INTRODUCTION

The Monte Mario succession has been studied by various authors since the end of the 19th century due to its structural and stratigraphic characteristics. The earliest researchers highlighted the regional importance of this site, which has all of the features of the Neogene succession of central Italian basins (Brocchi, 1820; Ponzi, 1872; Blanc et al., 1953). The international scientific value of the “Monte Mario section” was permanently recognised at the 18th IGC in London, 1948, which established this site as one of the four most

RIASSUNTO - [Le associazioni a foraminiferi del Plio-Pleistocene del sito di Monte Mario (Roma)] - I lavori per la costruzione della Galleria “Giovanni XXIII” che attraversa tutto l’alto strutturale di Monte Mario, hanno permesso una nuova campionatura e quindi la possibilità di rivedere, nella sua totalità, tutta la successione di questo sito storicamente noto per la stratigrafia plio/pleistocenica dell’area laziale. Sebbene lo studio faccia parte di una ricerca multidisciplinare più ampia che ha coinvolto più aspetti della geologia, dalla paleontologia al paleomagnetismo, qui vengono presentati nuovi dati di carattere paleoambientale e stratigrafico evidenziati dall’analisi qualitativa e quantitativa condotta sulle associazioni a foraminiferi.

Da un punto di vista bio e cronostratigrafico la parte basale della successione (Formazione di Monte Vaticano) è attribuibile allo Zancleano superiore, Zona a Globorotalia puncticulata. La presenza di livelli ricchi di Dentoglobigerina altispira altispira, riconosciuti nell’area laziale al top dello Zancleano, permettono quindi una più precisa collocazione cronostratigrafica di questi sedimenti che trova conferma dai dati sulle associazioni a nanoplankton calcarea. La parte superiore della successione (Formazione di Monte Mario) comprende cinque membri ed è stata attribuita interamente al Pleistocene inferiore, Calabrian - sottopiano Santerniano - per la presenza di Bulimina etnea.

Da un punto di vista paleoecologico, l’utilizzo dell’analisi quantitativa e di alcuni indici quali quello di diversità, rapporto plankton/benthos, percentuali dei maggiori taxa infanuali ed ossifilici, ha permesso di effettuare alcune considerazioni di carattere paleoambientale e paleoclimatico. I sedimenti pleistocenici sono caratterizzati da un ambiente profondo (bataile superiore) con acque calde, oligotrofiche e fondali ben ossigenati. I depositi pleistocenici sono invece contraddistinti da una maggiore variabilità ambientale dovuta all’effetto combinato della tettonica e dei cambiamenti climatici. Le condizioni di maggiore profondità si registrano in corrispondenza dei Limi di Farneto relativi ad un ambiente circolatorio superiore caratterizzato da acque fredde, con fondali ricchi di sostanza organica tendenti all’estravasazione. Ambiente di acque basse con copertura vegetale e quindi condizioni più ossigenate si verificano dalle Sabbie grigie con “panchina”. Il trend regressivo che caratterizza tali sedimenti è marcato dall’instaurarsi di ambienti sempre più marginali (laguna, laguna salmastra) fino al passaggio con il continentale (Sabbie gialle con intercalazioni siltose). Alla base dell’ultimo membro (Argille e sabbie con Cerastoderma) si registra un breve episodio di ambiente di acque basse franamente marine, rapidamente sostituito verso l’alto da ambienti transizionali, caratterizzati da associazioni tendenti all’oligotopia ad evidente influenza salmastra, indicativi di una fase di avanzata progradazione della parte superiore della Formazione di Monte Mario.
significant sections for geological, stratigraphical and palaeoenvironmental studies of the Plio/Pleistocene boundary.

At regional level, three Plio-Pleistocene sedimentary cycles characterise the Tuscany and Latium successions (Barberi et al., 1994). The first cycle spans from the Sphaeroidinellopsis seminulina s.l. to the Globorotalia puncticulata Zone and is truncated by deposits related to the Globorotalia aemiliana Zone (second cycle). The third cycle occurred in the lower part of the Early Pleistocene (Ambrosetti & Bonadonna, 1967; Bonadonna, 1968; Conato et al., 1980; Marra et al., 1995). At the Monte Mario site, the last cycle lies directly on Early Pliocene deposits (first cycle; Cosentino et al., 2009); the unconformity separating the Plio-Pleistocene deposits is related to the “Acquatraversa” erosional phase and is connected to the sea level drop that resulted from both tectonic uplift and glacio-eustatic changes. Since the Middle Pleistocene, a regressive trend occurred in the Rome area and shifted the Tyrrenian coast from Rome to its present position (Malatesta, 1978; Milli, 1997; Florindo et al., 2007).

Previous foraminiferal studies based on data collected on outcrops and cores only partially described the chronostratigraphic and palaeoenvironmental evolution of the succession in the Monte Mario area (Marra et al., 1995; Bergamin et al., 2000). Tunnelling for the “Giovanni XXIII” gallery by the Astaldi S.p.A. presented the opportunity to continuously sample the entire Monte Mario hill succession. This multidisciplinary study encompasses palaeontological (ostracods, nannoplankton and foraminifers), palaeomagnetic and structural analyses (Cosentino et al., 2009), whereas the current paper describes the main foraminiferal fauna results.

The aim of this paper is to provide a detailed description of the foraminiferal assemblages present at the historical Monte Mario site as well as the most significant taxa association, which are illustrated in four plates and described according to their age and stratigraphic position. For the chronostratigraphic and geological framework of this site, including palaeomagnetic, tectonic, and sequence stratigraphical reconstruction, we refer to Cosentino et al. (2009).

**STRATIGRAPHY AND LITHOLOGY**

The succession includes two lithological formations: Monte Vaticano and Monte Mario. These formations are separated by a sharp unconformity that was identified by

![Fig. 1 - Lithological, chronostratigraphical and palaeoeccological scheme of Monte Mario succession.](image-url)
Blanc (1955) as the “Acquatraversa erosional phase” (Bonadonna, 1968). The Monte Vaticano Formation is composed mainly of blue-grey marls with regular intercalations of grey sands (“Marne Vaticane” Auct.). These sediments are attributed to the Lower Pliocene, Late Zanclean, Globorotalia punculatula Zone (Iaccarino, 1985) based on the presence of the marker species.

The unconformity includes a hiatus ranging from the Middle Pliocene to the basal part of the Pleistocene (Calabrian - Santernian) and is marked by a glauconite-rich layer (the basal part of the Farneto silts).

The Monte Mario Formation is subdivided into five lithological members (Fig. 1): Farneto silts, Yellow sands with “panchina,” Yellow sands with silty intercalations, and Clays and Cerastoderma-bearing sands (Cosentino et al., 2009). The basal member consists of about 8 m of sandy clays and clays with frequent peaty and oxidised levels (Sabbie argillose grigie ad Arctica islandica by Bonadonna, 1968; Limi di Farneto by Marra et al., 1993). The second member consists of a 3 m-thick, fossiliferous, medium-coarse-grained grey sands (Sabbie argillose grigie ad Arctica islandica by Bonadonna, 1968). The third member consists of 18 m of medium-fine-grained yellow sands with rare gravel intercalations. These sediments are characterised by cross-stratification, which is typical of a littoral marine environment (Sabbie gialle marine di Monte Mario by Bonadonna, 1968). The fourth member comprises 3 to 10 m-thick beds of massive, medium-coarse-grained yellow sands (Yellow sands with silty intercalations by Cosentino et al., 2009). The last member includes 12 m of clays, silty clays, silts and sands that, in their upper part, are thinly bedded and contain the intertidal and estuarine Cerastoderma lamarcki (Clays and Cerastoderma-bearing sands, Cosentino et al., 2009).

On the whole, this formation was attributed to the Lower Pleistocene, Calabrian stage, Santernian substage, Globigerina cariacoensis Zone because Bulimina etnea is present since the basal part of the section.

**MATERIALS AND METHODS**

Foraminiferal analyses were carried out on 41 samples collected from the “Giovanni XXIII” tunnel, including four samples from the Monte Vaticano Fm., seven samples from the Farneto silts Member, four samples from the Grey sands with Arctica islandica, nine samples from the Yellow sands with “panchina” Member, six samples from the Yellow sands with silty intercalations Member and eleven samples from the Clays and Cerastoderma-bearing sands Member (Fig. 1).

Sediment was washed through 63 and 125 µm mesh sieves. The finest fraction was subjected to qualitative analysis; coarser fraction was considered for quantitative analysis and was split into aliquots containing at least 300 specimens. Of the sediment samples, 28 contained sufficient foraminiferal fauna for quantitative analysis, 5 were barren and 8 contained very scarce foraminifera. The homogeneity of the assemblages allowed assessing the mean percentages of single taxa, which facilitated an overview of the assemblage composition and the immediate comparison among the different members. The mean percentages of single species were calculated separately for planktonic and benthic assemblages and are summarised in the tables. The assemblages were analyzed to identify the taxa yielding the highest percentage values. The generic attribution of benthic taxa follows Loeblich & Tappan (1987); species and their ecological characteristics were mainly determined based on previous studies of the Mediterranean benthic species (Cimerman & Langer, 1991; Sgarrella & Moncharmont-Zei, 1993). Information on the planktonic foraminifers ecological preferences and stratigraphic distribution were evaluated by comparison with similar studies carried out in the Mediterranean area (Iaccarino, 1985; Hemleben et al., 1989; Iaccarino et al., 2007).

Palaeobathymetric considerations were assessed based on the ecological characteristics of the single species and the %P [(P/P+B) %] (Van der Zwaan et al., 1990). Species diversity was described using the α-index (Fishier et al., 1943), which reliably accounts for rare species and their ecological characteristics were mainly determined based on previous studies of the Mediterranean benthic species (Cimerman & Langer, 1991; Sgarrella & Moncharmont-Zei, 1993). Information on the planktonic foraminifers ecological preferences and stratigraphic distribution were evaluated by comparison with similar studies carried out in the Mediterranean area (Iaccarino, 1985; Hemleben et al., 1989; Iaccarino et al., 2007).

**Table 1** - List of the oxyphilic and inbenthic taxa according to previous studies (i.e., Corliss, 1985; Corliss & Chen, 1988; Murray, 1991; Kairo, 1994, 1999; De Stiger et al., 1998; Den Dulk et al., 2000).
species and increases only slightly with sample size. The α-index assumes that the number of individuals of each species follows a logarithmic series (Murray, 1991). The Shannon index, which accounts for both the abundance and the evenness of species, was also calculated in order to supplement the information given by the α-index (Murray, 1991). Diversity indices were calculated by means of the PAST (PAleontological STatistics) data analysis package (ver. 1.38). For each sample, the frequencies of inbenthic and oxyphilic taxa (Báldi & Hohenegger, 2008) were calculated in order to evaluate bottom water oxygenation. Inbenthic and oxyphilic taxa are listed in Table 1 according to the life strategies reported in previous studies (i.e., Corliss, 1985; Corliss & Chen, 1988; Murray, 1991; Kaiho, 1994, 1999; De Stiger et al., 1998; Den Dulk et al., 2000).

Digital images of selected species were acquired by Scanning Electron Microscope (SEM, FEI Quanta 400) at the Laboratory of Electron Microscopy and Microanalysis, Earth Science Department, University “La Sapienza,” Rome.

The studied samples are housed at the Micropalaeontology Laboratory of the Earth Science Department of the University “La Sapienza” of Rome.

RESULTS - FORAMINIFERAL ASSEMBLAGES

**MONTE VATICANO FORMATION (SAMPLES PNOI22, PNOI23, PNOI14, PNOI18; FIG. 1)**

PLANULINA ARIMINENSIS, LENTICULINA spp., UVIGERINA spp., AND HIGH P/P+B VALUE ASSEMBLAGE

The foraminiferal assemblage of the Monte Vaticano Formation is abundant (80-90%) and very well preserved (Tab. 2). Planktonic taxa (24 species) are dominant, but even the benthic assemblage is well diversified (76 species). In the grey sands locally intercalated in the marls, foraminifers are scarce and specimens are badly preserved.

Plankton is mainly represented by the following species: Globorotalia gr. puncticulata, Globigerina bulloides, Globigerina praecalida, Globigerina falconensis, Globigerinella siphonifera, Globigerinoides trilobus, Globigerinoides sacculifer, Globigerinoides gr. obliquus, Globigerinida glutinata, Globoturborotalia aperture, Sphaeroidinellopsis seminulina and Orbulina universa. Sample PNOI14 is characterised by common Dentoglobigerina altispira altispira (11.76%), and shows a composition very similar to the uppermost Zanclean sediments observed at the Latium coastal site Lido delle Sirene, between Tor Caldara and Anzio (Carboni & Di Bella, 1997). This level also records a strong increase in S. seminulina (10.46%).

Sample PNOI23 is very rich in Globigerinids. The most abundant are Globigerina bulloides (32%) and Globigerina praecalida (11%) both characterised by a large intraspecific variability. Notably, some Globigerina praecalida show a tendency towards elongation of the last chambers, leading to Globigerina affinis valida calida (Colaolongo & Sartoni, 1977) or Globigerina valida calida (Parker, 1962). Moreover, specimens of Globigerina bulloides show a greater number of chambers (often five) in the last whorl and an open coiling, leading to Globigerina calabra (Pl. 2). The increase in cold-water mixed-layer species like G. bulloides (Rohling et al., 1993) is associated with a strong decrease of the genus Globigerinoides (2%), which typically represents warm, oligotrophic waters (Pujol & Vergnaud-Grazzini, 1995; Hemleben et al., 1989). Frequent species of O. universa indicate deep waters and mixed-layer conditions (Rohling et al., 1993).

The benthic assemblage is dominated by Planulina ariminensis (7.48%), Lenticulina spp. (11.39%, L. cultrata, L. echinata, L. rotulata), and Uvigerina spp. (5.03%, U. peregrina, U. rutula). Living counterpart taxa occupy the bathyal and/or lower circalittoral environments and they are associated with other typical

<table>
<thead>
<tr>
<th>Monto Vaticano Formation</th>
<th>Upper bathyal - P. ariminensis, Lenticulina spp., Uvigerina spp., high value of P/P+B assemblage</th>
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<tr>
<td><strong>Bartho</strong></td>
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<td>Ostracodella seminulina</td>
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Tab. 2 - Mean percentages of each species, %P [(P/P+B)%], and diversity indices in the Monte Vaticano Formation.
cricallitoral taxa, including the following: Hoeglundina elegans, Anomalinoidea helicinus, Sphaeroidina bulloides, Pyrgo depressa, Siphonina reticulata, Dentalina leguminiformis, Globobulimina pyrula, Bolivina punctata, Bigerinina nodosaria, Stilostomella spp., Plectofrondicularia semicostata, and Lagena spp. The benthic assemblage is characterised by dominant oxyphilic taxa (35.57%) and high diversity values (α-index 29.31; H 3.22), which suggest oligotrophic, well-oxygenated conditions at the bottom waters.

The high percentage of plankton (83.89%) and the circallitoral benthic assemblage indicate an upper epibathyal environment (300-350 m depth).

The presence of Globorotalia puncticulata, which is always present and abundant (10.86%), allows these sediments to be attributed to the Early Pliocene, Zanclean Stage, Globorotalia puncticulata Zone.

**MONTE MARIO FORMATION**

Farneto silts Member (samples PNOI19, PNOI29, PNOI11, PNOI21, PNOI24, PNOI26, PNOI27; Fig. 1)

**BULIMINA spp., CASSIDULINA CARI NATA AND CRIBROELPHIDIUM DECIPIENS ASSEMBLAGE**

This foraminiferal assemblage is abundant and well preserved in all samples of this member (Tab. 3). Planktonic taxa (11 species) are scarce (10.36% mean value of the total assemblage), and the benthic fraction is abundant and well diversified (91 species). This assemblage is characterised by dominant Bulimina fusiformis, Bulimina elegans marginata, Bulimina marginita, Bolivina spp. and Cassidulina carinata along with frequent C. decipiens (11.99%), Elphidium spp. (E. granosum, E. macellum) and Textularia spp. (mainly T. bocki). On the whole, the number of inbenthic taxa (38.48%) exceeds oxyphilic taxa (18.56%); the diversity degree is high (α-index 15.67; H 3.10), although it presents a decrease in comparison to the Marne Vaticano Formation assemblage. The planktonic assemblage is represented by rare specimens of Globigerinoides ruber, Globigerinoides trilobus, Globigerinoides elongatus, Globorotalia inflata, Globorotalia oscitans, Globigerina falcenensis, Globigerina bulloides and Turborotali a quinqueloba. The low frequencies of planktonic taxa and the abundance of infralittoral species indicate a generally shallow-water environment (infrarlittoral, 40-30 m depth), although some depth fluctuations are highlighted (upper circallitoral, 70-75 m depth).

At the base of the Farneto silts (PNOI11, PNOI19, PMOI29), the increase of typical infralittoral species (Elphidium spp., Ammonia beccarii, Textularia spp., Lobatula lobatula, and Nonion fabum) in combination with reduced plankton content (<5%) indicates a shallow-water environment (infrarlittoral). In samples PNOI21, PNOI24 and PNOI26, slightly deeper, infra/circallitoral transition and/or upper circallitoral conditions are recorded by increased Bulinimina (14.75%), C. carinata (13.01%), Bolivinidae (6.77%) and typical circallitoral species like Valvulineria bradyana and M. barleeanum.

In the upper part of the member (PNOI27), an increase in shallow-water species (Quinqueloculina spp., Triloculina spp., Adelosina spp., Rosalina spp., Lobatula lobatula, Asterigerinata spp.) indicates a bathymetric decrease. Significantly increased oxyphilic and epiphytic taxa suggest a bottom covered with vegetation.

From the bio-chronostratigraphic perspective, the presence of Bulimina etnea in the lowermost sample (PNOI19) allows these sediments to be attributed to the Early Pliocene, Calabrian Stage, Santernian substage (Globigerina cariocensis Zone).

**Table 3 - Mean percentages of each species, %P [(P/P+B)%], and diversity indices in the Monte Mario Formation: Farneto silts Member.**
Grey sands with Arctica islandica Member (samples PNOI30, PNOE9, RM6, PNOI44; Fig. 1)

**ELPHIDIUM spp., LOBATULA LOBATULA AND ASTERIGERINATA PLANORBIS ASSEMBLAGE**

The foraminiferan assemblage is similar to the assemblage of the Farneto silts Member (Tab. 4). Planktonic assemblage (14 taxa) displays low frequencies (11.00%) and is represented mainly by *Globigerinoides ruber* (41.71%), *Globigerina bulloides* (28.29%) and *Globorotalia inflata* (8.46%). The benthic assemblage dominates (80 taxa), and is characterised by high frequencies of infralittoral taxa (*Elphidium* spp. 15.75%, *A. planorbis* 11.90%, *L. lobatula* 12.27%, *Ammonia beccarii* 6.60%, *Nonion fabum* mean 5.16%). In sample PNOI45 abundant species with an epiphytic mode of life (keeled *Elphidium*, *Asterigerinata planorbis*, *Lobatula lobatula*, *Neoconorbina orbicularis*, *P. mediterranei*, *miliolids*) are observed. The highest infralittoral oxyphilic percentage (59.49%) and degree of diversity (α-index 16.34; H 3.31) of all of the M. Mario Formation foraminiferal fauna, suggest an infralittoral environment with a well-oxygenated and vegetated bottom (about 30 m depth). The inbenthic taxa are very scarce (10.25%) and represented mainly by *B. frigida granulata*, *C. carinata*, *B. marginata* and *S. wrightii*.

The presence, always rare, of *Bulimina etnea* allows the assignment of these sediments to the Early Pleistocene, Santernian Stage (*Globigerina cariacoensis Zone*).

Yellow sands with “panchina” Member (samples RM7, PNOI45, PNOI33-PNOI38, PNOE40; Fig. 1)

This member is characterised by marked environmental variability and ranges from a normal marine infralittoral environment to a brackish/fresh-brackish lagoon and an upper shoreface-backshore environment (Tab. 5).
ELPHIDIUM SPP., AMMONIA SPP. AND LOBATULA LOBATULA ASSEMBLAGE

This assemblage occurs from the base of the member (RM7, PNOI45, PNOI33) and represents normal marine infralittoral conditions (about 30 m depth) based on the dominance of shallow-water taxa (mainly A. beccarii 8.61% and A. parkinsoniana 6.29%) and epiphytic species such as Elphidium spp. (E. adenium 17.88%, E. granosum 5.30%, E. macellum 3.31%, Cribroelphidium decipiens 5.96%), Asterigerinata planorbis (7.61%) and Lobatula lobatula (5.96%). Oxypelvic taxa are dominant (44.34%). Although species diversity is reduced, the value remains typical of normal marine shelf deposits (α-index 11.86, H 3.11). The benthic species (10.25%) are characterised by B. frigida granulata, C. carinata and H. depressula.

Planktonic foraminifers are very scarce (mean value 7.83% of the total assemblage) and are represented mainly by small-sized specimens (Globigerinoides ruber, G. trilobus, Globigerina bulloides, G. falconensis, N. pachyderma, Orbulina universa).

AMMONIA PARKINSONIANA, A. TEPIDA AND ELPHIDIUM GRANOSUM ASSEMBLAGE

This assemblage extends from PNOI34 to the top of the member and indicates a shallow trend and the development of marginal environments (<10 m depth). The foraminiferal assemblage shows an oligospecific feature according to the α-index and H values that are below 1. It is composed entirely of benthic, low-salinity-tolerant species (A. tepida 36.64%, A. parkinsoniana 52.33%, and E. granosum 11.03%). Oxypelvic species are absent. A similar association is recorded frequently in brackish lagoon settings in modern and in ancient deltaic sediments (Jorissen, 1988; Serandrei Barbero et al., 1997; Fiorini & Vaiani, 2001; Donnici & Serandrei Barbero, 2002).

A second brackish lagoon episode recorded at PNOI38 is followed by backshore sediments bearing rare mollusc fragments and reworked foraminiferal specimens (PNOI40).

Yellow sands with silty intercalations Member

(samples PNOE41, PNOE13, PNOE17, PNOE15, PNOE18, PNOE19; Fig. 1)

Microfauna is very scarce or totally absent in the sandy layers (PNOE17, 15 18, 19). Rare reworked and badly preserved specimens, indicating a backshore setting sporadically occur in the silty intercalations.

AMMONIA PARKINSONIANA, A. TEPIDA AND AUBYGNINA PERLUCIDA ASSEMBLAGE

This assemblage is recorded in the silty intercalations (PNOI41 and PNOE13) and is characterised by foraminiferal fauna like those in the Yellow sands with "panchina" Member (Tab. 6). It shows a low diversity value (α-index 1.11 and H 1.27) and is dominated by inbenthic and low-salinity-tolerant species such as A. parkinsoniana (47.30%) and A. tepida (31.30%). These species are associated with Aubygnina perludica,
Cribroelphidium decipiens and Haynesina depressula, which are generally common in lagoonal environments (Albani et al., 1998). Therefore, it can be assumed that these sediments record the development of a brackish lagoon that was confined in a backshore environment (0-2 m depth).

Clays and Cerastoderma-bearing sands Member (samples PNOI 46-PNOI48, PNOI50-PNOI57; Fig. 1)

**AMMONIA PARKINSONIANA, A. TEPIDA AND NONIONELLA TURGIDA ASSEMBLAGE**

This association is present from the base of the interval; its foraminiferal content indicates the reestablishment of a normal marine shallow-water environment (15-20 m depth). The foraminiferal assemblage is well preserved and diversified (Tab. 6, α-index 6.85 and H 2.43) and composed by shallow-water oxyphilic species (15.22%; Ammonia spp., Nonion fabum, Aubygyna perlucida, Elphidium spp.) associated with organic matter-tolerant taxa, mainly inbenthic species (3.30%), including Nonionella turgida, Brizalina aenariensis and Bulimina elongata (Sgarrella & Monchamont-Zei, 1993; Morigi et al., 2005).

**AMMONIA SPP. AND HAYNESINA SPP. ASSEMBLAGE**

From PNOI 50, the foraminiferal assemblage is marked by an increase in Ammonia parkinsoniana (53.00%) and Ammonia tepida (23.50%), which suggests greater inputs of fresh water and organic matter (Tab. 6). The sequence ends (PNOI56 - PNOI57) with a regressive trend; developing marginal and confined environments (0-2 m depth) are shown by the oligotopic associations according to the significant percentages of inbenthic taxa.

**EXPLANATION OF PLATE 1**

Foraminifers from Monte Vaticano Formation.

Fig. 1  - Lenticulina echinata (d’Orbigny): lateral view, sample PNOI23 (scale bar = 400 µm).
Fig. 2  - Lenticulina peregrina (Scwager): lateral view, sample PNOI18.
Fig. 3  - Lenticulina cultrata (de Montfort): lateral view, sample PNOI23.
Fig. 4  - Lenticulina rotulata (Lamarck): lateral view, sample PNOI22.
Fig. 5  - Marginulina costata (Batsch): lateral view, sample PNOI22.
Fig. 6  - Marginulinopsis cfr. nana (Costa): lateral view, sample PNOI22.
Fig. 7  - Valvulina pennatula (Batsch): lateral view, sample PNOI22.
Fig. 8  - Vaginulinopsis bononiensis (Fornasini): lateral view, sample PNOI22.
Fig. 9  - Astacolus crepidulus (Fichtel & Moll): lateral view, sample PNOI18.
Fig. 10 - Planularia auris (Defrance): lateral view, sample PNOI22.
Fig. 11 - Plectofrondicularia semicosta (Karrer): lateral view, sample PNOI22.
Fig. 12 - Stilostomella adolphina (d’Orbigny): lateral view, sample PNOI14.
Fig. 13 - Stilostomella hispida (d’Orbigny): lateral view, sample PNOI22.
Fig. 14 - Amphicoryna cfr. proxima (Silvestri): lateral view, sample PNOI14 (scale bar = 200 µm).
Fig. 15 - Bolivina leonardii Accordi & Selmi: lateral view, sample PNOI14.
Figs. 16-17 - Anomalinoides helicinus (Costa), sample PNOI23. 16- umbilical view. 17 - spiral view.
Figs. 18-19 - Anomalinoides ornatus (Costa), sample PNOI23. 13 - spiral view. 14 - umbilical view.
Figs. 20-21 - Cibicoides pseudoungerianus (Cushman), sample PNOI18. 20 - umbilical view. 21 - spiral view.
Figs. 22-23 - Cibicoides robertsonianus (Brady), sample PNOI18. 22 - umbilical view. 23 - spiral view.
Fig. 24 - Planulina ariminiensis d’Orbigny: spiral view, sample PNOI23.
Fig. 25 - Praeoglobulimina ovata (d’Orbigny): lateral view, sample PNOI22.
Fig. 26 - Uvigerina pygmaea (d’Orbigny): lateral view, sample PNOI22.
Fig. 27 - Bulimina costata d’Orbigny: lateral view, sample PNOI14.
Fig. 28 - Uvigerina peregrina Cushman: lateral view, sample PNOI14.
Fig. 29 - Uvigerina ratita Cushman & Todd: lateral view, sample PNOI22.
Figs. 30-31 - Siphonina reticulata (Czjzek), sample PNOI18. 30 - lateral view. 31 - lateral view.

Scale bar = 250 µm (unless reported differently).
L. Di Bella - Plio-Pleistocene foraminifers of the Monte Mario site

Pl. 1
such as *Haynesina germanica* (6.20%) that are typically tolerant of high organic matter and low oxygen content (Murray, 2006).

### BIOSTRATIGRAPHICAL CONSIDERATIONS

Based on the bio- and chronostratigraphic framework used in this study, the lower part of the Monte Mario section (Monte Vaticano Formation) is attributed to the Early Pliocene, Zanclean Stage, *Globorotalia puncuitculata* Zone according to the presence of *Globorotalia puncuitculata*. At regional level, these sediments belong to the first sedimentary cycle of the neoautochthonous Central Italian basins and, more precisely, could be correlated with the upper part of this sedimentary sequence (Barberi et al., 1994).

High frequencies of *G. puncuitculata padana* allow the upper part of the Monte Vaticano Formation to be attributed to the Zanclean Stage, confirming previous results based on nannoplankton data (NN16a nannofossil zone: Rio et al., 1990) specifically at 3.81-3.70 Ma (Cosentino et al., 2009). Moreover, the presence of *Dentoglobigerina altispira* represents a useful biostratigraphical proxy of regional value for the Zanclean Stage. Foraminiferal analyses highlight the presence of stratigraphic levels rich in *Globigerina* spp. and in *G. bulloides* and *G. praecalida* both showing large intraspecific variability. Two morphological trends are pointed out: *G. bulloides* morphotypes leading to *G. calabra* and *Globigerina praecalida* morphotypes leading to *G. calida*. Additional study on other Early Pliocene central Italian sites will attempt to enhance knowledge of the Pliocene Central Italy succession, which usually lacks common foraminifer markers.

Pleistocene sediments (Monte Mario Formation) belong entirely to the third cycle and directly overlie Pliocene deposits by means of an unconformity. The unconformity includes a *hiatus* of different temporal extension across the region; at the Monte Mario site, the gap ranges from about the Early Piaceznian to the Early Calabrian (about 2 Ma, Cosentino et al., 2009) and was induced by regional uplift.

The presence of *Bulimina etnea* at the base of the Monte Mario Formation (Farneto silts Member) allows assigning these sediments to the Santernian. Moreover, foraminifer assemblages enriched in Cassidulinidae and

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**EXPLANATION OF PLATE 2**

Foraminifers from Monte Vaticano Formation.

Figs. 1-2 - *Globigerina bulloides* d’Orbigny, sample PNOI23.
1 - umbilical view.
2 - umbilical view five-chambered morphotype.

Fig. 3 - *Globoturborotalita decoraperta* (Takayanagi & Saito): umbilical view, sample PNOI14.

Fig. 4 - *Globoturborotalita apertura* (Cushman): umbilical view, sample PNOI23.

Figs. 5-8 - *Globigerina gr. praecalida*, sample PNOI23.
5 - umbilical view elongated morphotype with five chambers in last whorl.
6 - spiral view.
7 - open umbilical morphotype.
8 - open umbilical morphotype.

Figs. 9-10 - *Globorotalia puncuitculata puncuitculata* (Deshayes), sample PNOI22.
9 - umbilical view, typical morphotype.
10 - umbilical view, *Globorotalia bononiensis* trend morphotype.

Figs. 11-13 - *Globorotalia puncuitculata padana* Dondi & Papetti, sample PNOI22.
11 - umbilical view.
12 - umbilical view.
13 - spiral view.

Fig. 14 - *Dentoglobigerina altispira altispira* Cushman & Jarvis: umbilical view, sample PNOI14.

Figs. 15-17 - *Globorotalia crassaformis* Galloway & Wissler, sample PNOI18.
15 - lateral view.
16 - umbilical view.
17 - umbilical view.

Fig. 18 - *Globigerina falconensis* Blow: umbilical view, sample PNOI18 (scale bar = 200 µm).

Fig. 19 - *Globigerinita glutinata* (Egger): morphotype with bulla covering the umbilical part, sample PNOI14.

Fig. 20 - *Globigerinoides sacculifer* (Brady): umbilical view, sample PNOI22.

Fig. 21 - *Globigerinoides elongatus* (d’Orbigny): umbilical view, sample PNOI14.

Fig. 22 - *Globigerinoides obliquus obliquus* Bolli: umbilical view, sample PNOI22.

Fig. 23 - *Globigerinoides trilobus* (Reuss): umbilical view, sample PNOI22.

Fig. 24 - *Sphaeroindelopsis seminulina* (Schwager), sample PNOI14: a) umbilical view, b) detail of the test, note the presence of nannoplankton specimens (*Gephyrocapsa* sp., *Helicospheara sellii*, *Pseudoemiliania lacunosa*) (scale bar = 15 µm).

Scale bar = 250 µm (unless reported differently).
Buliminidae, such as those recorded in the Farneto silts, are very common in Early Pleistocene (Santerian) sediments from Central Italian basins (Chiani-Tevere Formation). Therefore, similar palaeoenvironmental conditions developed at regional level at the beginning of the third cycle (Borzi et al., 1998; Girotti & Mancini, 2003). The absence of stratigraphic markers from Yellow sands with “panchina” Member to the top of the section, precludes a more precise biostratigraphic assignment. The attribution of the whole formation to the Santerian is possible according to the reconstruction based on sequence stratigraphy (Cosentino et al., 2009).

**PALAEOENVIRONMENTAL AND PALAEOCLIMATIC CONSIDERATIONS**

Microfaunal analysis of the Monte Mario succession (Monte Vaticano and Monte Mario formations) provides new and more detailed palaeoenvironmental and biostratigraphical constraints on the Plio-Pleistocene sequence in the urban area of Rome. Palaeoenvironmental conditions are deduced from the percentages of each taxa [(P/P+B)%], diversity indices, and inbenthic and oxyphilic species. In particular, data show that diversity indices correlate positively with oxyphilic taxa and negatively with inbenthic species. The planktonic fraction correlates well with the diversity indexes (Tab. 7).

Pliocene deposits (Monte Vaticano Formation) record high palaeo-depth (upper bathyal conditions), warm oligotrophic water (high diversity) and a well-oxygenated bottom (dominant oxyphilic taxa). They are consistent with isotopic stratigraphy, which records a subtropical climate for the Mediterranean basin from 5.3 to 3.3 Ma (Sprovieri, 1985). Globigerinids-rich levels coupled with decreased Globigerinoides spp. probably indicate changing palaeoceanographic conditions related to temperature and vertical circulation effects (nutrient content) of the cooling trend that characterised the upper part of the Early Pliocene (Rio et al., 1990; Shackleton et al., 1990; Hohenegger et al., 2008; Cosentino et al., 2009). This cooling trend could have accelerated the regressive trend caused by regional uplift (Barberi et al., 1994).

Pleistocene sediments (Monte Mario Formation) present a wide variety of environments controlled by sea...
L. Di Bella - Plio-Pleistocene foraminifers of the Monte Mario site

Pl. 3

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level oscillations due to the combined effects of tectonics and climate change. A first transgressive cycle ranges from the Farneto silts Member (upper circalittoral and infra/circalittoral transition) to the Yellow sands with “panchina” Member (backshore environment). Farneto silts represent the deepest Pleistocene environments and have an assemblage of Bulimina spp., Cassidulina carinata and Cribroelphidium decipiens that is indicative of an upper circalittoral environment. The high percentage of inbenthic species and the decrease in diversity index suggest a high productivity in the bottom waters leaning towards eutrophic conditions. The increases in Cassidulinidae and Buliminidae suggest a cooling trend; this trend is confirmed by the presence of the nordic guest Arctica islandica, which is recorded from the base of the Farneto silts to the Grey sands containing the Arctica islandica Member (Fig. 1). In particular, the occurrence of C. carinata which prefers cold and productive bottom-waters (Hald & Vorren, 1987; Mackensen & Hald, 1988), and of Bulimina spp. is in agreement with the fine grain-size sediments of this member (Jorissen, 1988). The remarkable decrease in water temperature may correlate

EXPLANATION OF PLATE 4

Foraminifers from Monte Mario Formation - Grey sands with Arctica islandica Member.

Tab. 7 - Summarizing table related to mean percentages of oxyphilic and inbenthic taxa, diversity indices and %P in each member and formation.

<table>
<thead>
<tr>
<th>Member</th>
<th>Marine Vaticane</th>
<th>Farneto silts</th>
<th>Grey sands Aiasiandica</th>
<th>Yellow sands with “panchina”</th>
<th>Yellow sands silty intercalations</th>
<th>Clays Cerast. sands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environments</td>
<td>Upper bathyal</td>
<td>Infra/circalittoral transition</td>
<td>Infraal</td>
<td>Brackish</td>
<td>Fresh - Brackish</td>
<td>Brackish</td>
</tr>
<tr>
<td>Plancton %</td>
<td>83.80</td>
<td>16.26</td>
<td>11.00</td>
<td>7.83</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxyphile taxa %</td>
<td>23.41</td>
<td>38.43</td>
<td>11.69</td>
<td>10.25</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Inbenthic taxa %</td>
<td>29.31</td>
<td>15.67</td>
<td>16.34</td>
<td>11.86</td>
<td>0.58</td>
<td>1.11</td>
</tr>
<tr>
<td>Fisher alpha</td>
<td>3.22</td>
<td>3.10</td>
<td>3.11</td>
<td>6.95</td>
<td>1.27</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Foraminifers from Monte Mario Formation - Grey sands with Arctica islandica Member.

Fig. 1 - Planorbulina mediterranensis d’Orbigny: unattached side, sample RM6.
Fig. 2 - Elphidium macellum (Fichtel & Moll): lateral view, sample RM6.
Fig. 3 - Elphidium incructum (Williamson): lateral view, sample RM7.
Fig. 4 - Elphidium crispum (Linnè): lateral view, sample PNOE9.
Fig. 5 - Sigmoilinita tenuis (Czjzek): lateral view, sample PNOI30 (scale bar = 50 µm).
Figs. 6-7 - Triloculina schreibertiana d’Orbigny, sample RM7.
6 - lateral view.
7 - face view.
Figs. 8-9 - Buccella frigida granulata (di Napoli), sample PNOE9.
8 - ventral view.
9 - spiral view.
Fig. 10 - Siphonaperta aspera (d’Orbigny): sample PNOE9.
Figs. 11-12 - Quinqueloculina cfr. disparilis d’Orbigny, sample RM6.
11 - face view.
12 - lateral view.
Fig. 13 - Quinqueloculina seminulum (Linnè): lateral view, sample RM6.

Foraminifers from Monte Mario Formation - Yellow sands with “panchina” Member, Yellow sands with silty intercalations Member and Clays and Cerastoderma-bearing sands Member.

Fig. 14 - Nonion fabum (d’Orbigny): lateral view, sample PNOI33.
Fig. 15 - Haynesina depressula (Walker & Jacob): lateral view, sample PNOI41 (scale bar = 100 µm).
Fig. 16 - Ammonia beccarini (Linnè): spiral view, sample RM5.
Fig. 17 - Ammonia tepida Cushman: ventral view, sample PNOI52.
Fig. 18 - Cancris auriculus (Fichtel & Moll): ventral view, sample RM5.
Figs. 19-20 - Asterigerinata planorbis (d’Orbigny), sample RM5.
19 - spiral view.
20 - ventral view.
Figs. 21-22 - Lobatula lobatula (Walker & Jacob), sample RM5.
21 - ventral view.
22 - spiral view.
Fig. 23 - Ammonia parkinsoniana (d’Orbigny): ventral view, sample PNOI50.
Figs. 24-25 - Rosalina bradyi Cushman, sample RM5.
24 - spiral view.
25 - ventral view.

Scale bar = 250 µm (unless reported differently).
L. Di Bella - Plio-Pleistocene foraminifers of the Monte Mario site

Pl. 4
with the MIS 58 glacial period and fits within the context of the regional cooling. The association of frequent *G. ruber*, which is commonly considered a warm-water, stratified and oligotrophic species (Hemleben, 1989; Pujol & Vernaud-Grazzini, 1995), with temperate and cool taxa such as *G. bulloides*, *T. quinqueloba*, *G. inflata* (Rohling et al., 1993) could reflect the influence of marked seasonality.

An oxygenated, shallow-water environment is recorded in the Grey sands with *Arctica islandica* Member (*Elphidium* spp., *Lobatula lobatula* and *Asterigerinata planorhis* assemblage), which contains the highest frequencies of oxyphic and epiphytic taxa. Widespread vegetated bottoms are recorded through the base of the Yellow sands with “panchina” Member (*Elphidium* spp., *Ammonia* spp. and *Lobatula lobatula* assemblage). The progressive disappearance of the northem *Arctica islandica* and the development of vegetated bottoms with frequent miliolids could be related to climate amelioration (MIS 57, Cosentino et al., 2009).

More marginal environments developed successively as the result of a shallowing trend of the sea-level. Lagoon/brackish lagoon environments characterised by oligospecific euryhaline foraminiferal assemblages (*Ammonia parkinsoniana*, *A. tepida* and *Elphidium granosum* assemblage) developed in the Yellow sands with silty intercalations Member (*Ammonia parkinsoniana*, *A. tepida* and *Aubignina perlucida* assemblage). Cosentino et al. (2009) attributed this sea-level drop to the following glacial phase MIS 56.

The second transgressive episode is recorded in the Clays and *Cerastoderma*-bearing sands Member and is marked, at the base of the member, by the reestablishment of normal marine infralittoral conditions (*Ammonia parkinsoniana*, *A. tepida* and *Nonionella turigida* assemblage) characterised by nutrient input and fresh-water influence. The slight sea level rise associated with warm ostracofuna (Faranda & Gliozi, 2008) could be related to MIS 55.

The top of the stratigraphic succession records a more confined brackish lagoon environment (*Ammonia* spp. and *Haynesina* spp. assemblage), indicating a progradational phase of the upper portion of the Monte Mario Formation (Cosentino et al., 2009).

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