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Pliocene Mediterranean Foraminiferal Biostratigraphy: A Synthesis and Application to the Paleoenvironmental Evolution of Northwestern Italy

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1. Introduction

In this chapter biostratigraphic concepts and methods are applied to the Pliocene foraminiferal assemblages of the central Piedmont (Northwestern Italy), with examples of correlations at regional and Mediterranean scale. The order of discussion of topics is as follows: foraminifers and biostratigraphy and ecobiostratigraphy methods, a review of previous definitions of the Pliocene series and its stages, the Mediterranean foraminiferal biozonation, brief description of the Northwestern Italy Pliocene succession and of Piedmont selected sections, correlations and applications to the paleoenvironmental and tectonic history of the area. Locations of the stratotype sections, of cited sites, and of the studied sections are reported in Fig. 1.

Foraminifers are one of the most widespread marine protozoans, inhabiting both the water colomn with planktonic forms and bottom sediments from the inner neritic zone to bathyal depths with very diversified taxa. Planktonic species, known from the Jurassic, are characterized by a very high evolutive rate and provide the biostratigraphic markers in pelagic, deep sea sediments of Upper Mesozoic and Cenozoic. Appearance or occurrence, as well as disappearance of a taxon represent biostratigraphic data.

Moreover, other data could be obtained by environmentally controlled parameters, such as frequency peaks or coiling changes of a taxon occurring nearly simoultaneously in the same area. In the Mediterranean Pliocene, ecobiostratigraphical data, recognized all over the region, are the delayied re-entry of some planktonic (*Globorotalia scitula*) and benthic species (*Cibicidoides robertsonianus, Siphonina reticulata*) during the lower Early Pliocene, slightly later than the basin infilling after the Mediterranean Salinity Crisis. Ecobiostratigraphy based correlations are obviously more dependent from environmental parameters than biostratigraphical events, but are useful to improve the stratigraphic resolution almost at the regional scale.

The peculiar geological history of the Mediterranean was at the origin of a distinct bioprovince, and justifies the necessity of a regional biostratigraphic zonation. During the

Neogene, the closure of marine connections with the Indian Ocean, to the East, and the reduction of comunications with the Atlantic, to the West, led to the progressive decrease of exchanges with oceanic waters. From the Oligocene and Miocene, the latitudinal northward shift was the main cause of the disappearance of tropical macroforaminifers, whereas the stronger climatic deterioration during the Upper Pliocene and the Pleistocene affected also the warm or warm-temperate water planktonic and benthic foraminifers. Aims of this paper are to document the application of foraminiferal biostratigraphy and ecobiostratigraphy to the Pliocene succession of Piedmont, that provide new data on the evolution of the Northwestern Mediterranean margin and its relation with the central basin.

2. Biostratigraphy and ecobiostratigraphy methods

From the second half of the last century, planktonic foraminifers provide fundamental tools for biostratigraphy, the part of stratigraphy using the fossil distribution to construct relative time scales and to correlate time-equivalent sediment layers. From the Jurassic, and mainly from their explosive diffusion in the Cretaceous, many planktonic foraminiferal species have had the quality for being successfully applied as index fossils: a world-wide diffusion in the marine realm, good preservation in sediments due to their calcareous test, common to abundant specimens in marine deposits, fastly evolving taxa with many short-lived species, and various morphological features, allowing taxonomic identification of different species and subspecies. In the last decades, the integration of micropaleontological, geomagnetic and radiometric data with orbital periodicities provided an accurate calibration of biostratigraphic units and events.

The biozone, formal unit of biostratigraphy, is defined as the stratigraphic interval characterized by a typical fossil content, different from those of the adjacent rock bodies (Salvador, 1994). Primary data for the definition of biozones and biostratigraphic scales are bioevents, such as:

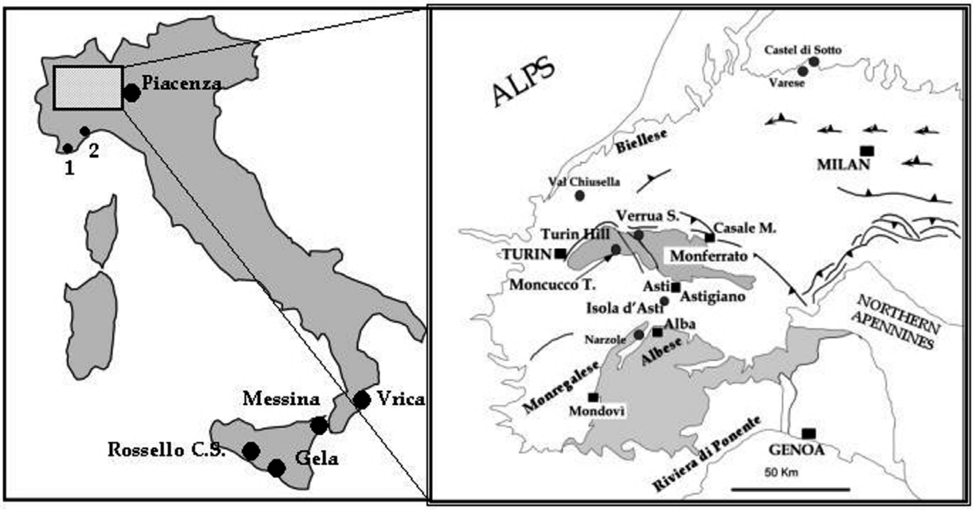

Fig. 1. Location of the Rossello Composite Section (Zanclean and Piacentian GSSP = Global Sections and Points), of cited sites and studied sections. 1: Ventimiglia, 2: Ceriale, Rio Torsero.

- the First Appearance Datum (FAD), defined as the first finding of a new taxon. The datum is an evolutive event, inferred geologically instantaneous in the speciation area.
- the Last Appearance Datum (LAD), defined as the last finding of the marker species. It corresponds to the end of the distribution range of the taxon.
- the First Occurrence (FO) and First Common Occurrence (FCO). The diffusion of a new species outside the origin area requires time and favourable environmental conditions. Therefore its occurrence is diachronous at different sites, and its FO and FCO will occurr at younger ages than the taxon FAD in the origin area. The taxon FO is often difficult to detect, for rareness of specimens, unfavourable paleoenvironment or sedimentary gaps. For these reasons, the FCO is preferred as a more reliable datum.
- the Last Occurrence (LO) and the Last Common Occurrence (FCO). Opposite to the FO and FCO, the LO and LCO register the local disappearance, or the last common recovery of a species.

All these bioevents are applied to define biozone boundaries or as datum planes or datum levels for the definition of biohorizons. Among the different types of biozones used by paleontologists, one of the more frequently used by micropaleontologists is the Interval Zone, defined as the interval, or body of strata, between two specified bioevents (FAD, LAD, FO, etc.). Other biozones of common application are the two type of Range Zones: the Taxon-Range Zone or Total Range Zone, defined as the total range of stratigraphic and geographic occurrence of the selected marker, and the Concurrent Range Zone, defined as the body of strata including the overlapping parts of the distribution of two marker taxa. Abundance Zones, frequently called Acme or Peak Zones, are defined as the sedimentary interval in which an unusual abundance of a peculiar taxon is registered. The species abundance is strongly influenced by local environmental factors and can occur at different times in different sites. Acme zones are more properly ecobiostratigraphical zones, strongly dependent on environmental factors (water depth and temperature, trophic resources, etc.), that influence the species diffusion and abundance (Iaccarino, 1985). Lineage Zones are defined as the sedimentary interval yielding specimens of a peculiar (total or partial) segment of an evolutionary lineage. Lineage Zones are considered the most reliable units for biostratigraphic correlations and their boundary can approximate those of chronostratigraphic units. They require confident philetic relations between the selected taxa and therefore their application is limited to few well known lineages. For the Pliocene, an example is provided by the evolution of *Globorotalia margaritae*. The taxon is an index species for the Mediterranean Pliocene foraminiferal biozonation and evolved in the equatorial Atlantic during the Messinian (Late Miocene), probably from the ancestral forms *Globorotalia scitula* and *G. juanai* (Kennett & Srinivasan, 1983). The species, originally described from sediments of Venezuela of dubious Miocene age (Bolli & Bermudez, 1965), was later entirely ascribed to the Pliocene (Bolli, 1970). Cita (1973) documented the morphological evolution of *G. margaritae* in Mediterranean deep-sea Pliocene assemblages and recognized two new subspecies, *Globorotalia margaritae primitiva* and *Globorotalia margaritae evoluta*, besides the typical *Globorotalia margaritae margaritae*. On the basis of their stratigraphical distribution, the author defined two lineage zones, comprised with the younger *Sphaeroidinellopsis* acme zone in a super zone, named *Globorotalia margaritae* Total Range Zone, that covered the entire Lower Pliocene (in the twofold division in Lower and Upper Pliocene).

Cita (1973) zonal scheme was substituted by the Mediterranean Pliocene zones, (MPl1 to 6), numbered from bottom to top (Cita, 1975a). Nevertheless, the *G. margaritae* lineage zones remain successfully applied to Mid-Atlantic (Bolli & Saunders, 1985) and Southern Atlantic successions (Coimbra et al., 2009). Cita (1973) also hypothesized that the *Globorotalia margaritae* Total Range Zone would cover an undefined interval of the late Miocene. In the upper Messinian, the closure of communications with the Atlantic prevented the diffusion of the taxon within the Mediterranean. The hypothesis of a Miocene origin of *G. margaritae* was confirmed by following researches, dating its FAD at 6.2 Ma (Chaisson & Pearson, 1997) in the central Atlantic Ocean. A taxon related to the G*loborotalia margaritae* plexus is *Globorotalia praemargaritae*, described in Early Messinian sections of Sicily (Catalano & Sprovieri, 1969; 1971), recognized also in coeval interval of land sections in Spain (Berggren et al., 1976). The presence of this unkeeled species testified influxes of the *G. margaritae* lineage ancestrals in the Mediterranean, before the onset of the Messinian Salinity Crisis.

Ecobiostratigraphy applies to stratigraphy paleobiological signals derived or influenced by the ecosystem, so increasing the biostratigraphic resolution and allowing detailed correlations. The FO, FCO, LO and LCO, as well as fluctuations in abundance of a taxon, are diachronous in different paleobioprovinces or in distant areas of the same geographical province and are influenced by paleoenvironmental factors, such as temperature, changes in water-mass circulation, basin depth, etc. Also variations of ecophenotypical characters such as the coiling pattern are successfully applied as bioevents and for local or world-wide correlations. This is the case of the coiling change of *Neogloboquadrina acostaensis* from sinistral to dextral, registered worl-wide in the Late Miocene (Messinian) (Bolli & Saunders, 1985). In the Mediterranean successions it marks the upper boundary of the *Globorotalia conomiozea* Zone (pre-evaporitic Messinian) (Iaccarino, 1985). Other coiling shifts of *N. acostaensis,* recognized in the lowermost Pliocene (Di Stefano et al., 1996), provide tools for correlations in the Mediterranean area (Iaccarino et al., 1999a; Pierre et al., 2006). A high resolution sampling and detailed quantitative studies are needed to obtain a reliable ecobiostratigraphic record. The most important feature of ecobiostratigraphic events is that they occurred in the same stratigraphic order in different sites. Integrated micropaleontological, cyclostratigraphic, isotopic and paleomagnetostratigraphic analyses precisely calibrated many ecobiostratigraphic events occurring in the Pliocene, that will be discussed in the following paragraphs.

3. The Pliocene chronostratigraphy

It is beyond the scope of this work to propose a detailed review of former biostratigraphic and chronostratigraphic researches on the Pliocene and its subdivisions. Wide discussion and references can be found in Berggren et al. (1985), Cita (1975b), Gradstein et al. (2004), Iaccarino et al. (1985), Rio et al. (1991) and Vai (1997). Here the present state-of-the-art will be presented, with a synthesis of selected previous studies.

The Pliocene series was introduced by Lyell (1833), accepting the "Sub Apennine Strata" in northern Italy (Brocchi, 1814) as its sedimentary documentation. During the XIX century, the Pliocene stages were also described in Italy, mainly on the basis of lithology and macrofossil assemblages preserved in the marine deposits. Following researches evidenced the poor definition of the original stages description and the necessity of formally defined chronostratigraphic subdivisions. The bloom of micropaleontological studies in the second half of the XX century provides tools for a detailed description of type sections as well as for the erection of biostratigraphic zonations. More recently, integrated biostratigraphy, magnetostratigraphy, cyclostratigraphy and climatostratigraphy greatly improved the age resolution of the Pliocene record. Meanwhile, these researches demonstrated that the original sections introduced as stratotypes for the historical Pliocene stages (Zanclean, Tabianian, Piacenzian, Astian) were inadequate, because now not accessible (Zanclean) or for gaps (Tabianian, Piacenzian). Other stages, as the Astian (Mayer-Eymar, 1868) and the Fossanian (Sacco 1887), originally proposed in Piedmont, later resulted to represent time-equivalent sedimentary facies, often heteropic to the Early Pliocene sediments. The Sicilian (Doderlein, 1870-1872), introduced as representing the older Pliocene, was soon referred as to the Pleistocene and now abandoned. Many chronostratigraphic subdivisions of the Pliocene series in two or three subseries were proposed, often with different chronological significance. A brief selection is summarized in Tab. 1. As a consequence, Pliocene stages and their boundaries were frequently revised and modified, increasing instability in stratigraphic nomenclature and confusion in correlations between different successions.

Biostratigraphic zones, based on datum planes such as FAD, LAD etc., are indipendent from fluctuating chronostratigraphic boundaries and provided more stable references. The continuous sediments cored in the Mediterranean Sea by the DSDP Leg 13 (Ryan et al., 1973), ODP Leg 107 (Kastens et al., 1990), Leg 160 (Robertson et al., 1998) and Leg 161 (Zahn et al., 1999) provided reference deep-sea sequences, with a micropaleontological record more complete and better preserved than in most Pliocene land-sections.

4. The Pliocene stages

4.1 Zanclean

The Zanclean stage was introduced by Seguenza (1868) on the Gravitelli (Sicily) outcrop of the Trubi Formation, whitish calcareous marls with abundant planktonic foraminifers. Gravitelli, at Seguenza's time a village near the city of Messina, in the following years was included in the city and now the described Trubi outcrop is not accessible.

PLIOCENE			PLEISTOCENE	REFERENCES
PIACENZIAN	ASTIAN	FOSSANIAN		Sacco, 1889-1890
PIACENZIAN	ASTIAN	SICILIAN		De Lapparent, 1906
EARLY	MIDDLE	UPPER		Ruggieri & Selli, 1949
TABIANIAN	PIACENZIAN			Barbieri, 1967
ZANCLEAN	PIACENZIAN			Cita & Gartner, 1973; Cita, 1975
EARLY	MIDDLE	UPPER		AGIP, 1982
ZANCLEAN	PIACENZIAN			Iaccarino, 1985
ZANCLEAN	PIACENZIAN	GELASIAN		Rio el al., 1994
ZANCLEAN	PIACENZIAN	GELASIAN		Gradstein et al., 2004
ZANCLEAN	PIACENZIAN		GELASIAN	Gibbard et al., 2010
PLIOCENE			PLEISTOCENE	

Table 1. A brief synthesis of chronostratigraphic divisions proposed for the Pliocene Series and Stages.

Cita & Gartner (1973) and Cita (1975b) proposed a neostratotype for the Zanclean stage in the Trubi section of Capo Rossello (Agrigento, Sicily), where calcareous microfossils were extensively studied (Sprovieri, 1978; Vismara Schilling & Stradner, 1977; Zachariasse et al., 1978 among others) and the Messinian/Zanclean boundary crops out. Following magnetostratigraphic, biostratigraphic and cyclostratigraphic researches in the Capo Rossello area resulted in the designation of the boundary-stratotype for the Lower Pliocene Zanclean stage and GSSP for the base of the Pliocene series (Van Couvering et al., 2000) at Eraclea Minoa, near Capo Rossello, on the basis of the exceptional continuity of paleomagnetic and astrochronologic signals and an accessible exposure (Hilgen, 1991; Hilgen & Langereis, 1988; Langereis & Hilgen, 1991; Lourens et al., 1996). The Rossello Composite Section, made from bottom to top by the Eraclea Minoa, Punta di Maiata, Punta Grande and Punta Piccola sections, represents the global reference section for the Zanclean and Piacenzian stages (Hilgen, 1991; Langereis & Hilgen, 1991; Lourens et al., 1996). The base of the Pliocene series, and Messinian/Zanclean boundary, is identified by the sharp contact between the underlying non-marine dark brown sands and marls of the Arenazzolo Formation and the whitish Trubi marls, deposited on open marine slope bottoms (Zachariasse et al., 1978), at inferred water depth of about 600-800 m (Sgarrella et al., 1997). The lithological discontinuity marking the Messinian/Zanclean boundary is widely recognized throughout the Mediterranean area and is assumed to derive by the sudden infilling of the totally or partyally desiccated basin after the Messinian Salinity Crisis (Hsü et al., 1973). The return to deep marine conditions appears to have been synchronous at the geological scale in different and very far areas (Iaccarino et al., 1999a; Pierre et al., 2006; Spezzaferri et al., 1998; Sturani, 1978; Trenkwalder et al., 2008). Outside the Mediterranean marine sedimentation occurred during the Messinian Salinity Crisis and the boundary does not show lithological evidences. An international debate on global correlations of the Messinian/Zanclean boundary produced a great amount of publications and more detailed and high resolution studies on the Miocene/Pliocene succession of the Atlantic coast of Morocco (Benson & Rakic El-Bied, 1996; Suc et al., 1997) as well as of Sicily and Crete (Greece) (Di Stefano et al., 1996; Hilgen & Langereis, 1988; Lourens et al., 1996; Zachariasse, 1975 among others). These researches supported the definition of the Eraclea Minoa as reference section for the Early Pliocene and the validity to mantain Pliocene stratotypes in Italy, where the Pliocene Series was originally designated. The base of the Zanclean stage is defined at the base of the carbonate bed of the small-scale lithostratigraphic cycle 1 (Hilgen & Langereis, 1988; Langereis & Hilgen, 1991), coincident with the insolation cycle 510, dated at 5.33 Ma (Lourens et al., 1996). The base of the Thvera magnetic chron (C3n.4n of Cande & Kent, 1992; 1995), dated at 5.236 Ma (Lourens et al., 1996), approximates the boundary. Biostratigraphic events for global correlations are mainly provided by calcareous nannofossils: the *Discoaster quinqueramus* LO, dated at 5.537 Ma, and the first occurrence of *Ceratolithus acutus* dated at 5.37 Ma in the equatorial Atlantic slightly predating the Messinian/Zanclean boundary (Backman & Raffi, 1997). The disappearance of *Triquetrorhabdulus rugosus* was recorded in Mediterranean deep-sea cores (Castradori, 1998; Di Stefano et al., 1996) and in the equatorial Atlantic (Backman & Raffi, 1997) at 5.23 Ma. Planktonic foraminiferal events, such as the *Sphaeroidinellopsis* spp. acme, and the *Globorotalia margaritae* FCO can be recognized only in the Mediterranean area.

4.2 The Piacenzian stage

The Piacenzian, which now is the second Pliocene stage, was originally established by Mayer-Eymar (1858) as representative of the older interval of the Pliocene. The same author later proposed the stage Astian for the upper and younger Pliocene portion (Mayer-Eymar, 1868). The author indicated the gray-blue clays of the Argille Azzurre (Blue Clays) Formation cropping out in Castell'Arquato and Lugagnano, near Piacenza, as typical of the Piacenzian stage. The Argille Azzurre Formation is well known in literature for its abundant and diversified macrofossils (mainly molluscs). Following studies demonstrated an older than earliest Pliocene age for the Argille Azzurre sediments, confirmed the importance of the fossiliferous record and extended the use of the term Piacenzian to stratigraphical correlations in Italy. The necessity of formal definition for stratigraphical units was object of increasing scientific debate in the second half of the last century. In the meanwhile, micropaleontology became widely applied to stratigraphical studies, foraminiferal and calcareous nannofossil biozonations were proposed and amended, providing higher resolution biostratigraphic tools than bivalvs and gastropods. Barbieri (1967) designated a unit-stratotype in the Castell'Arquato section and proposed the disappearance of the planktonic foraminifers *Globorotalia margaritae* as indicator of the Piacenzian base. Further micropaleontological studies (Raffi et al., 1989; Rio et al., 1988) demonstrated a hiatus at the very base of the Castell'Arquato section, corresponding to a large part of the lower Piacenzian, and the lack of the Zanclean/Piacenzian boundary. Therefore the proposed stratotype section resulted inadequate to represent the Piacenzian stage and the foraminiferal event (*G. margaritae* LA) was devoid of biostratigraphic value. A complete sedimentary documentation of the Piacenzian stage was recognized in the Punta Piccola section (Lourens et al., 1996; Spaak, 1983; Sprovieri, 1992, 1993; Sprovieri et al., 2006), the upper part of the Rossello Composite section, located in Southern Sicily (Cita et al., 1996). Here the GSSP of the Zanclean/Piacenzian boundary and the Piacenzian stratotype section have been ratified (Castradori et al., 1998). In the well exposed succession at Punta Piccola, the Zanclean Trubi calcareous marls crop out at the bottom and gradually pass upward to the more laminated marls of the Monte Narbone Formation. The Piacenzian/Gelasian boundary was detected in the upper part of the section. Micropaleontological data testify an upper epibathyal setting and a water depth of about 800-1000 m. The Piacenzian GSSP, and the coincident Zanclean/Piacenzian boudary, was defined at the base of the small-scale carbonate cycle 77, correlated to the astrochronological insolation cycle 347, dated at 3.6 Ma. The Gilbert-Gauss magnetic reversal, dated at 3.596 Ma, approximates the boundary (Lourens et al., 1996). The foraminiferal event applied to recognize the lower Piacenzian boundary is the disappearance of *G. puncticulata*, dated at 3.57 Ma (Channel et al., 2009; Lourens et al., 1996). Among calcareous nannofossils, the end of the paracme interval of *Discoaster pentaradiatus*, dated at 3.61 Ma, approximates the boundary, the *Sphenolithus* spp. LO, dated at 3.70 Ma in the Mediterranean (Lourens et al., 1996), was recognized at 3.66 in the Atlantic Ocean (Shackleton et al., 1995). A bioevent previously proposed as useful for global correlations, such as the LO of *Globorotalia margaritae*, was recently recalibrated, from 3.58 (Berggren et al. 1995; Castradori et al., 1998) to 3.81 Ma (Channel et al., 2009).

4.3 The Gelasian stage

The Gelasian stage was proposed by Rio et al. (1994; 1998) to represent the uppermost and third interval of the Pliocene Series, corresponding to the strong climatic deterioration due to orbitally controlled glacial cycles in the Northern Hemisphere. The stage was named from the Greek name of the town of Gela, near to the Monte S. Nicola section where the Gelasian GSSP was established. This location was preferred to the also detailed studied Singa section

(Calabria, Southern Italy) (Negri et al., 2003; Zijderveld et al., 1991) for its better paleomagnetic signal, exposition and accessibility. In the Monte S. Nicola section an undisturbed and complete Pliocene-Pleistocene succession crops out. From the bottom, marls and limestones of the Trubi Formation, documenting the upper Zanclean and the Piacenzian, grade upward to the silty marls of the Monte Narbone Formation, deposited from the Piacenzian to the Pleistocene (Rio et al. 1994; Spaak, 1983; Sprovieri, 1992, 1993). In the Gelasian time interval of the Monte S. Nicola section, micropaleontological data suggested a deposition in a slope-basin setting, at depths ranging from 500 to 1000 m. The Piacenzian/Gelasian boundary ("golden spike") was defined at the base of the marly layer overlying sapropel MPRS 250 (Mediterranean Precession Related Sapropel), and corresponds to the insolation cycle 250, astronomically dated at 2.588 Ma (Lourens et al., 1996). The base of the Gelasian falls in isotopic stage 103 (Raymo et al., 1989) and predates by about 60 ky the cold isotopic stage 100, marking the major climatic deterioration in the Northern Hemisphere. The Gauss/Matuyama reversal boundary predates of about 20 ky the Gelasian base. Calcareous microfossil events approximating the lower Gelasian boundary are the LO of *Globorotalia bononiensis* and *Neogloboquadrina atlantica*, dated at 2.41 Ma and nearly isochronous in Mediterranean and central Atlantic (Gradstein et al. 2004; Sierro et al. 2009), the LO of *Discoaster surculus*, dated at 2.53 Ma and the LO of *Discoaster pentaradiatus*, dated at 2.53 Ma (Sprovieri et al., 1998; Rio et al. 1998). Other biostratigraphic tools for global correlations are provided by siliceous microfossils. The LO of the radiolarian *Stichocorys peregrina*, the FO of the diatom *Nitzschia jouseae* and the LO of *Denticulopsis kamtschatica* approximate the Gauss/Matuyama boundary. In open-marine successions, other biovents occurring during the Gelasian are the FO of *Globorotalia truncatulinoides*, dated at 2.03 Ma in the Atlantic Ocean (Sierro et al. 2009), the LO of *Globigerinoides extremus*, dated at 1.98 Ma, and the FCO of *Neogloboquadrina pachyderma* sinistral, registered at 1.79 Ma (Gradstein et al., 2004; Rio et , 1998).

The upper boundary of the Gelasian was originally defined as coincident with the base of the Pleistocene Series and Calabrian stage, dated to 1.806 Ma (Lourens et al., 2004) in the thoroughly studied Vrica section (Calabria, Southern Italy), where the Pliocene/Pleistocene GSSP was proposed (Aguirre & Pasini, 1985) and formally accepted by the IUGS in 1984 (Bassett, 1985; Cita, 2008). In 2009, the IUGS formally ratified the proposal to lower the base of the Quaternary System and Pleistocene Series to the GSSP of the Gelasian stage (Gibbard et al., 2010). As a consequence, the Gelasian represents the first stage of the revised Pleistocene, the GSSP at Vrica section remains valid as the base of the Calabrian, now the second stage of the Pleistocene.

5. The Mediterranean Pliocene foraminiferal biozonation

During the 1960's and 1970's many foraminiferal biozonation for the Mediterranean Pliocene have been proposed (Bizon & Bizon, 1972; Cita, 1975a; Colalongo et al., 1982, among others), most of them were summarized by Iaccarino, 1985. The most successful was the zonal scheme of Cita (1975a), based on six foraminiferal zones, designated with the initials MPl (Mediterranean Pliocene) and numbered from 1 (the oldest) to 6 (the youngest). Rio et al (1984) integrated the foraminiferal and calcareous nannofossil Mediterranean Pliocene biozonations. Sprovieri (1992) amended the Cita (1975) scheme, introducing four new foraminiferal Subzones and so increasing the biostratigraphical resolution in the MPl4 and

MPl5 Zones (Tab. 2). The definition of each foraminiferal Zone and Subzone will be briefly described. Datum planes absolute ages are based on Gradstein et al. (2004).

Ma	STRATIGRAPHY			FORAMINIFERAL ZONES		FORAMINIFERAL BIOEVENTS	CALCAREOUS NANNOFOSSIL ZONES	
	Gradstein et al., 2004	Walker et al., 2009		Cita, 1975 Sprovieri,1992	Iaccarino, 1985		Rio et al., 1990	
	PLEISTOC.	PLEISTOCENE	CALABR.	*G. cariacoensis*	*G. cariacoensis*	FAD *G. cariacoensis* 1.75	MNN19b	*C. macintyrei*
2.0	PLIOCENE		GELASIAN	MPL6	*Globorotalia inflata*	FCO *N. pachyder.* s. 1.79 FAD *G. inflata* 2.09	MNN19a MNN18	*D. productus* *Discoaster brouweri*
2.5				MPL5b	*Globorotalia aemiliana*	LAD *G.bononiensis* 2.41 LO *N. atlantica* 2.41		
3.0		PLIOCENE	PIACENZIAN	MPL5a		FO *N. atlantica* 2.72 LAD *Sphaer.* spp. 3.19	MNN16b/17	*Discoaster pentaradiatus*
3.5				MPL4b	*Globorotalia puncticulata*	FAD *G.bononiensis* 3.31 LAD *G. puncticulata* 3.57	MNN16a	*Discoaster tamalis*
				MPL4a				
4.0 4.5			ZANCLEAN	MPL3	*Globorotalia puncticulata* & *Globorotalia margaritae*	LCO *G. margaritae* 3.98 FO *G. puncticulata* 4.52	MNN14/15 MNN13	*Reticulofenestra pseudoumbilicus* *Ceratolithus rugosus*
5.0				MPL2	*Globorotalia margaritae*	FCO *G. margaritae* 5.08	MNN12	*Amaurolithus tricorniculatus*
05:33				MPL1	*Sphaeroidinell.* acme			

Table 2. Planktonic foraminifer and calcareous nannofossil integrated biostratigraphic scheme for the Mediterranean Pliocene.

5.1 MPl1 Zone (*Sphaeroidinellopsis* spp. Acme-Zone, Cita, 1975a)

Lower boundary - the return to open marine conditions, related to the Mediterranean infilling after the Messinian Salinity Crisis. It coincides with the Pliocene base, dated at 5.33 Ma.

Upper boundary - *Globorotalia margaritae* FCO, dated at 5.08 Ma.

The biozonal marker *Sphaeroidinellopsis*, a deep mesopelagic taxon, is absent at the very base of the MPl1 Zone and is often rare in this interval both in deep-sea and land successions (Cita, 1973; Cita. 1975b; Di Stefano et al., 1996; Iaccarino et al., 1999b; Pierre et al., 2006). The *Sphaeroidinellopsis* increase in relative abundance, corresponding to its acme, is dated at the interval from 5.29 to 5.20 Ma (Iaccarino et al., 1999b) and extends from lithological cycle 2 to cycle 6 (Di Stefano et al., 1996). Acme zones are more properly ecobiostratigraphical zones, strongly dependent from environmental factors (water depth and temperature, trophic resources, etc.), that influence the species diffusion and abundance. In particular, *Sphaeroidinellopsis* specimens did not occur in shelf deposits, they were very rare and sporadic in upper epibathyal assemblages too.

Many ecobiostratigraphic events have been recognized in MPl1 Zone, and provide tools for correlations in the Mediterranean area, from bottom to top:

- an abundance peak of *Globigerina nepenthes* was recognized at the very base of the Pliocene succession, in Southern Italy (Zachariasse & Spaak, 1983) and in the Western Mediterranean (Iaccarino et al., 1999b) as well as in Northwestern Italy (Trenkwalder et al., 2008).
- two sinistral shifts of *N. acostaensis* were identified below the *Sphaeroidinellopsis* spp. acme in the Roccella Ionica-Capo Spartivento (Southern Italy) composite section (Di Stefano et al., 1996), where the basal Zanclean succession is completely preserved: the first and older between the lithological cycles 1-2, the second and younger between the cycles 2-3, near the base of the *Sphaeroidinellopsis* spp. acme, which encompasses cycles 2 to 6.
- the Common Occurrence (CO) of dextral coiling *Globorotalia scitula*, was registered in cycle 6 of the basal Zanclean in the Western Mediterranean and interpreted as a "delayed invasion event" (Iaccarino et al., 1999b).
- the re-immigration of the epibathyal to mesobathyal benthic foraminifer *Siphonina reticulata*, a nearly synchronous event, recognized at considerable geographic distance (Iaccarino et al., 1999b; Pierre et al., 2006; Spezzaferri et al., 1998; Violanti et al., 2009; 2011). *S. reticulata* was proposed as a Mediterranean quasi-endemic form, indicative of Early Pliocene Mediterranean Intermediate Water (EPMIW) (Sgarrella et al., 1997, 1999). Its re-diffusion after the Messinian Dessication Event was correlated to lithological cycle 6 (Di Stefano et al., 1996).
- the subsequent re-entry of the deep, oxyphilic *Cibicidoides robertsonianus*. The benthic taxon is a typical NADW (Nord Atlantic Deep Water) species. Its delayed diffusion was related to the basin deepening and establishment of deep oceanic-type conditions during the early Zanclean (Hasegawa et al., 1990; Spezzaferri et al., 1998).

5.2 MPl2 Zone (*Globorotalia margaritae margaritae* Interval-Zone, Cita, 1975a)

Lower boundary - *Globorotalia margaritae* FCO, dated at 5.08 Ma. The zonal marker is generally rare in the lower part of the zone and became common in bathyal assemblages upwards.

Upper boundary - *Globorotalia puncticulata* FO, dated at 4.52 Ma.

No ecobiostratigraphic events are reported in this interval zone.

5.3 MPl3 Zone (*Globorotalia margaritae - Globorotalia puncticulata* Concurrent range-Zone, Cita, 1975a)

Lower boundary - *Globorotalia puncticulata* FO, dated at 4.52 Ma.

Upper boundary - *Globorotalia margaritae* LCO, dated at 3.98 Ma.

This concurrent range zone is well recognizable in bathyal assemblages, less detectable in outer shelf assemblages, for the local absence of one or both of the two zonal markers.

Cita (1973), on the basis of morphological statistical studies, distinguished the new subspecies *G. margaritae primitiva*, a never keeled form, characterized by small, almost non-lobate tests, and *G. margaritae evoluta*, a large, strongly lobate form with an imperforate keel evident almost on the two last chambers, from the typical *G. margaritae margaritae*, with intermediate characteristics. Cita (1973) proposed a Lower Pliocene biozonation on the basis of the *G. margaritae* lineage. The author pointed out that *G. margaritae margaritae* and *G. margaritae primitiva* commonly co-occur in all the interval of the *G. margaritae margaritae* Lineage Zone (corresponding to the MPl2 Zone, Cita, 1975a). *G. margaritae evoluta* is common only in the upper part of the species range, in the *G. margaritae evoluta* Lineage Zone (corresponding to the MPl3 Zone, Cita, 1975a).

5.4 MPl4 Zone (*Sphaeroidinellopsis subdehiscens* Interval-Zone, Cita, 1975a)

Lower boundary - *Globorotalia margaritae* LCO, dated at 3.98 Ma.

Upper boundary - *Sphaeroidinellopsis* spp. LAD, dated at 3.19 Ma.

Cita (1973; 1975a) noted that the zonal marker was not abundant in the deep-sea reference cores (Site 125 and 132, DSDP Leg 13). In continental successions, *Sphaeroidinellopsis* spp. are absent or occur very randomly. *G. puncticulata* is common in the lower portion of the interval. *Globigerina (Globoturborotalita) apertura, Globigerina (Globoturborotalita) decoraperta* and *Globigerinoides extremus* are still common. Sprovieri (1992) formalized previous suggestions (Spaak, 1983) and proposed the division of the MPl4 Zone in two subzones:

5.4.1 MPl4a Subzone (*Globorotalia puncticulata* Interval-Subzone, Sprovieri, 1992)

The lower MPl4a Subzone extends from the *Globorotalia margaritae* LCO up to the *G. puncticulata* LAD, now dated at 3.57 Ma and therefore nearly approximates the Zanclean/Piacenzian boundary, dated at 3.60 Ma.

5.4.2 MPl4b Subzone (*Globorotalia planispira* Interval-Subzone, Sprovieri, 1992)

The upper MPl4b Subzone is comprised between the *Globorotalia puncticulata* LAD and the *Sphaeroidinellopsis* spp. LAD. The *Globorotalia bononiensis* FAD, dated at 3.31 Ma, an isochronous event in the Mediterranean, occurs in the upper part of this subzone. Also *Globorotalia aemiliana*, a taxon of the *Globorotalia crassaformis* plexus, firstly occurs nearly in the same horizon of *Globorotalia bononiensis* FAD. Iaccarino (1985) proposed *G. aemiliana* as index form of her homonimous zone, extending from the appearance of the zonal marker up to the appearance of *Globorotalia inflata*, encompassing part of the MPl4b Subzone and all the MPl5 Zone of Cita (1975a), amended Sprovieri (1992). Following studies evidenced a *G. aemiliana* diachronous diffusion in the Mediterranean and as a consequence the taxon inadequacy as zonal marker.

5.5 MPl5 Zone (*Globigerinoides elongatus* Interval-Zone, Cita, 1975a)

Lower boundary - *Sphaeroidinellopsis* spp. LAD, dated at 3.19 Ma.

Upper boundary - *Globorotalia inflata* FAD, dated at 2.09 Ma.

In the same time interval Cita (1973) proposed the *Globigerinoides obliquus extremus* Zone, defined as the interval between the *Sphaeroidinellopsis* spp. LAD and the extinction of the zonal marker. Cita (1975a) named the MPl5 Zone as *Globigerinoides elongatus* Interval Zone, for the rareness of the previous zonal marker in the upper part of the interval, in which it is substituted in abundance by *G. elongatus*. Sprovieri (1992) introduced two subzones:

5.5.1MPl5a Subzone (*Globorotalia bononiensis* Interval-Subzone, Sprovieri, 1992)

The lower MPl5a Subzone is defined as the interval comprised between the *Sphaeroidinellopsis* spp. LAD and the *Globorotalia bononiensis* LAD, dated at 2.41 Ma. The *Neogloboquadrina atlantica* FO in the Mediterranean Pliocene is dated at 2.72 Ma, its LO is dated at 2.41, isochronous to the *Globorotalia bononiensis* LAD. The *G. crassaformis* group (*G. aemiliana, G. crassaformis, G. crassula*) is often common. In particular, *G. aemiliana*, an easily recognizable species for its typical morphology, is often more frequent than *G. bononiensis* and can help the biostratigraphic assessment of poorly diagnostical assemblages.

5.5.2 MPl5b Subzone (*Globorotalia incisa* Interval-Subzone, Sprovieri, 1992)

The upper MPl5b Subzone is defined as the interval comprised between the *Globorotalia bononiensis* LAD and the *Globorotalia inflata* FAD. Assemblages are poor of useful biostratigraphic taxa. *G. (Gt.) apertura, G. (Gt.) decoraperta, G. obliquus,* and *G. extremus* are rare and become extinct at the top of this subzone or soon after in the Gelasian.

5.6 MPl6 Zone (*Globorotalia inflata* Interval-Zone, Cita, 1975a)

Lower boundary - *Globorotalia inflata* FAD, dated at 2.09 Ma

Upper boundary - *Neogloboquadrina pachyderma* FCO, dated at 1.79 Ma

Lourens et al. (2004) introduced a subdivision of the MPl6 Zone in two subzones, MPl6a and MPl6b respectively, separated on the basis of the appearance of *Globorotalia truncatulinoides*, dated at 2.0 Ma. In many on-land successions *G. truncatulinoides* very seldom occurs and the subzones can hardly be recognized.

The upper boundary of the MPl6 Zone was coincident with the top of the Gelasian stage, correlated with the Pliocene/Pleistocene boundary (Gradstein et al., 2004 and literature until 2009). On the contrary, if following the recent controversial revision of this boundary ratified by the International Union of Geological Sciences (IUGS) (Gibbard et al., 2010), the entire MPl6 Zone pertains to the Pleistocene Series (see Tab. 2).

6. Previous foraminiferal studies on the Northwestern Italy Pliocene

Pliocene marine sediments of Northwestern Italy widely crop out in the central part of Piedmont (Astigiano and Monferrato) and are well know in literature for their rich macrofossil assemblages. Foraminiferal assemblages were also analyzed in progressively increasing detail, from the first taxonomical descriptions carried out in the region by Dervieux (1892). Small and discontinuous Pliocene marine deposits crop out in the northern part of the sector, along the Alps margins, and to the south, along the western Ligurian coast (Fig. 1). The northernmost Pliocene foraminiferal assemblages along the southern side of the Alps were described at Castel di Sotto (Canton Ticino, Switzerland) few kilometers outside the Italian border. Sediments were referred to the upper part of the Early Pliocene on the occurrence of *Globigerinoides extremus, G. obliquus*, and *Bolivina placentina* (Premoli Silva, 1964; Violanti, 1994). A more precise biostratigraphic correlation was hampered by the absence of biozonal planktonic markers. Statistical analysis of the abundant benthic taxa documented deep outer neritic, disoxic muddy bottoms, dominated by the stress-tolerant *Globobulimina affinis*, and affected by high sedimentation rates of terrigenous and vegetal debris. Similar assemblages, with scarce and long-ranging planktonic forms, dominant benthic taxa indicative of outer neritic to inner neritic paleoenvironment, characterize other nearby Pliocene subsurface deposits (Morbio (Canton Ticino) core, Violanti, unpublished data) as well as cropping out in the Varese area (Cremaschi et al., 1985; Lualdi 1981; Martinis, 1950).

In the Biellese, a Piedmont region at the foothills of the Western Alps, Barbieri et al. (1974) and Aimone & Ferrero Mortara (1983) described foraminiferal assemblages typical of inner neritic to outer neritic bottoms, referred by the authors to the Middle-Upper Pliocene. Basilici et al. (1997), in their interdisciplinary study of Val Chiusella outcrops, dated the lower deposits of the marine to continental succession to the uppermost Zanclean, on the occurrence of the benthic foraminifer *Buccella granulata* and of the gastropod *Bufonaria marginata*, which disappeared in correspondence with the LAD of *Globorotalia puncticulata*, marking the upper boundary of the MPl4a Zone. Foraminiferal and mollusc assemblages were indicative of an inner neritic paleoenvironment.

In the central part of Piedmont, Martinis (1954) analyzed the foraminiferal assemblages of the Pliocene succession in a number of localities, from Verrua Savoia to the North, to Villalvernia to the Southeast, to the Astigiano and the Monregalese to the Southwest, collected both from the Argille di Lugagnano (now reported as Argille Azzurre, Blue Clays) and from the Sabbie di Asti (Asti Sands). The author dated the Argille Azzurre, with generally abundant planktonic foraminifers, indicative of neritic paleoenvironment, to the Early Pliocene and referred the outer neritic to inner neritic assemblages of the Sabbie di Asti to the Middle and Upper Pliocene.

Casnedi (1971) presented another detailed review of Lower Pliocene assemblages from the Southern and Western Piedmont Argille Azzurre, characterized by sometimes common *Globorotalia margaritae* and/or *G. puncticulata* and by deep outer neritic to bathyal benthic species such as *Anomalinoides helicinus,* and *Uvigerina rutila*. Poorly diversified assemblages, dominated by shallow water foraminifera (*Ammonia beccarii, Elphidium* spp. and *Cibicides* spp.) were described by the same author from the sandy deposits cropping out in the surroundings of Asti. In the Albese area, Montefameglio et al. (1979) dated the clayey marls and sandy clays to the Lower Pliocene MPl3 Zone on the occurrence of locally common *Globorotalia puncticulata, Anomalinoides helicinus*, *Bulimina minima* and *Uvigerina rutila*. In the South-Western Piedmont Boni et al. (1987) documented deep water Lower Pliocene assemblages, yielding *Globorotalia margaritae*, overlaid by shallow water deposits, referred by the authors to the Upper Pliocene-Pleistocene, along the Pesio Stream (Monregalese). In other nearby outcrops Pavia et al. (1989) pointed out the absence of globorotalias and the presence of typical Lower Pliocene taxa such as *Bolivina leonardii* (Breolungi, Mondovì). The absence of planktonic biostratigraphic markers was also evidenced in the Monregalese assemblages (Violanti & Giraud, 1992), dated at the Lower-Middle Pliocene mainly on the occurence of benthic taxa.

Violanti (2005) provided data on foraminiferal assemblages from the North-Eastern Monferrato, Astigiano, Langhe and Monregalese. The lowermost MPl1 Zone was unequivocally documented only in the Moncucco Torinese quarry (Turin Hill). Rich and diversified assemblages referable to the MPl2 Zone, with *Globorotalia margaritae*, and to the MPl3 Zone, with *G. margaritae* and *G. puncticulata*, indicative of upper epibathyal depths, suggested paleoenvironmental conditions similar to those of coeval pelagic successions of Sicily and of the Tyrrhenian Sea. Basin shallowing and increasing transport from emerged areas and shallow water bottoms were documented during the MPl3 Zone, and chiefly MPl4 Zone. Following researches excluded a marine sedimentation during the following MPl5 Zone in the central Piedmont basin, tentatively proposed by Violanti (2005). The youngest marine succession of the region, ranging from the MPl4a to the MPl5a Subzones, was described from sediments cored at Casale Monferrato (AL), at the margin of Monferrato (Violanti & Sassone, 2008). Here, *Globorotalia puncticulata* and *G. puncticulata padana* occurred in the lower layers, whereas *Globorotalia aemiliana* and *G. bononiens* specimens were detected upwards. Recent researches in the Piedmont region, focusing on the Messinian paleoenvironmental evolution (Clari et al., 2008; Dela Pierre et al., 2011; Lozar et al. 2010), revealed an unexpected nearly complete documentation of the Early Pliocene in the Turin Hill (Moncucco Torinese quarry: Trenkwalder et al., 2008; Violanti et al., 2011) and in the Albese area (Narzole core: Violanti et al., 2009). The Moncucco T. section, spanning from the uppermost non-marine Messinian (Lago-Mare deposits) to the upper Zanclean MPl4a Zone, will be discussed and integrated by new data in the following pages. The Narzole core also encompasses the Messinian/Zanclean boundary, marked by a 0.50 cm thick barren arenitic layer, dark brown to black, similar to that recovered in the same stratigraphic position at Moncucco T. Microfossils (foraminifers, calcareous nannofossils and ostracods) documented the MPl1 and MPl2 foraminiferal Zones and the MNN12 calcareous nannofossils Zone of the Early Pliocene. Many bioevents, which occurred during the MPl1 Zone and previously discussed, such as one sinistral coiling shift of *Neogloboquadrina acostaensis*, the *Globorotalia scitula* sinistral CO, the re-immigration of *Siphonina reticulata*, the first influx of the Nord Atlantic Deep Water (NADW) taxon *Cibicidoides robertsonianus*, were recognized in the Narzole core and allowed correlations with the Moncucco T. section and the Mediterranean deep-sea succession. Integrated studies are in progress on subsurface and surface deposits of the region, mainly focusing on the Messinian/Zanclean boundary and the lower Pliocene paleonvironmental evolution.

On the southern margin of the Alps, Pliocene sediments discontinously crop out along the coast of the western Ligury. The thickest and fossiliferous deposits were described between Ventimiglia, to the West, and Ceriale (Rio Torsero), to the East. Rich foraminiferal assemblages, yielding common specimens of *Sphaeroidinellopsis* spp., were described in the older Pliocene mudstones and marls. Less diversified assemblages, poor of biostratigraphic indices, characterized the upper deposits (Boni et al., 1985; Giammarino & Tedeschi, 1980; Giammarino et al., 1984). Recently, Breda et al. (2009) analyzed the sedimentological and tectonic evolution of Ventimiglia incised valley and described a Pliocene succession spanning from the Zanclean MPl1 and MNN12 Zones to the Piacenzian MPl5 and

MNN16b/17 Zones. A successions dated from the MPl3 Zone, by the co-occurrence of *Globorotalia margaritae* and *Globorotalia puncticulata*, to the MPl4 Zone, with *G. puncticulata,* was described along the Rio Torsero (Violanti, 1987), near Ceriale.

7. Recent and new data on the Piedmont Pliocene

Three sections, from Moncucco Torinese, Isola d'Asti and Verrua Savoia, will be analyzed, as representative of the Pliocene biostratigraphic succession and paleoenvironmental evolution in the central Piedmont, from the very Pliocene base to the upper Zanclean MPl4a Subzone.

7.1 Material and methods

Foraminiferal analyses of Pliocene Piedmont assemblages were carried out on sieving residues prepared following standard procedures (Haynes, 1981). 500-100 g of dry sediment (clay, silt and sand) were disaggregated with water and a small amount of hydrogen peroxide (H_2O_2) or by gently boiling with water for 1-2 hours, rather consolidated sediments as some calcarenites were partially disaggregated by boiling with water and a small quantity of soda (Na_2CO_3). When disaggregated, the material was gently washed, sieved into grain size fractions greater than 250 µm, 125-250 µm and 125-63 µm, dried at 50° C and weighed. Percentages of the separate grain size fractions were calculated, the total >63 µm residue percentages will be discussed here. Assemblages of well consolidated calcarenites were studied on thin sections.

Qualitative foraminiferal analyses were made on the three grain size fractions in order to identify the often rare biostratigraphic markers. Quantitative analyses were carried out on the whole of the >125 µm fraction, split into aliquots containing at least 300-400 well preserved foraminiferal tests. Semiquantitative studies were performed on thin sections and when the tests poor preservation or abundant reworked forms prevented the quantitative analysis.

Taxonomy is according to Kennett & Srinivasan (1983) and Stainforth et al. (1975), for planktonic species, to AGIP (1982), Loeblich and Tappan (1988) and Van Morkhoven et al. (1986) for benthic species. The biostratigraphic scheme here adopted is that of Cita (1975a), amended by Sprovieri (1992). Selected taxa are shown in Plate 1.

7.2 The Moncucco Torinese section

The Pliocene succession exposed in the Moncucco Torinese (Torino Hill, Tertiary Piedmont Basin) quarry, represents, at the present state of study, the more complete documentation of Early Pliocene (Zanclean) upper epibathyal deposits in the Piedmont area as well as in the Northwestern Italy (Trenkwalder et al., 2008; Violanti et al., 2011). In the Moncucco T. quarry a thick Messinian evaporitic and post-evaporitic succession is overlaid by a 10-50 cm thick barren black arenitic layer, marking the Messinian/Zanclean boundary, followed by about 26 meters of Zanclean gray to whitish marly clays, pertaining to the Argille Azzurre (Blue Clays) Formation. The Zanclean unit is rather uniform, without evident bedding, a thin silty layer was detected in the middle/upper section, two biocalcarenitic layers, 0.50 cm thick each ones, are interbedded in its upper part. Pleistocene continental deposits cover with an erosional surface the Zanclean marly clays.

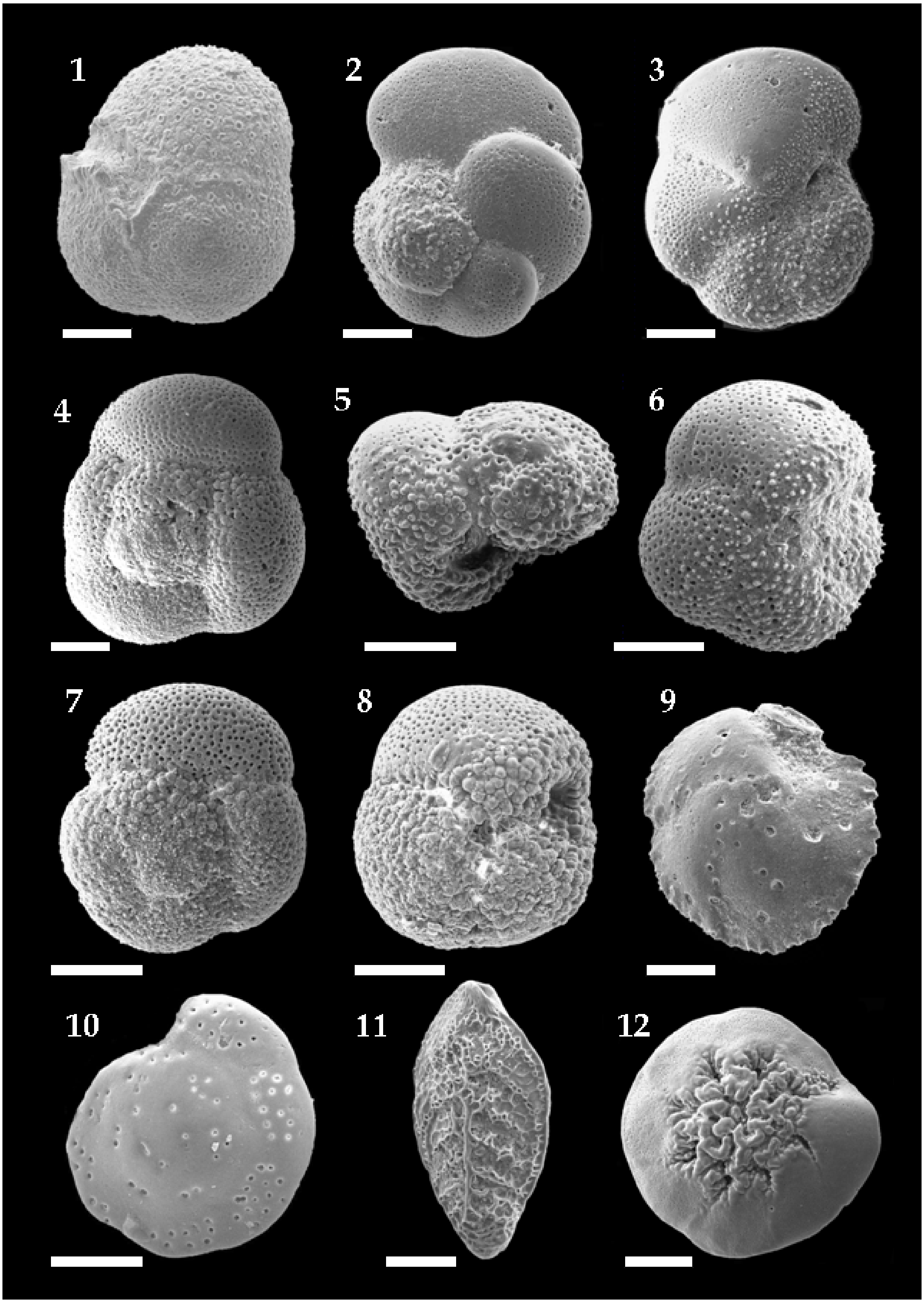

Plate 1. Fig. 1: *Sphaeroidinellopsis subdehiscens* Blow, sample M7, umbilical view. Figs. 2- 3: *Globorotalia margaritae* Bolli & Bermudez, sample Is12: Fig. 2, spiral view, Fig. 3, umbilical

view,. Figs. 4-6: *Globorotalia puncticulata* (Deshayes), sample Is21: Fig. 4, spiral view, Fig. 5, lateral view, Fig. 6, umbilical view. Figs. 7-8: *Globorotalia puncticulata padana* Dondi & Papetti, sample Is35: Fig. 7, spiral view, Fig. 8, umbilical view. Fig. 9: *Siphonina reticulata* (Czjzek), sample Is10, umbilical view. Fig. 10: *Cibicidoides robertsonianus* (Brady), sample M26, spiral view. Fig. 11: *Bolivina leonardii* Accordi & Selmi, sample Is7, lateral view. Fig. 12: *Buccella granulata* (Di Napoli), sample Vc39, umbilical view. Scale bar = 100 µm

Primary biostratigraphic data are given by occurrence and frequency of the zonal markers. The basal MPl1 Zone (*Sphaeroidinellopsis* spp. acme Zone, Cita, 1975a) is documented by the occurrence of *Sphaeroidinellopsis* spp. from about 1 m above the marly clays bottom. *Sphaeroidinellopsis* spp. reach their abundance peak (acme) in a short interval, encompassing sample 6 to 11 and extending from 5.29 Ma, base of the *Sphaeroidinellopsis* acme (Di Stefano et al., 1996; Iaccarino et al., 1999b), to 5.17 Ma (Di Stefano et al., 1996) or 5.20 Ma (Iaccarino et al., 1999a; 1999b), top *Sphaeroidinellopsis* acme (Fig. 2). The absence of *Sphaeroidinellopsis* spp. characterizes the very base of the Pliocene succession and was described both in Mediterranean deep sea sediments (Cita, 1973; Iaccarino et al., 1999a, 1999b; Spezzaferri et al., 1998), as well in outcrops (Di Stefano et al., 1996; Pierre et al., 2006; Spaak, 1983; Sprovieri, 1992; Sprovieri, 1993; Zachariasse, 1975). At Moncucco T., as well as in the rather nearby Narzole core (Alba, Piedmont) (Violanti et al., 2009), specimens of the zonal marker are smaller and rarer in comparison with those occurring in the Sicily Trubi Formation (Sprovieri, 1992; Vismara Schilling & Stradner, 1977; Violanti, 1989) and suggest local paleoenvironmental conditions non optimal for the taxon. Percentages of the zonal marker are very low, always less then 2%, but are similar to those registered in other Mediterranean sites (Iaccarino et al., 1999a; Spaak, 1983). The upper boundary of the MPl1 Zone was indicated by the *Globorotalia margaritae* FCO (5.08 Ma, Gradstein et al., 2004), recorded in sample 26, about 11.50 m above the marly clays bottom (Fig. 2). The taxon showed two abundance peaks (5-6%) at about 15 m and 20.5 m from the bottom and was detected up to sample 48. Rare tests of *Globorotalia puncticulata* firstly occurred in sample 40, about 18 m above the bottom and became common in most of the upper samples (Fig. 2). Nevertheless, the upper boundary of the MPl2 Zone (*G. margaritae* zone), or lower boundary of the MPl3 Zone (*G. margaritae/G. puncticulata* Concurrent Zone) was proposed in correspondence to the lower sample 39, where the *Helicosphaera sellii* FO was recorded (Trenkwalder et al., 2008). This calcareous nannofossil bioevent indicates the MNN12/MNN13 boundary (Rio et al., 1990) and is coeval with the Mediterranean FO of *Globorotalia puncticulata* (4.52 My, Hilgen, 1991). Finally, the upper boundary of the MPl3 Zone, corresponding to the lower boundary of the MPl4a Subzone (Cita, 1975a, amended Sprovieri, 1992) was recorded in sample 48, where the *G. margaritae* LCO (3.98 My, Gradstein et al., 2004) was registered (Fig. 2).

Other secondary data are given by ecobiostratigraphical events, recognized at Mediterranean scale and also in the Narzole (Albese area) core (Violanti et al., 2009). They characterize the lowermost Pliocene succession, referable to the MPl1 Zone, and are related to the re-establishment of deep marine conditions in the Mediterranean basin. In stratigraphic order they are (Fig. 2): 1) an abundance peak of *Globigerina nepenthes*, recorded at the very base of the Pliocene succession, reported also in the Western Mediterranean (Iaccarino et al., 1999b) as well as in Southern Italy (Zachariasse & Spaak, 1983); 2) one sinistral shift of *Neogloboquadrina acostaensis*, observed in the same basal layer (sample 4). Two sinistral shifts of *N. acostaensis* have been described below the *Sphaeroidinellopsis* spp. acme within complete successions (Di

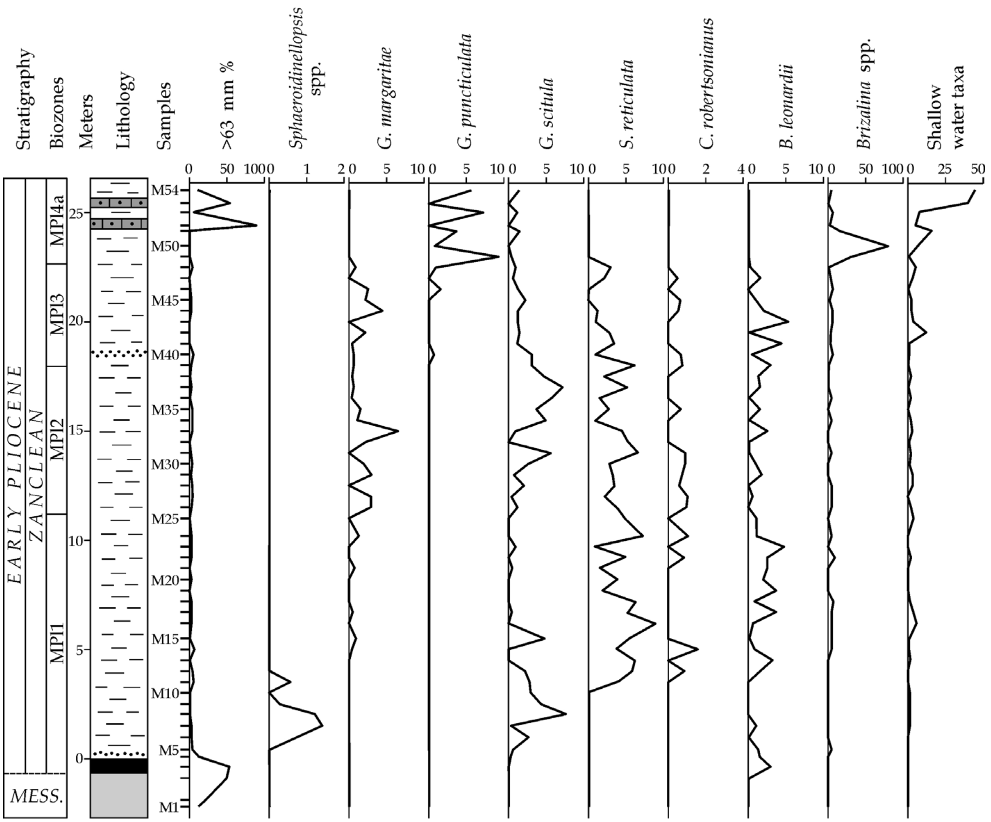

Fig. 2. Moncucco T. section. Chronostratigraphic synthesis, lithological column, samples position, percentage variations of the grain sized > 63 µm fraction, of planktonic (*Sphaeroidinellopsis* spp., *Globorotalia margaritae*, *Globorotalia puncticulata* and *Globorotalia scitula*) and benthic (*Siphonina reticulata, Cibicidoides robertsonianus*, *Bolivina leonardii, Brizalina* spp. and Shallow water taxa) foraminiferal taxa.

Stefano et al., 1996; Iaccarino et al., 1999b). A short hiatus in the basal Pliocene of Moncucco T. was therefore inferred, also on the basis of *Triquetrorhabdulus rugosus* absence, a calcareous nannofossil taxon usually recorded in the lowermost Zanclean (Castradori, 1998); 3) the *Globorotalia scitula* dextral Common Occurrence (CO), a “delayed invasion event”, was recorded in sample 8 of the Moncucco T. section and in the basal Early Pliocene of the Western Mediterranean (Iaccarino et al., 1999b); 4) the re-immigration of the epibathyal to mesobathyal benthic foraminifer *Siphonina reticulata*, and the subsequent re-entry of the deep, oxyphilic benthic *Cibicidoides robertsonianus*, nearly synchronous events, recognized at considerable geographic distance (Iaccarino et al., 1999b; Pierre et al., 2006; Spezzaferri et al., 1998) in the Mediterranean basin. The re-immigration of bathyal benthic species, disappeared from the Mediterranean before the Messinian Salinity Crisis (Kouwenhoven et al., 1999), was related to the establishment of deep oceanic-type conditions during the early Zanclean (Hasegawa et al., 1990; Spezzaferri et al., 1998).

In the upper MPl2 Zone and in the following MPl3 Zone the decrease to disappearance of bathyal benthic taxa (*C. robertsonianus*, *S. reticulata* etc.) is opposite to the frequency increase of infaunal, low-oxygen tolerant taxa such as *Brizalina* spp. (Fig. 2), suggesting more disaerobic and probably rather shallower bottoms. High percentages of winnoved shallow water forms (*Ammonia beccarii, Cibicides lobatulus, Elphidium* spp.) characterized the uppermost calcarenitic levels and document enhancing trasport from the inner shelf during the MPl4a Zone. In many samples the distribution of *Bolivina leonardii*, a typical Pliocene taxon, shows an opposite pattern to that of *Brizalina* spp. (Fig. 2) and a positive correlation with the deep, oxyphilic taxa.

Trenkwalder et al. (2008) inferred an only partial documentation of the MPl2 and MPl3 Zones in the Moncucco T. section, due to the reduced thickness of sediments representing these intervals in comparisong with those preserved in on-land sections (Rossello Composite Section, Sgarrella et al., 1997; Sprovieri, 1992; Zachariasse et al., 1978) and deep-sea cores (Cita, 1973, 1975a; Cita et al., 1999; Pierre et al., 2006). Planktonic and benthic assemblages suggested paleodepths similar to those proposed in the correspondent interval of the previously cited Southern Mediterranean successions: upper epibathyal bottoms, probably not deeper than 500 m, at the very base of the MPl1 Zone, a basin deepening, probably to about 800-1000 meter depth during the same MPl1 Zone and stable deep bottoms during most of the MPl2 Zone. Upwards, a shallowing to deep outer neritic or uppermost epibathyal zone, and a correspondent increase of transport from the inner shelf, was suggested at Moncucco T. by the progressive disappearance of deep bathyal taxa and by the higher frequency of shallow water taxa (Fig. 2).

7.3 The Isola d'Asti section

The Isola d'Asti section was studied for its good documentation of upper epibathyal sediments in the Astigiano area, where silty or sandy deposits indicative of outer neritic to inner neritic bottoms, very poor of biostratigraphic indices, dominantly occur.

The Isola d'Asti section was sampled behind the Merlino brickyard (now shutted down), at about 1,5 km NE of Isola d'Asti and 8 km SW of Asti (Fig. 1) The succession pertains to the Argille Azzurre (Blue Clays) Formation and is represented by dominant bioturbated and massive marly-silty clays. Four layers of finely laminated pelites, few centimeters or decimeters thick, are interbedded to the clays. Two coarse sandy levels, rich in macrofossils (mainly bivalvs, gastropods), interpreted as turbiditic deposits, occurred from 6.5-7.2 m above the bottom of the outcrop and are separated by a 0.2 m thick layer of silty-sandy clays. Samples for foraminiferal analyses were collected at distance of 5-10 cm each others in the laminated layers, of 0.5-1 m in the bioturbated silty clays.

Foraminiferal preservation is very good, dominant planktonic species in the >125 μm fraction are *Globigerina (Globoturborotalita) apertura, Globigerina bulloides, G. (Gt.) decoraperta, Globigerinella obesa, Globigerinoides obliquus, G. extremus. Globorotalia scitula* and *Orbulina universa* are often rare. The mesopelagic globorotalias are represented by rare but large specimens of *G. margaritae* (*G. margaritae margaritae* and *G. margaritae evoluta*) occurring in the lower samples up to sample 17 and by *G. puncticulata* and *G. puncticulata padana*, randomly occurring from sample 5 upwards and frequent in the interval between the samples 16 and 23 (Fig. 3). On the basis of *G. margaritae* and *G. puncticulata* distribution, the

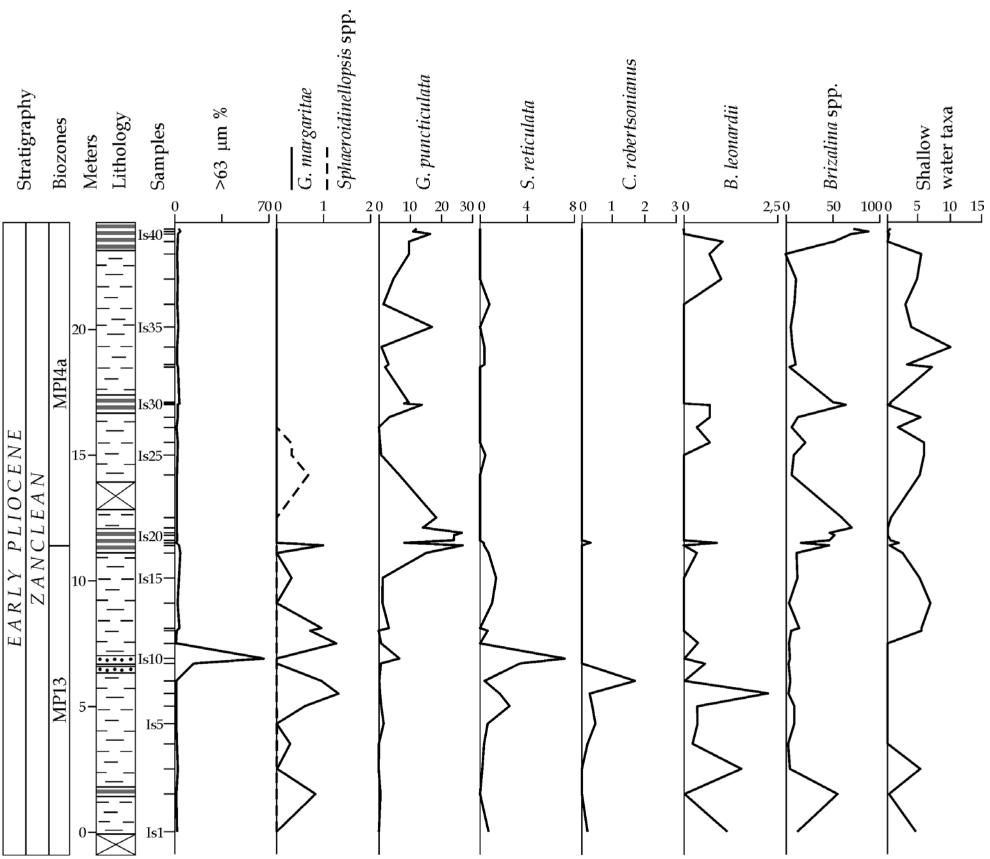

Fig. 3. Isola d'Asti section. Chronostratigraphic synthesis, lithological column, samples position, percentage variations of the grain sized > 63 µm fraction, of planktonic (*Sphaeroidinellopsis* spp., *Globorotalia margaritae* and *Globorotalia puncticulata*) and benthic (*Siphonina reticulata, Cibicidoides robertsonianus*, *Bolivina leonardii, Brizalina* spp. and Shallow water taxa) foraminiferal taxa.

MPl3 and MPl4a Zones are documented, the first in the lower part of the section, from the bottom to 11.4 m, the latter in the upper part of the section. Calcareous nannofossil assemblages (Lozar, pers. comm.) allow the correlation to the MNN14/15 Zone (Rio et al., 1990), coeval of the upper MPl3 and lower MPl4a foraminiferal Zones. Very rare specimens of *Sphaeroidinellopsis subdehiscens*, a deep mesopelagic taxon, were collected in few samples (Fig. 3) and suggest a deep water colomn. Benthic foraminiferal assemblages are rich and well diversified in the massive clays. Deep outer neritic to bathyal taxa, such as *Cibicidoides pseudoungerianus, Hoeglundina elegans, Siphonina reticulata, Uvigerina peregrina,* and Nodosariidae (Van Morkhoven et al., 1986; Wright 1978) are common, more frequent in the MPl3 interval. Many taxa that go extinct during the MPl5 Zone (*Anomalinoides helicinus, Bolivina leonardii, B. placentina, Bulimina minima, Uvigerina rutila*) are present or common (AGIP, 1982; Sprovieri 1986). In particular, the epifaunal *S. reticulata*, indicative of Early

Pliocene Mediterranean Intermediate Water (EPMIW) (Sgarrella et al., 1997) reach its frequency peaks in the central samples dated to the MPl3 Zone (Fig. 3) and occurs also, even if very rare, in some upper levels referred to the MPL4a Subzone. Another bathyal species, just occurring in the Moncucco MPl1 to MPl3 interval, is *C. robertsonianus*, indicative of well-oxygenated deep paleoenvironment (Kouwenhoven et al., 1999). At Isola d'Asti, its last recovery immediately follows the *G. margaritae* LO (sample 18 and 17, respectively). Specimens of *B. leonardii* are more common in the lower section and occur mainly below the laminated sapropelitic layers or in the basal laminite samples.

In contrast with the high diversity of benthic foraminifers in the massive clays, nearly oligotypic benthic assemblages characterize the laminated layers. *Brizalina* spp. (*B. aenaeriensis, B. dilatata* and *B. spathulata*) is strongly dominant, followed by other infaunal, stress tolerant taxa as Buliminids, *Fursenkoina schreibersiana,* and *Stainforthia complanata*, widespread in organic matter rich sediments. Disaerobic bottom conditions are responsible for the origin of the laminated, sapropelitic intervals recognized in many Pliocene outcrops and correlated to the deep sea Mediterranean succession (Capozzi & Picotti, 2003; Negri et al., 2003; Rio et al., 1997; Thunell et al., 1984).

At Isola d'Asti, the second laminated layer from the bottom occurs just above the *G. margaritae* LO at the base of the MPl4a Zone. A generally positive correlation of the *Brizalina* spp. and *G. puncticulata* curves is also registered. The displaced shallow water forms (mainly epiphytic species, such as *Cibicides lobatulus* and *Rosalina globularis*) randomly occur in the lower samples and become common to frequent upwards. They are absent or extremely rare in the laminated layers, and suggest a reduced transport from the inner shelf during the sapropelitic levels deposition.

Planktonic and benthic assemblages document an open-sea setting for all the succession, on epibathyal bottoms probably at depth of at least 600-800 m up to its middle part, in which *Sphaeroidinellopsis* occurred. A slight shallowing is inferred in the upper MPl4a zone, by the decrease or disappearance of the deep benthics *S. reticulata* and *C. robertsonianus*.

7.4 The Verrua Savoia composite section

The studied site is located in central Piedmont, in the area of transpressive faults that separates the NE Monferrato, of North Apennine affinity, from the Turin Hill, of Alpine affinity (Piana & Polino, 1995) (Fig. 1). The Verrua Savoia succession was known in literature as being the thicker Pliocene outcrop of the central Piedmont (Bonsignore et al., 1969). Foraminiferal assemblages of few samples from the Verrua S. area were described by Martinis (1954) and Zappi (1961). A detailed sampling in the Cementi Vittoria quarry, opened at the foot of Verrua S. hill, was carried out during the Sheet 157 Trino, 1:50.000 of the Geological Map of Italy (Clari and Polino, 2003; Dela Pierre et al., 2003) survey. Preliminary data on planktonic and benthic foraminifers were presented by Bove Forgiot et al. (2005). The composite section here analyzed is represented by two transects: a lower transect, cropping out in the northern side of the quarry and a second upper transect, sampled at the top of the hill, below the Verrua S. castle (Fig. 4). At the bottom, Pliocene sediments overlay with an erosional surface Upper Eocene gray calcareous marls (sample Va1 and Va2), the boundary is evidenced by bioturbations infilled by the overlying Pliocene grayish marly silts. The Pliocene succession is represented by about 80 meters of well stratified marly clays, silts and sandy silts, affected by faults, with interbedded sand and calcarenite banks, progressively more frequent and thicker upwards. Only sandy silts, sands and calcarenites are represented in the upper transect. Foraminiferal assemblages were analyzed on washing residues, prepared from silty or sandy samples and from the less consolidated calcarenites, and on thin sections. Only semiquantitative micropaleontological analyses were carried out, because the abundant reworked tests, of Eocene forms in the lower section, and of Miocene to lower Pliocene taxa in the middle and upper layers, prevented the quantitative study. Foraminiferal preservation was generally poor, tests were encrusted or partially included in calcareous aggregates. The planktonic foraminiferal assemblages are nearly similar to those described in the Moncucco T. and Isola d'Asti section: they are mainly given by Miocene to Pliocene taxa such as *Globigerina (Globoturborotalita) apertura, G. (Gt.) decoraperta, Globigerinoides obliquus, G. extremus* and less common *Neogloboquadrina acostaensis*. Well preserved specimens of *G. margaritae* occur from sample Va3, base of the Pliocene succession, to sample Va31. *G. puncticulata* and *G. puncticulata padana* were recognized in all the samples, more frequent in the lower, thinner layers. Empty well preserved tests occur also in some uppermost samples, together with infilled, partially diagenized tests of the same species, interpreted as slightly older and reworked. Therefore, the lower part of the marly clays and silts was correlated to the MPl3 Zone and the following sandy silts and calcarenites to the MPl4a Zone. The reasonably *in situ* (not reworked) benthic foraminiferal assemblages of the Verrua S. silts are very diversified and yield common deep outer neritic to bathyal taxa (*Anomalinoides helicinus, Cassidulina carinata, Cibicidoides pseudoungerianus, Hoeglundina elegans, Planulina ariminensis, Siphonina reticulata, Uvigerina peregrina, U. rutila*) (Van Morkhoven et al., 1986; Wright 1978). In particular, *S. reticulata* occurs in the silty layers of the first transect, whereas it is absent in the upper calcarenites (Fig. 4). Very rare, small empty specimens of the deep water *C. robertsonianus* are present only in few lower samples, in which *S. reticulata* is also common. The infaunal, stress tolerant *Bolivina* (*B. placentina* and mainly *B. leonardii*), *Brizalina* (*B. aenaeriensis, B. spathulata*) and *Bulimina* spp., preferential of muddy sediments, are scarce.

In the uppermost sands and calcarenites rare test of *Buccella granulata* were recognized. The species, originally described as *Eponides frigidus granulatus* (Di Napoli Alliata, 1952), is living in inner neritic sandy bottoms and cool waters (Serandrei Barbero et al., 1999) and was firstly reported in the Early Pliocene MPl4 Zone (Basilici et al., 1997; Rio et al., 1988). The biostratigraphic application of this taxon is limited by its ecological preference for sandy sediments, devoid of biostratigraphic markers, and the precise calibration of its FO is dubious. The recovery of *B. granulata* only in the uppermost deposits and its absence in the lower sandy and calcarenitic layers of the Verrua S. section, suggest an occurrence during the MPl4a Subzone, but excluding its lowermost interval. Other peculiar characteristics of the Verrua S. assemblages are the very low recovery of *Brizalina* spp., absent or rare in most samples and the high frequency of shallow water forms, showing increasing abundances upwards. Epiphitic taxa (*Elphidium crispum*, *Neoconorbina terquemi* and *Rosalina* spp.) are dominant in the calcarenitic layers. The progressively coarser sediments and higher amounts of winnowed shallow water forms testify nearby inner shelf vegetated bottoms as well as the increasing frequency of turbiditic episodes. A basin shallowing to upper epibathyal and to outer neritic depths is inferred.

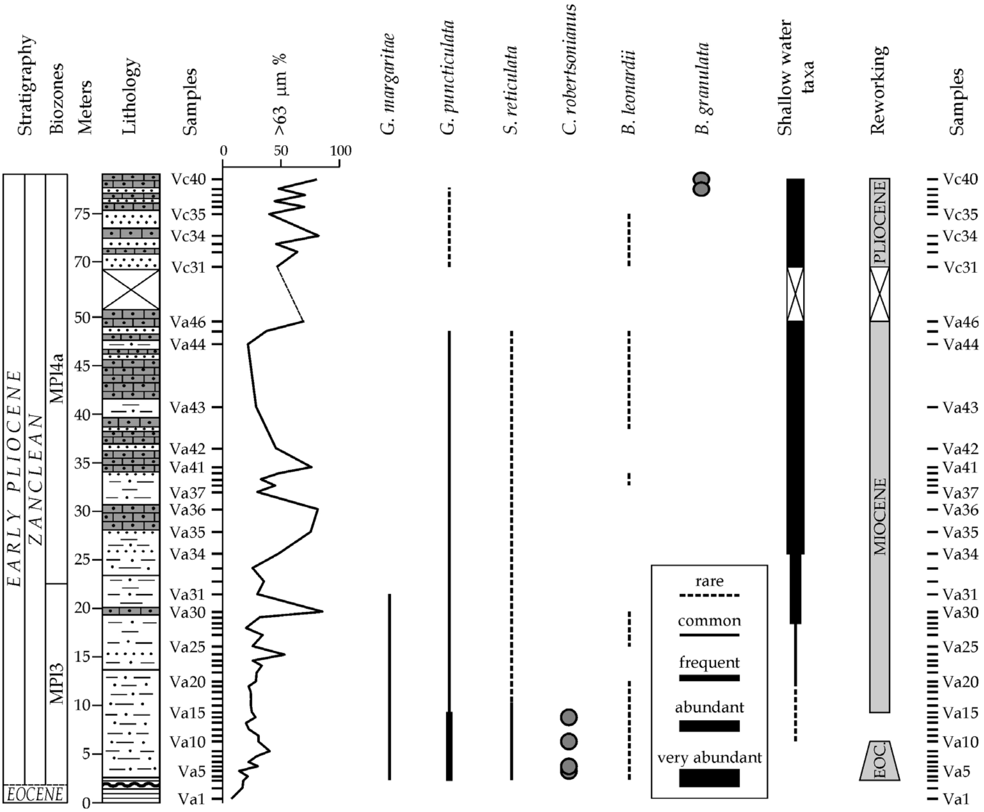

Fig. 4. Chronostratigraphic synthesis, lithological column, samples position, percentage variations of the grain sized > 63 µm fraction, qualitatitive distribution and frequency of planktonic (*Globorotalia margaritae* and *Globorotalia puncticulata*) and benthic (*Siphonina reticulata, Cibicidoides robertsonianus*, *Bolivina leonardii, Buccella granulata* and Shallow water taxa) foraminiferal taxa, age and abundance of reworked specimens.

7.5 Comparison and correlations

Biostratigraphic and paleoenvironmental data provide tools for comparisons and correlations between the three previously discussed sections, useful for the recontruction of the regional geological history. Moreover, biostratigraphic and ecobiostratigraphic events allow detailed correlations between the Piemont area and Mediterranean area.

The Messinian/Zanclean boundary and the early Zanclean are well preserved at the Moncucco T. section. During the lowermost MPl1 Zone, the recognized biovents (the abundance peak of *Globigerina nepenthes*, the sinistral shift of *Neogloboquadrina acostaensis*, the *Sphaeroidinellopsis* spp. acme, the *Globorotalia scitula* dextral CO, and the re-immigration of the benthic species *Siphonina reticulata* and *Cibicidoides robertsonianus*) occurred exactly in the same order and in similar stratigraphic position as in the Mediterranean reference successions (Di Stefano et al., 1996; Iaccarino et al., 1999a; 1999b; Spezzaferri et al., 1998).

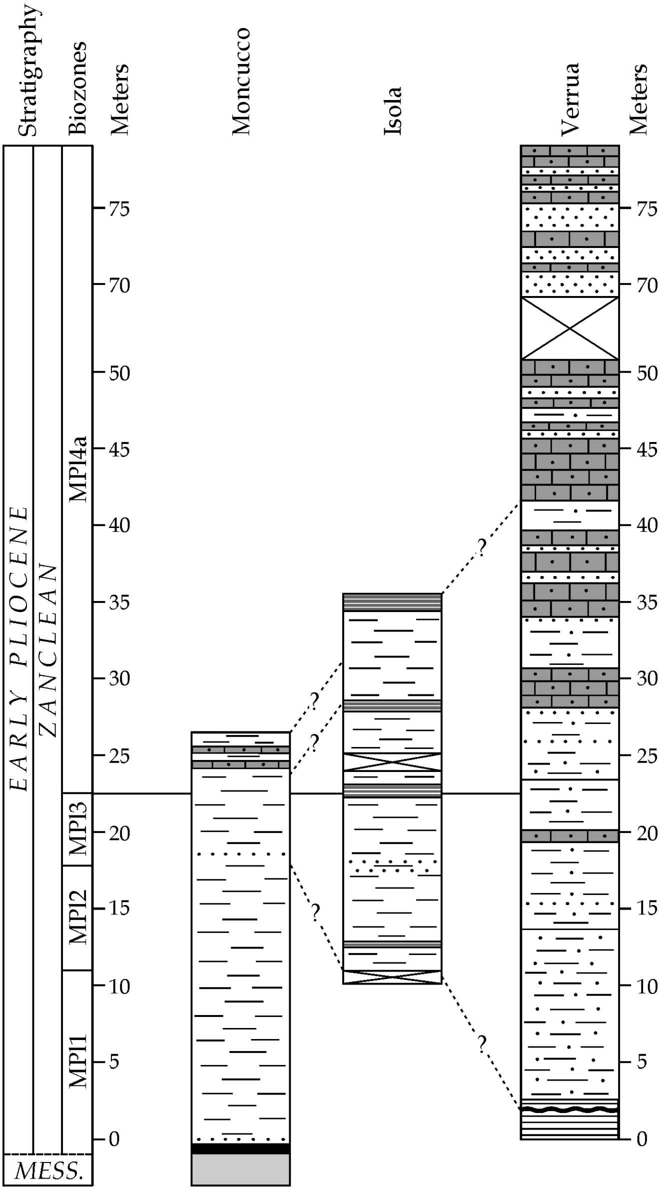

Fig. 5. Tentative correlation between the Moncucco T., Isola d'Asti and Verrua S. sections.

The paleodepths in the upper epibathyal zone, initially to about 500 m, then fastly deepening to about 800-1000 m, suggested in the Verrua S. section by the benthic foraminiferal assemblages during the MPl1 and MPl2 Zones, are similar to those proposed for the coeval interval of the Rossello Composite Section (Van Couvering et al., 2000) and of the Capo Rossello area (Barra et al., 1998; Sgarrella et al., 1997; 1999). All these data document deep open sea conditions in the Northwestern Italy in the early Zanclean, and very wide connections with the Mediterranean basin, that can explain the inferred synchronous record of the flooding event at the base of the Zanclean, as well as the following planktonic and benthic foraminifer bioevents.

Whereas the lower Zanclean is preserved only in the Moncucco T section, the MPl3 and MPl4a Zones are well documented in all the studied sections. Biostratigraphic data, provided by the occurrence of the zonal markers (*G. margaritae* and *G. puncticulata*), and in particular by the *G. puncticulata* FO, marking the MPl3/MPl4a boundary, are the main tools for correlation of the studied sections. A tentative correlation between the interval encompassing the MPl3 and MPl4a Zones (upper Moncucco T. section, Isola d'Asti and Verrua S. sections) is here proposed (Fig. 5).

Other elements for ecobiostratigraphic correlations and for the paleonvironmental recontruction are provided by benthic foraminifer distribution and frequencies. Marly clays pertaining to the MPl3 and MPl4a Zones in the Moncucco T. and Isola d'Asti sections, and to the MPl3 Zone at Verrua S., are inferred to be deposited at very similar epibathyal depths, on the basis of their similar planktonic (rare to frequent globorotalias, mainly *G. puncticulata*, most frequent at Isola d'Asti) and benthic assemblages (common epibathyal taxa, such as *P. ariminensis, S. reticulata, U. peregrina, U. rutila*). At Moncucco T., laminated layers were not evident, but in the MPl4a Zone the frequency peak of the infaunal, low-oxygen tolerant *Brizalina* spp. suggests a brief interval of disaerobic bottom condition, immediately below the increase in abundance of shallow water taxa, and the deposition of the first calcarenitic layer, both indicative of active transport from the inner shelf. At Isola d'Asti, four laminated layers are interbedded to the massive marly clays and testify repeated episodes of dysoxia at the sea bottom. All layers are characterized by nearly oligotypic benthic assemblages, dominated by the deep infaunal *Brizalina* spp. and by the rareness or absence of shallow water displaced forms. The first sapropelitic level occurs in the MPl3 Zone, the others are in coincidence with the *G. margaritae* LCO, marking the MPl3/MPl4a boundary, and in the MPL4a Zone. The third sapropelitic layer of Isola d'Asti could be correlated to the *Brizalina* spp. peak at Moncucco T. (Fig. 5), on the basis of their stratigraphic position and foraminiferal composition. In the same time interval, bottoms influenced by stagnant episodes are better documented at Isola d'Asti than at Moncucco T. In this latter succession, turbidic accumulation from shelfal areas appears to have been subsequent to the dysoxic episode (*Brizalina* spp. peak). Roveri & Taviani (2003) suggested a close relationship between the shallow water calcarenitic bodies, and the deep water sapropels, widespread in Northern Apennine (Castell'Arquato Basin) and Sicily (Belice and Caltanissetta Basins) upper Pliocene. Calcarenite and sapropel clusters appeared together and became more developed starting from 3.1 Ma. Roveri & Taviani (2003) proposed that the calcarenite and sapropel clusters formation were driven by periodical changes in orbital parameters and directly linked to the cooling trend culminating in the onset of the Northern Hemisphere glaciation. The authors left open the question if calcarenites and sapropels developed in opposite phases of a same climatic cycle or were synchronous. Data from the Moncucco T. and Isola d'Asti sections document very low or nearly absent downslope trasport of shallow water material during the sapropels deposition. Therefore, an opposite, diachronous relation between the two lithologies is here tentatively proposed.

Coarsening upward sediments and increasing frequence of turbiditic episodes characterize the Verrua S. section, nearly coeval to the Isola d'Asti section, also encompassing the MPl3/MPl4a Zones. At Verrua S., a deep epibathyal setting, similar to that inferred at Moncucco T. and Isola d'Asti, can be suggested only for the lower part of the section, dated to the MPl3 Zone, on the basis of the total benthic assemblage, of the occurrence of common to frequent *G. margaritae* and *G. puncticulata* and of rare deep benthic taxa (*S. reticulata* and *C. robertsonianus*). During the MPl4a zone, the basin shallowing is more evident at Verrua S. than in the other sites and the upper silty layers are inferred to have been deposited in the outer neritic zone. Peculiar characteristics of the Verrua S. section are the common to abundant terrigenous debris, the high amount of reworked foraminiferal tests, of Upper Eocene age in the lowermost part of the section, of Miocene to Pliocene age upwards and the progressively dominant calcarenitic layers. All these features document a depositional setting on the upper slope to the shelf margin, rather near to the inner shelf or to emerged areas, sources of the reworked specimens, just during the MPl3 Zone. Turbiditic episodes became more frequent during the MPl4a Zone and high amounts of terrigenous and biogenic debris of inner shelf source were accumulated on the seafloor. As a consequence, the Verrua S. succession could represent a more marginal counterpart of the deeper, open sea Moncucco T. and Isola d'Asti deposits. The tectonic activity of the area, where a succession of Apennine affinity (Monferrato) was translated and is separated by transpressive faults by the Alpine affinity Turin Hill (Piana & Polino, 1995), also favoured the turbidites accumulation.

8. Conclusions

Recent biostratigraphical and ecobiostratigraphical studies on Pliocene foraminiferal assemblages of Piedmont (Northwestern Italy) provide results concerning both correlations at the Mediterranean scale and applications to the regional tectonic and paleoenvironmental evolution.

In the Northwestern sector of the Pliocene Mediterranean basin, data from the Moncucco T. and Isola d'Asti sections document open-sea bottoms at similar depths than in the Southern Mediterranean areas. Foraminiferal biovents registered in the Piedmont sections and in the reference on-land or deep sea successions are inferred to be isochronous in the MPl1 Zone (the sinistral shift of *Neogloboquadrina acostaensis*, the *Sphaeroidinellopsis* spp. acme, etc.) up to the MPl3 Zone (progressive disappearance of deep benthic taxa) (Iaccarino et al., 1999a; Pierre et., 2006; Sgarrella et al., 1999; Spezzaferri et al., 1998, among others).

At a regional scale, the described sections can be correlated to the MPl3/MPl4a interval and represent different but related depositional settings: epibathyal well oxygenated bottoms in most of the Moncucco T. succession, similar epibathyal bottoms, but registering dysaerobic conditions and sapropelitic deposition at Isola d'Asti, and a more marginal setting, affected by turbidic transport from the inner shelf at Verrua S.

Moreover, biostratigraphic and paleoenvironmental data on epibathyal deposition up to the MPl4a Zone in the Turin Hill area, where the Moncucco T. section is located, provide data on a younger than Zanclean uplift of the sector and enlight the tectonical evolution of this sector, strongly related to the Alps and Northern Apennines uplift.

Data from the Moncucco T. and Isola d'Asti succession suggest an opposite correlation between laminated, sapropelitic layers, in which material from shallow waters is nearly absent, and calcarenitic layers, composed by terrigenous and biogenic debris of shelfal origin.

Nevertheless, this hypothesis needs to be verified by further researches, that should be extended to other Piedmont and Northern Apennines successions.

High resolution, integrated studies are also in progress in the central part of Piedmont to improve the biostratigraphic data and to verify the hypothesis of a stratigraphical gap between the MPl3/MPl4a Zones and its possible relationship with erosional surfaces.

9. Taxonomic list of cited taxa

9.1 Planktonic foraminifers

Globigerina bulloides d'Orbigny, 1826
Globigerina (Globoturborotalita) apertura Cushman, 1918
Globigerina (Globoturborotalita) decoraperta Takayanagi & Saito, 1962
Globigerina nepenthes Todd, 1957
Globigerinella obesa (Bolli, 1957) (= *Globorotalia obesa* Bolli)
Globigerinoides elongatus (d'Orbigny, 1826) (= *Globigerina elongata* d'Orbigny)
Globigerinoides extremus Bolli & Bermudez, 1965 (= *Globigerinoides obliquus extremus* Bolli & Bermudez)
Globigerinoides obliquus Bolli, 1957 (= *Globigerinoides obliquus obliquus* Bolli)
Globorotalia aemiliana Colalongo & Sartoni, 1967
Globorotalia bononiensis Dondi, 1962
Globorotalia crassaformis (Galloway & Wissler, 1927) (= *Globigerina crassaformis* Galloway & Wissler)
Globorotalia crassula Cushman, Stewart & Stewart, 1930
Globorotalia margaritae Bolli & Bermudez, 1965
Globorotalia margaritae evoluta Cita, 1973
Globorotalia margaritae primitiva Cita, 1973
Globorotalia praemargaritae Catalano & Sprovieri, 1969
Globorotalia puncticulata (Deshayes, 1832) (= *Globigerina puncticulata* Deshayes)
Globorotalia puncticulata padana Dondi & Papetti, 1968
Globorotalia scitula (Brady, 1882) (= *Pulvinulina scitula* Brady)
Neogloboquadrina acostaensis (Blow, 1959) (= *Globorotalia acostaensis* Blow)
Neogloboquadrina atlantica (Berggren, 1972) (= *Globigerina atlantica* Berggren)
Orbulina universa d'Orbigny, 1839
Sphaeroidinellopsis subdehiscens Blow, 1969

9.2 Benthic foraminifers

Ammonia beccarii (Linnaeus, 1758) (= *Nautilus beccarii* Linnaeus)
Anomalinoides helicinus (Costa, 1857) (= *Nonionina helicina* Costa)
Bolivina leonardii Accordi & Selmi, 1952
Bolivina placentina Zanmatti, 1957
Brizalina aenaeriensis Costa, 1856

Brizalina dilatata (Reuss, 1850) (*Bolivina dilatata* Reuss)
Brizalina spathulata (Williamson, 1858) (= *Textularia variabilis spathulata* Williamson)
Buccella granulata (Di Napoli, 1952) (= *Eponides frigidus granulatus* Di Napoli)
Bulimina minima Tedeschi & Zanmatti, 1957 = *Bulimina aculeata minima* Tedeschi & Zanmatti
Cassidulina carinata (Silvestri, 1896) (= *Cassidulina laevigata carinata* Silvestri)
Cibicides lobatulus (Walker & Jacob, 1798) (= *Nautilus lobatulus* Walker & Jacob
Cibicidoides pseudoungerianus (Cushman, 1922) (= *Truncatulina pseudoungeriana* Cushman)
Cibicidoides robertsonianus (Brady, 1884) (= *Truncatulina robertsoniana* Brady)
Elphidium crispum (Linnaeus, 1758) (= *Nautilus crispus* Linnaeus)
Fursenkoina schreibersiana (Czjzek, 1848) (= *Virgulina schreibersiana* Czjzek)
Globobulimina affinis (d'Orbigny, 1839) (= *Bulimina affinis* d'Orbigny)
Hoeglundina elegans (d'Orbigny, 1826) (= *Rotalia elegans* d'Orbigny)
Neoconorbina terquemi (Rzehak, 1888) (= *Discorbina terquemi* Rzehak)
Planulina ariminensis d'Orbigny, 1826
Rosalina globularis d'Orbigny, 1826
Siphonina reticulata (Czjzek, 1848) (= *Rotalina reticulata* Czjzek)
Stainforthia complanata (Egger, 1893) (= *Virgulina schreibersiana complanata* Egger)
Uvigerina peregrina Cushman, 1923
Uvigerina rutila Cushman & Todd, 1941

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