelino.
- Dela Pierre F., Clari P., Cavagna S. & Bicchi E. (2002). The Parona chaotic complex: a puzzling record of the Messinian (Late Miocene) events in Monferrato (NW Italy). *Sedimentary Geology*, 152: 289-311.
- Dela Pierre F., Festa A. & Irace A. (2007). Interaction of tectonic, sedimentary, and diapiric processes in the origin of chaotic sediments: An example from the Messinian of Torino Hill (Tertiary Piedmont Basin, northwestern Italy). *Geological Society of America Bulletin*, 119: 1107-1119.
- De Wever P., Dumitrica P., Caulet J.P., Nigrini C. & Caridroit M. (2001). Radiolarians in the Sedimentary Record. Gordon & Breach Science Publishers: 533 pp., New York.
- Donegan D. & Schrader H. (1982). Biogenic and abiogenic components of laminated hemipelagic sediments in the central Gulf of California. *Marine Geology*, 48: 215-237.
- Duchemin G., Jorissen F., Le Loc'h F., Andrieux-Loyer F., Hily C. & Thouzeau G. (2008). Seasonal variability of living benthic foraminifera from the outer continental shelf of the Bay of Biscay. *Journal of Sea Research*, 59: 297-319.
- Eberwein A. & Mackensen A. (2008). Last Glacial Maximum paleoproductivity and water masses off NW-Africa: Evidence from benthic foraminifera and stable isotopes. *Marine Micropaleontology*, 67: 87-103.
- Erba E. (1991). Deep mid-water bacterial mats from anoxic basins of the Eastern Mediterranean. *Marine Geology*, 100: 83-101.
- Fauquette S., Clauzon G., Suc J-P. & Zheng Z. (1999). A new approach for palaeoaltitude estimates based on pollen records: example of the Mercantour Massif (southeastern France) at

- the earliest Pliocene. *Earth and Planetary Science Letters*, 170: 35-47.
- Fairbanks R.G., Sverdrup M., Free M., Wiebe P.H. & Bé A.W.H. (1982). Vertical distribution of living planktonic foraminifera from the Panama basin. *Nature*, 298: 841-844.
- Festa A., Dela Pierre F., Irace A., Piana F., Fioraso G., Lucchesi S., Boano P., Forno M.G., Bicchi E., Violanti D., Trenkwalder S., Ossella L., Bellardone G., Campus S. & Tamberlani F. (2009). Note illustrative della Carta Geologica d'Italia alla scala 1:50.000 Foglio 156 Torino Est. ISPRA, Dipartimento Difesa del Suolo, Servizio Geologico d'Italia, Tipografia Geda: 143 pp., Nichelino.
- Flores J.A., Sierro F.J., Filippelli G.M., Bárcena M.A., Pérez-Folgado M., Vazquez A. & Utrilla R. (2005). Surface water dynamics and phytoplankton communities during deposition of cyclic late Messinian sapropel sequences in the western Mediterranean. *Marine Micropaleontology*, 56: 50-79.
- Frezza V. & Carboni M.G. (2009). Distribution of recent foraminiferal assemblages near the Ombrone River mouth (Northern Tyrrhenian Sea, Italy). *Revue de Micropaléontologie*, 52: 43-66.
- Frydas D. (1999). Paleoeology, stratigraphy and taxonomy of the Pliocene marine diatoms from central Crete (Greece). *Revue de Micropaléontologie*, 42: 269-300.
- Frydas D. & Hemleben C. (2007). Opal phytoplankton assemblages of the Late Quaternary sapropel layers S5 and S7 from the southeastern Mediterranean Sea. *Revue de Micropaléontologie*, 50: 169-183.
- Frydas D. & Stefanopoulos P. (2009). A new occurrence of siliceous microfossils of Neogene deposits of the city of Heraklion, Crete, Greece. *Berliner Paläobiologische Abhandlungen*, 10: 171-179.
- Gaudant J., Courme-Rault M-D. & Saint-Martin S. (2010). On fossil fishes, diatoms, and foraminifera from Zanclean (Lower Pliocene) diatomitic sediments of Aegina Island (Greece): a stratigraphical and palaeoenvironmental study. *Palaeodiversity*, 3: 141-149.
- Gersonde R. (1980). Paläoökologische und Biostratigraphische Auswertung von Diatomeenassoziationen aus dem Messinium des Caltanissetta-Beckens (Sizilien) und einiger Vergleichs-Profile in SO-Spanien, NW-Algerien und auf Kreta. Dissertation zur Erlangung des Doktorgrades der Mathematisch-Naturwissenschaftlichen Fakultät der Christian-Albrechts-Universität zu Kiel, 393 pp.
- Gibbs S.J., Shackleton N.J. & Young J.R. (2004). Orbitally forced climate signals in mid-Pliocene nannofossil assemblages. *Marine Micropaleontology*, 51: 39-56.
- Giraudeau J. & Rogers J. (1994). Phytoplankton biomass and sea-surface temperature estimates from sea-bed distribution of nannofossils and planktonic foraminifera in the Benguela upwelling system. *Micropaleontology*, 40 (3): 275-285.
- Giunta S., Negri A., Maffioli P., Sangiorgi F., Capotondi L., Morigi C., Principato M.S. & Corselli C. (2006). Phytoplankton dynamics in the eastern Mediterranean Sea during Marine Isotopic Stage 5e. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 235 (1-3): 28-47.
- Goineau A., Fontanier C., Jorissen F.J., Lansard B., Buscail R., Mouret A., Kerhervé P., Zaragosi S., Ernoult E., Artéro C., Anschutz P., Metzger E. & Rabouille C. (2011). Live (stained) benthic foraminifera from the Rhône prodelta (Gulf of Lion, NW Mediterranean): Environmental controls on a river-dominated shelf. *Journal of Sea Research*, 65: 58-75.
- Gooday A.J. & Alve E. (2001). Morphological and ecological parallels between sublittoral and abyssal foraminiferal species in the NE Atlantic: a comparison of *Stainforthia fusiformis* and *Stainforthia* sp. *Progress in Oceanography*, 50 (1-4): 261-283.
- Hammer Ø., Harper D.A.T. & Ryan P.D. (2008). PAST - Palaeontological Statistics, ver. 1.77, 87 pp., <http://folk.uio.no/ohammer/past>.
- Hemleben C.H., Spindler M. & Anderson O.R. (1989). Modern Planktonic Foraminifera, Springer-Verlag: 335 pp., New York.
- Hernández-Almeida I., Bárcena M.A., Flores J.A., Sierro F.J., Sanchez-Vidal A. & Calafat A. (2011). Microplankton response to environmental conditions in the Alboran Sea (Western Mediterranean): One year sediment trap record. *Marine Micropaleontology*, 78: 14-24.
- Ingram C. (1998). Palaeoecology and geochemistry of shallow marine ostracoda from the Sand Hole Formation, Inner Silver Pit, southern North Sea. *Quaternary Science Review*, 17: 913-929.
- Ivanova E.M., Conan S.M.H., Peeters F.J.C. & Troelstra S.R. (1998). Living *Neogloboquadrina pachyderma* sin. and its distribution in the sediments from Oman and Somalia upwelling areas. *Marine Micropaleontology*, 36: 91-107.
- Mana D. & Trenkwalder S. (2007). Ostracoda Associations: preliminary notes on the statistical reliability of some counting criteria. In Coccioni R. & Marsili A. (eds), Proceedings of the "Giornate di Paleontologia 2005", *Grzybowski Foundation Special Publication*, 12: 37-50.
- Martinis B. (1954). Ricerche stratigrafiche e micropaleontologiche sul Pliocene piemontese. *Rivista Italiana di Paleontologia e Stratigrafia*, 60 (2-3): 45-114/125-194.
- Mikkelsen N. (1990). Cenozoic Diatom biostratigraphy and paleoceanography of the Western Equatorial Indian Ocean. In Duncan R.A., Backman J., Peterson L.C. et al. (eds), *Proceedings of Ocean Drilling Program, Scientific Results*, 115: 411-432.
- Mojtahid M., Jorissen F., Durrieu J., Galgani F., Howa H., Redois F. & Camps R. (2006). Benthic foraminifera as bio-indicators of drill cutting disposal in tropical east Atlantic outer shelf environments. *Marine Micropaleontology*, 61: 58-75.
- Montenegro M.E., Pugliese N. & Bonaduce G. (1998). Shelf ostracods distribution in the Italian seas. In Crasquin-Soleau S., Braccini E. & Lethiers F. (eds), What about ostracoda! Actes du 3e Congrès Européen des Ostracodologues, (1996), *Mémoire Bulletin Centre Recherches Elf Exploration et Production*, 20: 91-101.
- Morigi C., Jorissen F.J., Fraticelli S., Horton B.P., Principi M., Sabbatini A., Capotondi L., Curzi P.V. & Negri A. (2005). Benthic foraminiferal evidence for the formation of Holocene mud-belt and bathymetrical evolution in the central Adriatic Sea. *Marine Micropaleontology*, 57: 25-49.
- Murray J.W. (1991). Ecology and Paleoeology of Benthic Foraminifera. Longman Scientific & Technical: 397 pp., New York.
- Murray J.W. (2006). Ecology and Applications of Benthic Foraminifera. Cambridge University Press: 426 pp., Cambridge.
- Naidu P.D. & Malmgren B.A. (1996). Relationship between late Quaternary upwelling history and coiling properties of *Neogloboquadrina pachyderma* and *Globigerina bulloides* in the Arabian Sea. *Journal of Foraminiferal Research*, 26 (1): 64-70.
- Nave S., Freitas P. & Abrantes F. (2001). Coastal upwelling in the Canary Island region: spatial variability reflected by the surface sediment record. *Marine Micropaleontology*, 42: 1-23.
- Negri A., Morigi C. & Giunta S. (2003). Are productivity and stratification important to sapropel deposition? Microfossil evidence from late Pliocene insolation cycle 180 at Vrica, Calabria. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 190: 243-255.
- Nigrini C. (1967). Radiolaria in the pelagic sediments from the Indian and Atlantic Oceans. *Bulletin of the Scripps Institution of Oceanography*, 11: 1-125.
- Nigrini C. & Sanfilippo A. (2001). Cenozoic radiolarian stratigraphy for low and middle latitudes with descriptions of biomarkers and stratigraphically useful species. *Ocean Drilling Program Technical Note*, 27: 1-486. <http://www-odp.tamu.edu/publications/tnotes/tn27/index.html>
- Palmer A. (1986). Cenozoic radiolarians as indicators of neritic versus oceanic conditions in continental-margin deposits: U.S. Mid-Atlantic coastal plain. *Palaios*, 1: 122-132.
- Pascual A., Rodriguez-Lazaro J., Maite M-R., Jouanneau J-M. & Weber O. (2008). A survey of the benthic microfauna

- (Foraminifera, Ostracoda) on the Basque shelf, southern Bay of Biscay. *Journal of Marine Systems*, 72: 35-63.
- Peypouquet J.P. (1973). Sur la présence d'espèces méditerranéennes au niveau des étages circalittoral et épibatial de la zone de Cap-Breton. *Bulletin Institut Géologique Bassin Aquitaine*, 13: 143-146.
- Piana F. (2000). Structural features of Western Monferrato (Alps-Apennines junction zone, NW Italy). *Tectonics*, 19: 943-960.
- Piana F. & Polino R. (1995). Tertiary structural relationship between Alps and Apennines: the critical Torino Hill and Monferrato area, Northwestern Italy. *Terra Nova*, 7: 138-143.
- Pujol C. & Vergnaud Grazzini C. (1995). Distribution patterns of live planktic foraminifers as related to regional hydrography and productive systems of the Mediterranean Sea. *Marine Micropaleontology*, 25: 187-217.
- Riedel W.R. & Sanfilippo A. (1971). Cenozoic Radiolaria from the western tropical Pacific, Leg 7. In Winterer E.L. et al. (eds), *Initial Reports of the Deep Sea Drilling Project*, 7 (2): 1529-1672.
- Riedel W.R., Sanfilippo A. & Cita M.B. (1974). Radiolarians from the stratotype Zanclean (Lower Pliocene, Sicily). *Rivista Italiana di Paleontologia e Stratigrafia*, 80 (4): 699-734.
- Rio D., Channell J.E.T., Bertoldi R., Poli M.S., Vergerio P.P., Raffi I., Sprovieri R. & Thunell R.C. (1997). Pliocene sapropels in the northern Adriatic area: chronology and paleoenvironmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 135: 1-25.
- Rio D., Raffi I. & Villa G. (1990). Pliocene-Pleistocene calcareous nannofossil distribution patterns in the Western Mediterranean. In Kastens K.A., Mascle J. et al. (eds), *Proceedings of Ocean Drilling Program, Scientific Results*, 107: 513-533.
- Rio D., Sprovieri R. & Thunell R. (1991). Pliocene-lower Pleistocene chronostratigraphy: a re-evaluation of Mediterranean type sections. *Geological Society of America Bulletin*, 103: 1049-1058.
- Rio D., Thunell R., Sprovieri R., Bukry D., Destefano E., Howell M., Raffi I., Sancetta C. & Sanfilippo A. (1989). Stratigraphy and depositional history of the Pliocene Bianco section, Calabria, southern Italy. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 76: 85-105.
- Romero O. & Hensen C. (2002). Oceanographic control of biogenic opal and diatoms in surface sediments of the Southwestern Atlantic. *Marine Geology*, 186: 263-280.
- Roth P.H. (1994). Distribution of coccoliths in oceanic sediments. In Winter, A. & Siesser W.G. (eds), *Coccolithophores*. Cambridge University Press: 199-218, Cambridge.
- Ruiz F. & González-Regalado M.L. (1996). Ostracodes of the SW Iberian Bay during the Mio-Pliocene. *Revue de Micropaléontologie*, 39 (2): 137-151.
- Sancetta C. (1982). Distribution of diatom species in surface sediments of the Bering and Okhotsk seas. *Micropaleontology*, 28 (3): 221-257.
- Sancetta C. (1983). Diatoms in sediments as indicators of the shelf-slope break. *SEPM Special Publications*, 33: 373-380.
- Sancetta C., Heusser L. & Hall M.A. (1992). Late Pliocene climate in the Southeast Atlantic: preliminary results from a multi-disciplinary study of DSDP Site 532. *Marine Micropaleontology*, 20: 59-75.
- Sancetta C. & Silvestri S.M. (1986). Pliocene-Pleistocene evolution of the North Pacific Ocean-Atmosphere system, interpreted from fossil diatoms. *Paleoceanography*, 1 (2): 163-180.
- Sanfilippo A. (1988). Pliocene Radiolaria from Bianco, Calabria, Italy. *Micropaleontology*, 34 (2): 159-180.
- Sanfilippo A., Burckle L.M., Martini E. & Riedel W.R. (1973). Radiolarians, diatoms, silicoflagellates and calcareous nannofossils in the Mediterranean Neogene. *Micropaleontology*, 19 (2): 209-234.
- Sanfilippo A., Caulet J.P. & Riedel W.R. (1978). Radiolaria from Mediterranean sediments, DSDP Leg 42A. In Kidd R.B. & Worstell P.J. (eds), *Initial Reports of the Deep Sea Drilling Project*, 42: 753-760.
- Sanfilippo A. & Nigrini C. (1998). Code numbers for Cenozoic low latitude radiolarian biostratigraphic zones and GPTS conversion tables. *Marine Micropaleontology*, 33: 109-156.
- Sanfilippo A., Westberg-Smith M.J. & Riedel W.R. (1985). Cenozoic Radiolaria. In H.M. Bolli, K. Perch-Nielsen and J.B. Saunders (eds), *Plankton Stratigraphy*. Cambridge University Press: 631-712, Cambridge.
- Schiebel R., Waniek J.J., Bork M. & Hemleben C. (2001). Planktic foraminiferal production stimulated by chlorophyll redistribution and entrainment of nutrient. *Deep-Sea Research I*, 48: 721-740.
- Schiebel R., Zeltner A., Treppke U.F., Waniek J.J., Bollmann J., Rixen T. & Hemleben C. (2004). Distribution of diatoms, coccolithophores and planktic foraminifers along a trophic gradient during SW monsoon in the Arabian Sea. *Marine Micropaleontology*, 51: 345-371.
- Schrader H.-J. & Gersonde R. (1978). Diatoms and Silicoflagellates. In Zachariasse W.J., Riedel W.R. & Sanfilippo A. (eds), *Micropaleontological Counting Methods and Techniques. Utrecht Micropaleontological Bulletins*, 17:120-176.
- Schrader H. & Matherne A. (1981). Sapropel formation in the Eastern Mediterranean Sea: evidence from preserved opal assemblages. *Micropaleontology*, 27 (2): 191-203.
- Schuette G. & Schrader H.-J. (1981). Diatom taphocoenoses in the coastal upwelling area off South west Africa. *Marine Micropaleontology*, 6: 131-155.
- Sgarrella F. & Moncharmont Zei M. (1993). Benthic Foraminifera of the Gulf of Naples (Italy): systematics and autoecology. *Bollettino della Società Paleontologica Italiana*, 32 (2): 145-264.
- Smart C.W., Waelbroeck C., Michel E. & Mazaud A. (2010). Benthic foraminiferal abundance and stable isotope changes in the Indian Ocean sector of the Southern Ocean during the last 20 kyr: Paleooceanographic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 297: 537-548.
- Spaak P (1983). Accuracy in correlation and ecological aspects of the planktonic foraminiferal zonation of the Mediterranean Pliocene. I.G.C.P. Project n. 1. *Utrecht Micropaleontological Bulletins*, 28: 159 pp.
- Thunell R.C. (1979). Pliocene-Pleistocene paleotemperature and paleosalinity history of the Mediterranean Sea: results from the Deep Sea Drilling Project Site 125 and 132. *Marine Micropaleontology*, 4: 173-187.
- Trenkwalder S., Violanti D., d'Atri A., Lozar F., Dela Pierre F. & Irace A. (2008). The Miocene/Pliocene boundary and the Early Pliocene micropaleontological record: new data from the Tertiary Piedmont Basin (Moncucco quarry, Torino Hill, Northwestern Italy). *Bollettino della Società Paleontologica Italiana*, 47 (2): 87-103.
- Van der Zwaan G.J., Jorissen F.J. & De Stigter H.C. (1990). The depth dependency of planktonic/benthic foraminiferal ratio; constrains and applications. *Marine Geology*, 95: 1-16.
- Van Hinsbergen D.J.J., Kouwenhoven T.J. & Van der Zwaan G.J. (2005). Paleobathymetry in the backstripping procedure: Correction for oxygenation effects on depth estimates. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 221: 245-265.
- Van Iperen J.M., Van Bennekom A.J. & Van Weering T.C.E. (1993). Diatoms in surface sediments of the Indonesian Archipelago and their relation to hydrography. In Van Dam (ed.), *Proceedings 12th International Diatom Symposium, Renesse, The Netherlands, 30 aug.-5 sept. 1992*, *Hydrobiologia*, 269/270: 113.
- Viličić D., Vučak Z., Škrivanić A. & Gržetić Z. (1989). Phytoplankton blooms in the oligotrophic open South Adriatic waters. *Marine Chemistry*, 28: 89-107.
- Violanti D. (2005). Pliocene Foraminifera of Piedmont (north-western Italy): a synthesis of recent data. *Annali dell'Università degli Studi di Ferrara - Museologia Scientifica e Naturalistica*, Spec. Vol. 2005: 75-88.
- Violanti D., Dela Pierre F., Trenkwalder S., Lozer F., Clari P., Irace A. & d'Atri A. (2011). Biostratigraphic and paleoenvironmental analyses of the Messinian/Zanclean boundary and Zanclean

- succession in the Moncucco quarry (Piedmont, Northwestern Italy). *Bulletin de la Société Géologique Française*, 182 (2): 149-162.
- Violanti D. & Sassone P. (2008). Il Pliocene del sottosuolo di Casale Monferrato (Piemonte, Italia Nord-occidentale): dati preliminari. *Atti Museo Civico di Storia Naturale di Trieste*, 53 (2006), Suppl.: 233-264.
- Violanti D., Trenkwalder S., Lozar F. & Gallo L.M. (2009). Micropalaeontological analyses of the Narzole core: biostratigraphy and palaeoenvironment of the late Messinian and early Zanclean of Piedmont (Northwestern Italy). *Bollettino della Società Paleontologica Italiana*, 48 (3): 167-181.
- Watkins J.M., Mix A.C. & Wilson J. (1996). Living planktic foraminifera: tracers of circulation and productivity regimes in the central equatorial Pacific. *Deep-Sea Research II*, 43 (4-6): 1257-1282.
- Wright R. (1978). Neogene paleobathymetry of the Mediterranean based on benthic foraminifers from DSDP Leg 42A. In Kidd R.B. & Worstell P.J. (eds), *Initial Reports of the Deep Sea Drilling Project*, 42: 837-846.
- Zarries M. & Mackensen A. (2010). The tropical rainbelt and productivity changes off northwest Africa: A 31,000-year high-resolution record. *Marine Micropaleontology*, 76: 76-91.
- Zheng Z. & Cravatte J. (1986). Etude palynologique du Pliocène de la Côte d'Azur (France) et du littoral ligure (Italie). *Géobios*, 19: 815-823.
- Ziveri P., Baumann K.-H., Boeckel B., Bollmann J. & Young J. (2004). Present day coccolithophore biogeography in the Atlantic Ocean. In Thierstein H. & Young J. (eds), *Coccolithophores - From Molecular Processes to Global Impact*, Springer-Verlag: 403-428, Berlin.

Manuscript received 31 August 2011

Revised manuscript accepted 14 October 2011

Published online 31 October 2011

Editor Johannes Pignatti