

PALAEOENVIRONMENTAL EVOLUTION OF THE PLIO-PLEISTOCENE MONTE MARIO SUCCESSION (ROME, ITALY) INFERRED FROM OSTRACOD ASSEMBLAGES

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Abstract. The whole “classical” Monte Mario succession has been recovered through the excavation of the Giovanni XXIII tunnel inside the city of Rome (Italy). The succession has been sampled from the Zanclean Monte Vaticano Fm. to the Lower Pleistocene Monte Mario Fm. Well-preserved and diversified ostracod faunas have been recovered and the ostracod assemblages have been studied using community structure analyses and statistical multivariate analyses. The Monte Vaticano Fm. has been referred to a bathyal marine environment (300-350 m of depth), the most represented genera being *Kritbe*, *Parakritbe*, *Bairdoppilata* and *Cytherella*. The Monte Mario Fm. provided ostracod assemblages referable to littoral environments with *Cimbourila*, *Aurila*, *Costa*, *Carinocythereis*, *Leptocythere* and *Loxococoncha* as dominant taxa. Within the Monte Mario Fm., three marine shallowing-up sequences have been recognised, the last two recording marginal marine conditions with shallow depths and variable salinity (dominant *Cyprideis torosa*). Two cold-water episodes have been recognised within the basal Monte Mario Fm. characterised by the occurrence of *Arctica islandica* and, within the upper level, by the presence of the northern guests *Cytheropteron depressum*, *Bythocythere zetlandica*, *Paradoxostoma ensiforme* and *Paradoxostoma abbreviatum*.

Riassunto. Durante gli scavi per la costruzione del tunnel Giovanni XXIII all'interno della città di Roma è stata attraversata l'intera classica successione di Monte Mario. La successione è stata campionata dalla Formazione di Monte Vaticano (Zancleano p.p.) alla Formazione di Monte Mario (Pleistocene inferiore, Santerniano p.p.). I campioni esaminati hanno fornito ostracofaune abbondanti e ben conservate che sono state studiate con l'analisi sinecologica e l'analisi statistica multivariata. La Formazione di Monte Vaticano è stata riferita ad un ambiente marino batiale (300-350 m di profondità). I generi più rappresentati nei campioni provenienti da questa formazione sono *Kritbe*, *Parakritbe*,

Bairdoppilata e *Cytherella*. La Formazione di Monte Mario, invece, è stata riferita a un ambiente marino litorale (generi dominanti *Cimbourila*, *Aurila*, *Costa*, *Carinocythereis*, *Leptocythere* e *Loxococoncha*). All'interno di questa formazione sono stati riconosciuti tre cicli *shallowing-upwards*, gli ultimi due riferibili ad un ambiente marino marginale con acque profonde pochi metri e salinità variabile (dominanza di *Cyprideis torosa*). Inoltre, all'interno della Formazione di Monte Mario sono state riconosciute due pulsazioni climatiche fredde caratterizzate dalla presenza di due livelli ad *Arctica islandica*. In corrispondenza del secondo livello sono stati rinvenuti quattro ospiti freddi, *Cytheropteron depressum*, *Bythocythere zetlandica*, *Paradoxostoma ensiforme* e *Paradoxostoma abbreviatum*.

Introduction

The Monte Mario succession crops out inside the city of Rome and is one of the Early Pleistocene “classical” sites in the Mediterranean area. In 1948, the Stratigraphical Commission of the XVIII International Geological Congress (London) defined the beginning of the Quaternary in correspondence to the first climatic deterioration occurring in the Mediterranean area. The Monte Mario succession, together with another four sections in northern and central Italy [the Crostolo and Stirone sections (Emilia, northern Italy), the Santerno River section (Romagna, northern Italy), and the Vallebiaia section (Tuscany, central Italy)] became an important record of the Santernian stage (the first stage, or substage, of the Pleistocene according to Ruggieri et al. 1984).

The extensive exposures, which were visible during the 19th century, and the rich fossiliferous content

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(mainly molluscs and bryozoans) made the Monte Mario succession the object of several geological and palaeontological studies (Brocchi 1820; Ponzi 1872, 1875; Clerici 1886, 1896; Tuccimei 1887; Verri 1905, 1915; Cerulli Irelli 1905, 1907-1916). Those old works recognised in the area two different lithologies. The clays and muddy clays named “argille del Monte Vaticano” were referred to Tortonian, Messinian or Early Pliocene. Along the Monte Mario slopes, the sands named “sabbie grigie e gialle a *Cyprina islandica*” cropped out, unconformably overlying the “argille del Monte Vaticano” and referred to the Pliocene or Pleistocene. The “sabbie grigie e gialle a *Cyprina islandica*” were particularly fossiliferous in the lower portion and, among over 270 mollusc species recovered (Cerulli Irelli 1907-1916), there were the northern guests *Arctica islandica* (Linnaeus), *Cochlodesma praetenuae* (Pultney) and *Buccinum humphreysianum* Bennet (Malatesta & Zarlenga 1986). Due to the urbanisation of the city of Rome, the Monte Vaticano and Monte Mario outcrops were buried or destroyed. Only during the middle of the last century new data came into light thanks to several boreholes, and the scientific interest for these deposits was renewed (Blanc et al. 1953; Blanc 1955; Segre, 1967; Ambrosetti & Bonadonna 1967; Bonadonna 1968; Conato et al. 1980; Marra 1993; Marra et al. 1995; Bergamin et al. 2000).

Recently, the excavation of the Giovanni XXIII tunnel cut the whole Monte Mario succession. Thanks to the courtesy of the ASTALDI S.p.A., it was possible to sample in detail the whole succession and to study it in a multidisciplinary perspective (Cosentino et al. in press).

The aim of the current study is to understand the palaeoenvironmental signals recorded by the ostracod assemblages collected in the Monte Mario succession. The Monte Mario ostracod fauna has been already studied at the beginning of the last century (Namias 1900; Cappelli 1905) and, more recently, it has been object of a taxonomic revision by Faranda & Gliozzi (in press).

Description of the sampled section

The Monte Mario succession recovered during the excavation of the Giovanni XXIII tunnel is as follows (Fig. 1):

1) Monte Vaticano Fm. (Funicello & Giordano, in press): irregular alternance of grey clays and silty/sandy clays, affected by extensional tectonics and inclined up to 45°. Its thickness is supposed to be of several hundred of metres. Its age, provided by planktonic foraminifers and calcareous nannoplankton, is Early Pliocene (basal part of the MNN16a Zone, correspond-

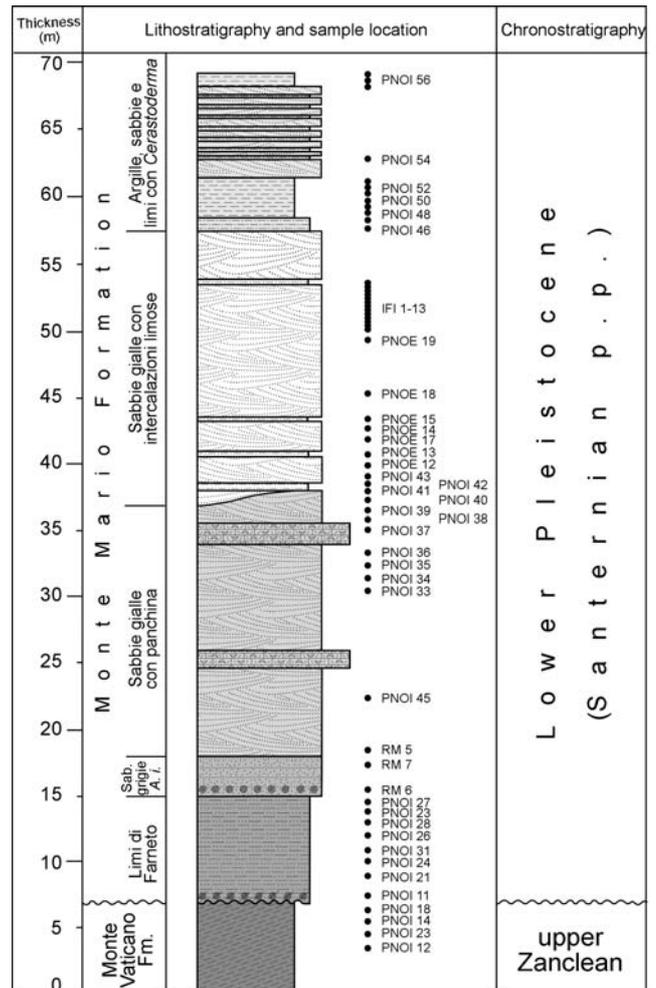


Fig. 1 - Log of the Monte Mario succession with the location of the samples (modified from Cosentino et al. in press).

ing to the *Globorotalia puncticulata* Zone) (Cosentino et al. in press);

2) Monte Mario Fm. (Conato et al. 1980): it unconformably overlies the Monte Vaticano Fm., with a whole sampled thickness of about 63 m. Its age, provided by nannoplankton and benthonic foraminifers, is constrained within the late Santerian by the presence of *Bulimina etnea* and medium *Gephyrocapsa* (Cosentino et al. in press). The erosional surface, which divides the two formations, is referred in the literature as the Acquatraversa Erosional Phase (Bonadonna 1968).

The Monte Mario Fm. consists of several members, which, from the bottom to the top, are:

a) the “Limi di Farneto” Member (Cosentino et al. in press) is made of 8 m-thick silty and clayey levels. Few centimetres above the basal unconformity, it is characterised by a 20-30 cm-thick shell bed bearing *Arctica islandica* (1st *Arctica* level);

b) the “Sabbie grigie ad *A. islandica*” Member (Cosentino et al. in press) is made of 3 m-thick grey sands bearing, at the base, a rich fossiliferous level with *Arctica islandica* (2nd *Arctica* level).

c) the “Sabbie gialle con panchina” Member (Cosentino et al. in press) is made of 18 m of medium-fine-grained yellow sands with scattered gravel intercalations and two biogenic carbonate horizons (“panchina”) rich in decalcified and scattered mollusc shells;

d) the “Sabbie gialle con intercalazioni limose” Member (Cosentino et al. in press) is made of 22 m-thick massive, medium- to coarse-grained yellow sands, with cross bedding and hummocky-cross-stratification;

e) the “Argille, sabbie e limi con *Cerastoderma*” Member (Cosentino et al. in press) is made of 12 m of clays, silty clays, silts and sands, bearing the mollusc *Cerastoderma lamarcki* in their upper part. *C. lamarcki* is a mollusc typical of intertidal and estuarine environments.

The analysed samples have been collected from the entire succession, as shown in Fig. 1.

Material and methods

Each sample was disaggregated in a 5% H₂O₂ solution, washed using a 0.125 mm mesh sieve and dried. Above 300 ostracod valves per sample were handpicked under the stereomicroscope and identified using SEM photos.

Ostracods were generally abundant and well preserved, mainly represented by loose valves and few carapaces. Each species frequency was normalised to 10 g of dried sieved sample and the relative abundance in percentage was calculated for each taxon. On the whole 145 species referable to 71 genera have been identified (Faranda & Gliozzi in press). The species represented only by juveniles or by one single valve have been critically examined and, in some cases, considered as displaced forms and not included in the statistical analyses, which has been performed on 138 species (Tab. 1, Pl. 1).

Community structure analyses [frequency, Margalef index, Shannon index and equitability index] (Dodd & Stanton 1990) and multivariate analyses [cluster analysis, Principal Coordinates Analysis (PCoA) and Detrended Correspondence Analysis (DCA)] have been used. For the cluster analysis and the Principal Coordinates Analysis (PCoA), a transformation exponent $c=2$ and the Morisita similarity index has been used. The multivariate analyses have been performed using the software package PAST – Palaeontological Statistics (ver. 1.53) (Hammer et al. 2001).

Community structure analyses

Community structure analyses have been performed on the ostracod assemblages collected from the Monte Vaticano and Monte Mario Fms., following the methods proposed by Valentine (1971) and Dodd & Stanton (1990). Normalised abundances and number of species have been compared with three community structure indexes calculated for each sample: Margalef index (richness), Shannon index (diversity) and equitability index (evenness) (Fig. 2).

Multivariate analyses

Cluster Analysis

A Q-mode hierarchical cluster analysis of the total association was computed using the Morisita distance measure and the un-weighted paired-group method using arithmetic average (UPGMA). Two well-discriminated super-clusters can be identified at an across-cluster similarity close to zero (Fig. 3). Supercluster 1 groups the Monte Mario Fm. samples, while Supercluster 2 groups the Monte Vaticano Fm. samples. The sharp separation is in good agreement with the palaeoecological data, which indicate a bathyal environment for the Monte Vaticano Fm. and a shallower environment for the remaining samples. There is no environmental overlapping between the two samples' groups. By selecting a cut-off value of 0.22 for the across-cluster similarity, Supercluster 1 can be split into three branches, grouping the “Limi di Farneto” samples in Cluster 1a, the “Sabbie grigie ad *A. islandica*” samples and the majority of the “Sabbie gialle con panchina” samples in Cluster 1b, the remaining “Sabbie gialle con intercalazioni limose” and “Argille, limi e sabbie con *Cerastoderma*” in Cluster 1c.

Ordination method analyses

To understand which environmental factors are related to the clustering of the different assemblages, a sample centered Principal Coordinates Analysis (PCoA) has been performed on the whole succession. Axes 1 and 2 explain together only the 28.91% of the total variance. As a matter of fact, the ordination of the samples is led by many different ecological parameters linked to several environments from bathyal marine to coastal with freshwater inputs. To better constrain the environmental factors affecting the marine samples near the Plio-Pleistocene boundary, a PCoA of the Monte Vaticano Fm., “Limi di Farneto”, “Sabbie grigie ad *A. islandica*” members and the lowest portion of the “Sabbie gialle con panchina” member has been performed (Fig. 4). The two axes explain together the 42.32% of the total variance.

Through a DCA analysis the distribution of the samples and species collected from the Monte Mario Fm. has been studied (Fig. 5). The Axis 1 and 2 account respectively for 37.95% and 23.36% of the total variance. Samples are almost continuously distributed along Axis 1, showing a progressive scattering along Axis 2. The samples with highest Axis 1 scores are characterised by mainly marine species and corresponds to Cluster 1b of the cluster analysis. Samples with decreasing Axis 1 scores correspond to those of Cluster 1c of the cluster analysis. These latter can be further subdivided in three groups taking into account the close distribution of their dominant species in the DCA plot.

Group I is characterised by assemblages made of dominant *Pontocythere turbida*, *Cytheridea neapolitana*, *Costa edwardsii*, *Palmoconcha turbida* and *Cyprideis withei* accompanied by a few *Cyprideis torosa* and some less halophile continental ostracods (*Potamocypris zschokkei*, *Candona (Neglecandona) neglecta*, *Heterocypris salina* and *Ilyocypris gibba*); Group II is characterised by dominant *C. torosa* accompanied by freshwater/oligohaline ostracods (*Ilyocypris getica*, *Ilyocypris monstrefica*, *Candona (Neclecandona) neglecta*, *Pseudocandona marchica*, *Trajancypris clavata*, *Potamocypris zschokkei*, *Potamocypris fallax* and *Limnocythere inopinata*). Finally, Group III is characterised by the presence of monospecific assemblages of *C. torosa* accompanied only by *Ammonia* spp. and *Cerastoderma lamarcki*. The location of this group at the far left of the plot is linked to the euryplastic behaviour of *C. torosa*. Concerning Axis 2, the majority of samples are located in the lower part of the plot and only samples RM 6 and PNOI 37 are isolated in the upper part.

Discussion

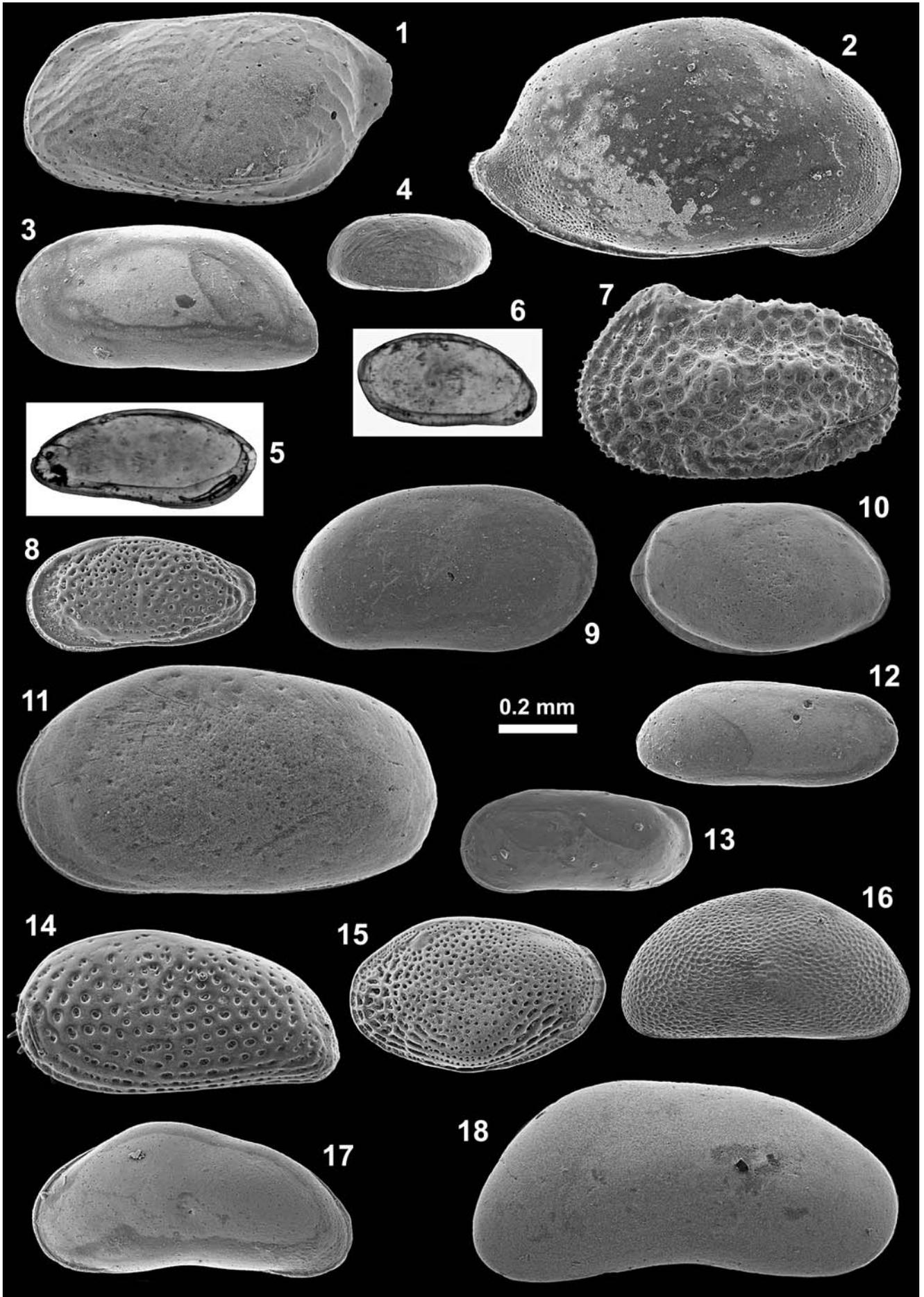
In the community structure analysis plot (Fig. 2), samples from the Monte Vaticano Fm. display low Margalef and Shannon indexes (linked to the low abundances and number of taxa) and rather high equitability. These parameters mirror rather stable environments, where mature ostracod communities could establish. The low abundances and oligotopy are linked to the bathyal environment testified by the presence of *Krithe*, *Henryhowella*, *Cytherella*, *Bythocypris* and *Paijenborchella*. At the base of the Monte Mario Fm. ("Limi di Farneto" Member), the samples show high equitability and Shannon indexes indicating stable environments subdivided into several ecological niches. Going upwards, both indexes decrease: the environment becomes more stable and starts to specialise; thus, ostracod assemblages are made of less numerous euryplastic species. The indexes recorded from the Monte Mario sands (upper four members) suggest several environmental changes: the rather high equitability, coupled with the highest Shannon and Margalef indexes characterising the "Sabbie grigie ad *A. islandica*" and "Sabbie gialle con panchina" members point to a stable and well diversified environment. The "Sabbie gialle con intercalazioni limose" and the lower part of the "Argille, limi e sabbie con *Cerastoderma*" members show low equitability coupled with rather low Shannon indexes recording unstable environments, where very few euryplastic species gave origin to rich populations. The uppermost two samples PNOI 56 and PNOI 57 are monospecific and made only by *Cyprideis torosa*. For these latter samples it is possible to suppose a stressed environment.

In the cluster analysis plot (Fig. 3), group samples 1a, 1b and 1c indicate deposition in littoral environments differing both for water depths and, most likely, for local inputs from freshwater bodies. The results of the cluster analysis clearly confirm the palaeoenvironmental information given by the species recovered in each assemblage and help to better differentiate the corresponding depositional environments.

The analysis of the assemblages distribution in the PCoA plot (Fig. 4) and the correlation with the ecological data available in the current literature for each species, has led to the following interpretation. Concerning Axis 1, samples collected from the two *Arctica islandica* levels (sample PNOI 11 from the first level and sample RM6 from the second level) are quite distant from each other. The bivalve *A. islandica*, a classical "northern guest" for the Mediterranean Pleistocene (Malatesta and Zarlenga 1986, with refs.), indicates water temperatures lower than present. Current studies on living *A. islandica* demonstrate that this species pre-

PLATE 1

- 1 - *Bythocythere zetlandica* Athersuch, Horne & Whittaker, 1983, LV, outer view, sample PNOI 45.
- 2 - *Aurila (Cruciaurila) cruciata* (Ruggieri, 1950), RV, outer view, sample PNOI 27.
- 3 - *Krithe compressa* (Seguenza, 1880), female LV, outer view, sample PNOI 23.
- 4 - *Cytheropteron (Cytheropteron) depressum* Brady & Norman, 1889, LV, outer view, sample RM 7.
- 5 - *Paradoxostoma ensiforme* Brady, 1868, LV, outer view in transmitted light, sample RM 7.
- 6 - *Paradoxostoma abbreviatum* Sars, 1866, RV, outer view in transmitted light, sample RM 7.
- 7 - *Henryhowella sarsii profunda* Bonaduce, Barra & Aiello, 1999, female LV, outer view, sample PNOI 23.
- 8 - *Leptocythere transiens* (Pucci, 1956), LV, outer view, sample PNOI 11.
- 9 - *Cytherella gibba* Aiello, Barra, Bonaduce & Russo, 1996, RV, outer view, sample PNOI 23.
- 10 - *Palmoconcha turbida* (Müller, 1894), female RV, outer view, sample PNOI 21.
- 11 - *Cyprideis torosa* (Jones, 1850), LV, outer view, sample PNOI 56.
- 12 - *Parakrithe ariminensis* (Ruggieri, 1967), RV, outer view, sample PNOI 23.
- 13 - *Leptocythere ramosa* (Rome, 1942), LV, outer view, sample PNOI 24.
- 14 - *Cytheridea neapolitana* Kollmann, 1960, female LV, outer view, sample RM 5.
- 15 - *Loxoconcha ovulata* (Costa, 1863), LV, outer view, sample RM 5.
- 16 - *Potamocypris zschokkei* (Kaufmann, 1900), RV, outer view, sample PNOI 42.
- 17 - *Potamocypris fallax* Fox, 1967, LV, outer view, sample PNOI 49.
- 18 - *Candona (Neglecandona) neglecta* Sars, 1887, RV, outer view, sample PNOI 42.



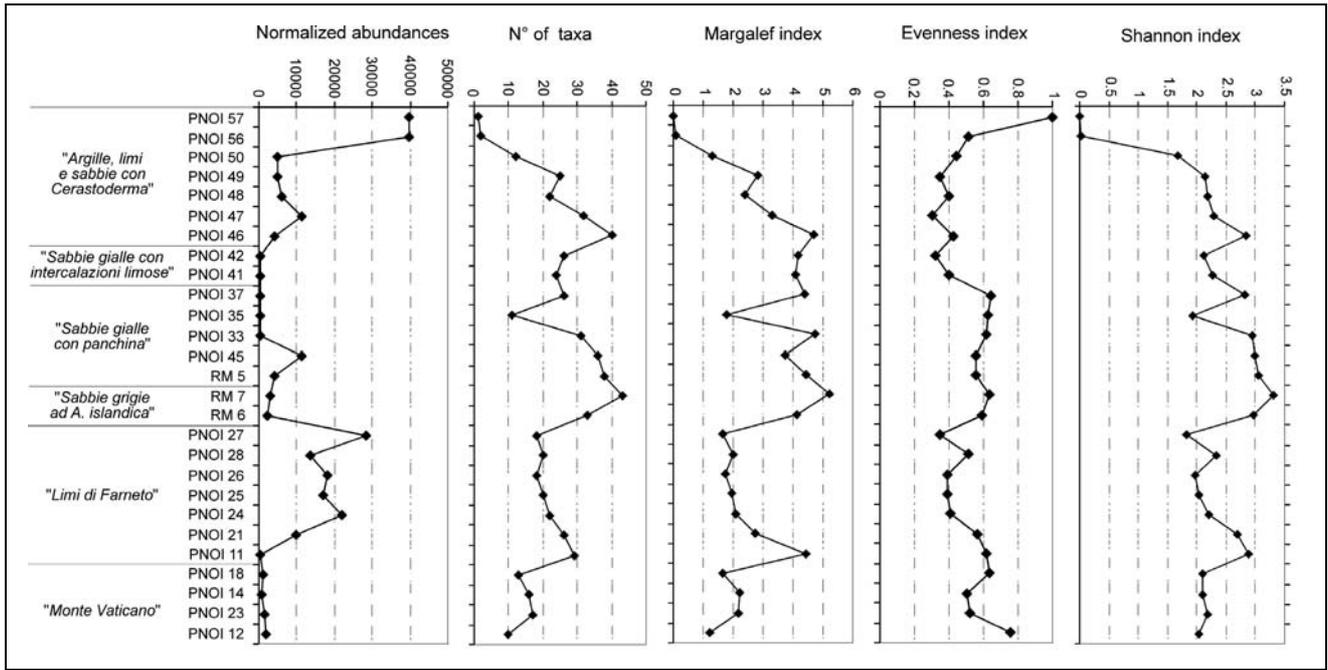


Fig. 2 - Community structure analysis on selected samples collected from the Monte Vaticano and Monte Mario fms. Normalised abundances, number of taxa, Margalef, Evenness and Shannon indexes are shown in the graphs.

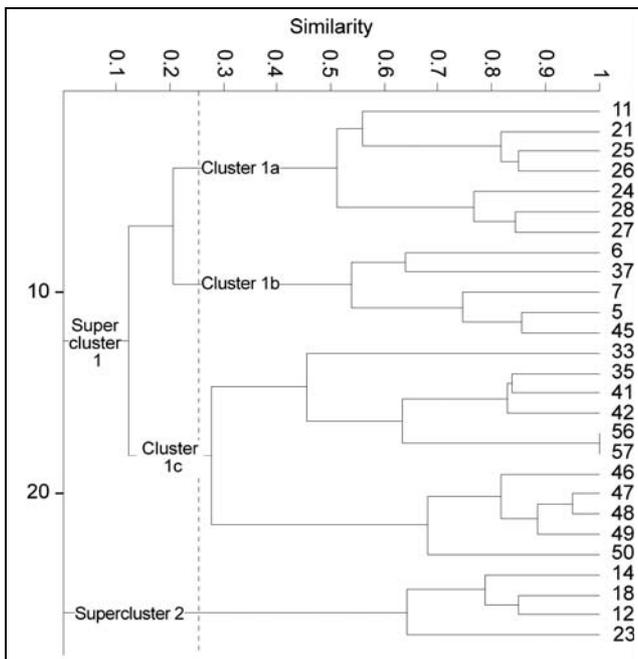


Fig. 3 - Dendrogram resulting from cluster analysis in Q-mode using UPGMA method and Morisita distance applied to the Monte Vaticano and Monte Mario fms. samples.

fers water temperatures within 6° and 16° C, and tolerates a water temperature range between 1° and 20°C (Cargnelli et al. 1999). Furthermore, the occurrence in the RM samples of the four “northern guests” *Cythero- pteron depressum*, *Bythocythere zetlandica*, *Paradoxos- toma ensiforme* and *Paradoxostoma abbreviatum* indi-

cates that the second *A. islandica* level records the lowest temperatures. Samples with the highest Axis 2 scores, which correspond to the Monte Vaticano Fm. assemblages, can be referred to a bathyal environment, with *Henryhowella sarsii profunda* as dominant species. At present, in the Tyrrhenian Sea, the water temperature under 100 m of depth is considered to have a constant temperature of 13° C all year around (Cognetti et al. 1999). Thus, Axis 1 seems related to water-temperature, decreasing from the negative to the positive part of the axis. Assuming that Axis 1 represents water-tempera- ture, samples with low scores of Axis 1 correspond to water-temperatures most likely around or exceeding 20° C and increasing scores of Axis 1 indicate progressively colder waters.

The environmental gradient corresponding to Axis 2 is most likely the water-depth. Samples with the highest Axis 2 scores include *Krithe compressa* (which inhabits depth even beyond 900 m, Barra et al. 1998) and are dominated by *H. sarsii profunda*, reported to live at water depths between 150 and 350 m in the Gulf of Naples (Bonaduce et al. 1999). Those samples correspond to major depths, exceeding 150 m, probably around 300-350 m. Samples with low Axis 2 scores and high Axis 1 scores are limited to shallower water depths, because they include samples with *A. islandica* at present found most commonly within 25 and 61 m of water depth (Cargnelli et al. 1999). Samples with low Axis 1 scores and Axis 2 scores, corresponding to the “Limi di Farneto”, display small water depth variations from an

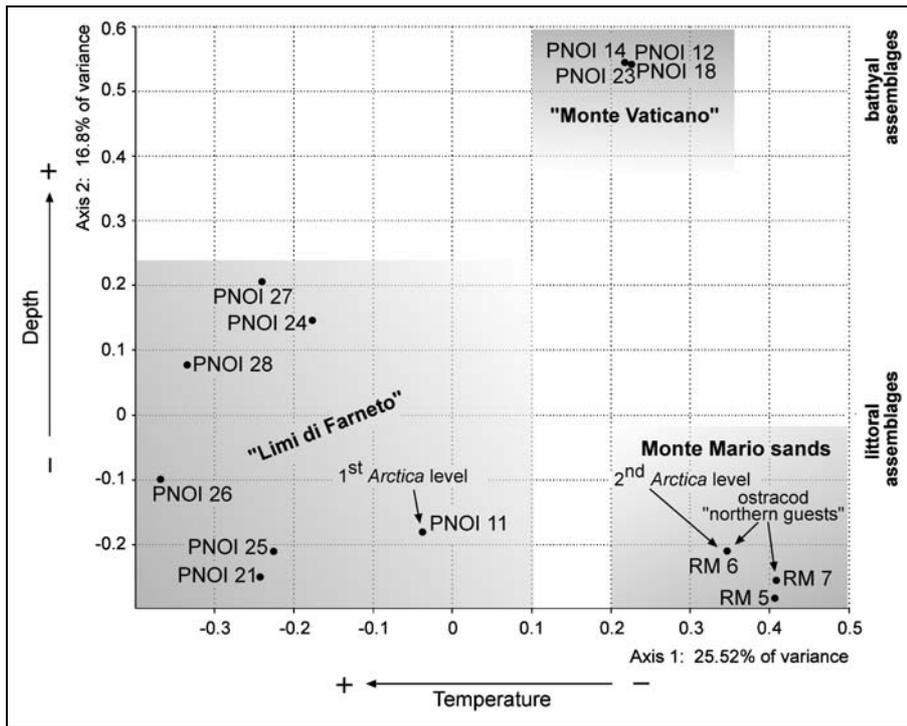


Fig. 4 - Principal Coordinates Analysis ordination plot of the samples collected from the Monte Vaticano Fm. and the lower portion of the Monte Mario Fm. ("Limi di Farneto" and Monte Mario sands which include "Sabbie grigie ad *A. islandica*" and the lowest portion of "Sabbie gialle con panchina" members).

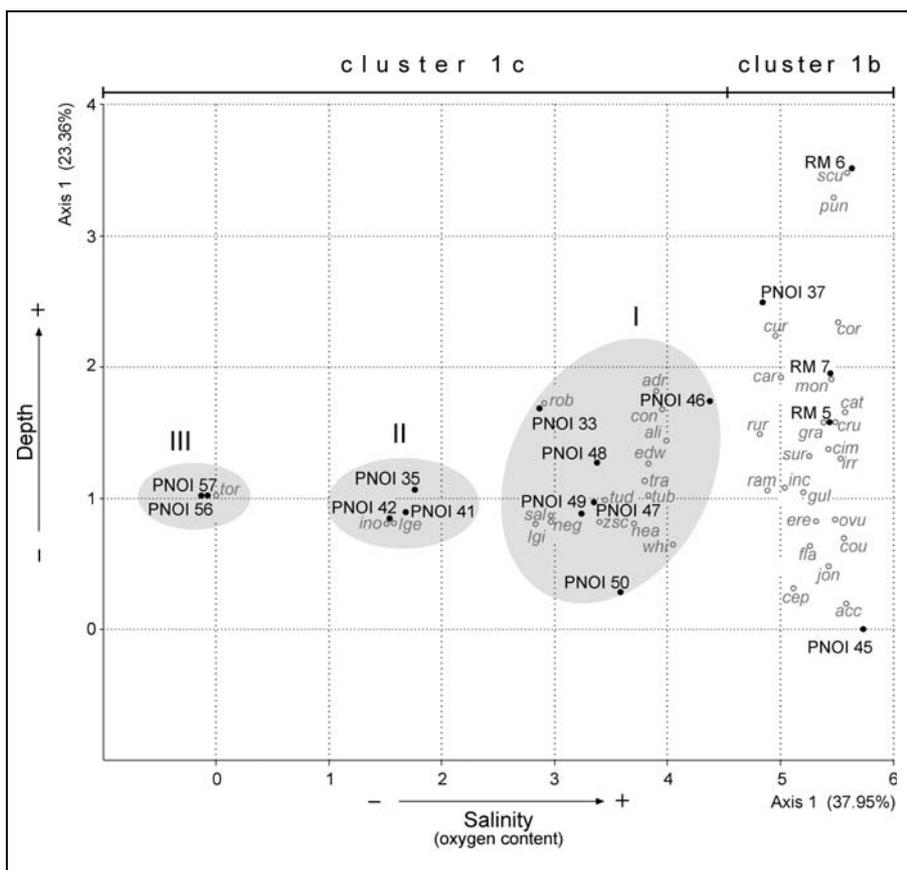


Fig. 5 - Detrended Correspondence Analysis ordination biplot of the Monte Mario sands. Samples and species are grouped in clusters 1b and 1c following the Cluster Analysis (see Fig. 3). Abbr.: acc. *S. acuticostata*; adr. *C. adriatica*; ali. *S. alifera*; car. *C. carinata*; cat. *C. carthaginiensis*; cep. *A. cephalonica*; cim. *C. cimbaeformis*; con. *A. convexa*; cor. *P. coronata*; cou. *X. communis*; cru. *A. cruciata*; cur. *E. curta*; edw. *C. edwardsii*; ere. *X. erecta*; fla. *C. flavidofusca*; gra. *H. gracillicosta*; gul. *E. gullentopsi*; Ige. *I. getica*; Igi. *I. gibba*; inc. *S. incongruens*; ino. *L. inopinata*; irr. *T. irregularis*; jon. *P. jonesi*; mon. *C. monoceros*; nea. *C. neapolitana*; neg. *C. neglecta*; oву. *L. ovulata*; pun. *A. punctata*; ram. *L. ramosa*; rob. *C. robusta*; rur. *S. ruggieri*; sal. *H. salina*; scu. *S. scutulum*; sur. *C. subradiosa*; tor. *C. torosa*; tra. *L. transiens*; tub. *Palmoconcha turbida*; tud. *Pontocythere turbida*; whi. *C. whitei*; zsc. *P. zschokkei*.

infralittoral environment to a lower circalittoral environment.

Within the "Limi di Farneto" samples, those corresponding to a lower circalittoral environment are characterised by dominant *Leptocythere transiens*, with

Palmoconcha turbida and *Aurila cruciata* subordinated. The samples corresponding to an infralittoral environment are dominated by *Leptocythere ramosa*, with *A. cruciata* and *Palmoconcha turbida* as subordinate species. Finally, the single sample PNOI 11 has dominant

Henryhowella partenopea and subordinate *A. cruciata* and *L. transiens*. Samples from the “Sabbie grigie ad *A. islandica*” and “Sabbie gialle con panchina” are dominated by *Loxoconcha ovulata*, *Semicytherura incongruens*, *Xestoleberis communis*, *C. neapolitana* and *C. edwardsii*. Samples from the Monte Vaticano Fm. are dominated by *H. sarsii profunda*, *K. compressa*, *Bairdopillata profunda* and *Cytherella gibba*.

In the DCA analysis (Fig. 5), salinity has been identified as the main environmental gradient of Axis 1 taking into account the ecological parameters of the dominant ostracod species. Thus, the marine euhaline samples are arranged on the right of the plot, while mesohaline and oligohaline samples are distributed towards the left. The presence of *C. torosa* within group III explains its position in the far left of the plot. In fact, this species is very abundant both in brackish and in hyperhaline environment, while generally lacks in marine euhaline environments (Meisch 2000, with refs.). Concerning the oxygen content, the genus *Cyprideis*,

and the species *C. torosa* in particular, is known to survive both in well oxygenated or rather anoxic environments (Debenay et al. 1994; Gamenick et al. 1997). Thus, it is possible to suppose that Group III records a rather stressed environment characterised by brackish and poorly oxygenated shallow waters.

According to their assemblage composition, samples RM 6, RM 7 and RM 5 are referable to outer infralittoral environments. Furthermore, the species *C. torosa*, dominant in samples PNOI 41, PNOI 42, PNOI 56 and PNOI 57, displays its optimum of depth at less than ten meters (around 7 m, Meisch 2000 with refs.). As a consequence, Axis 2 could represent the ecological parameter depth.

Palaeoenvironmental reconstruction

The multivariate analyses carried out on the ostracod assemblages of the Monte Vaticano and Monte

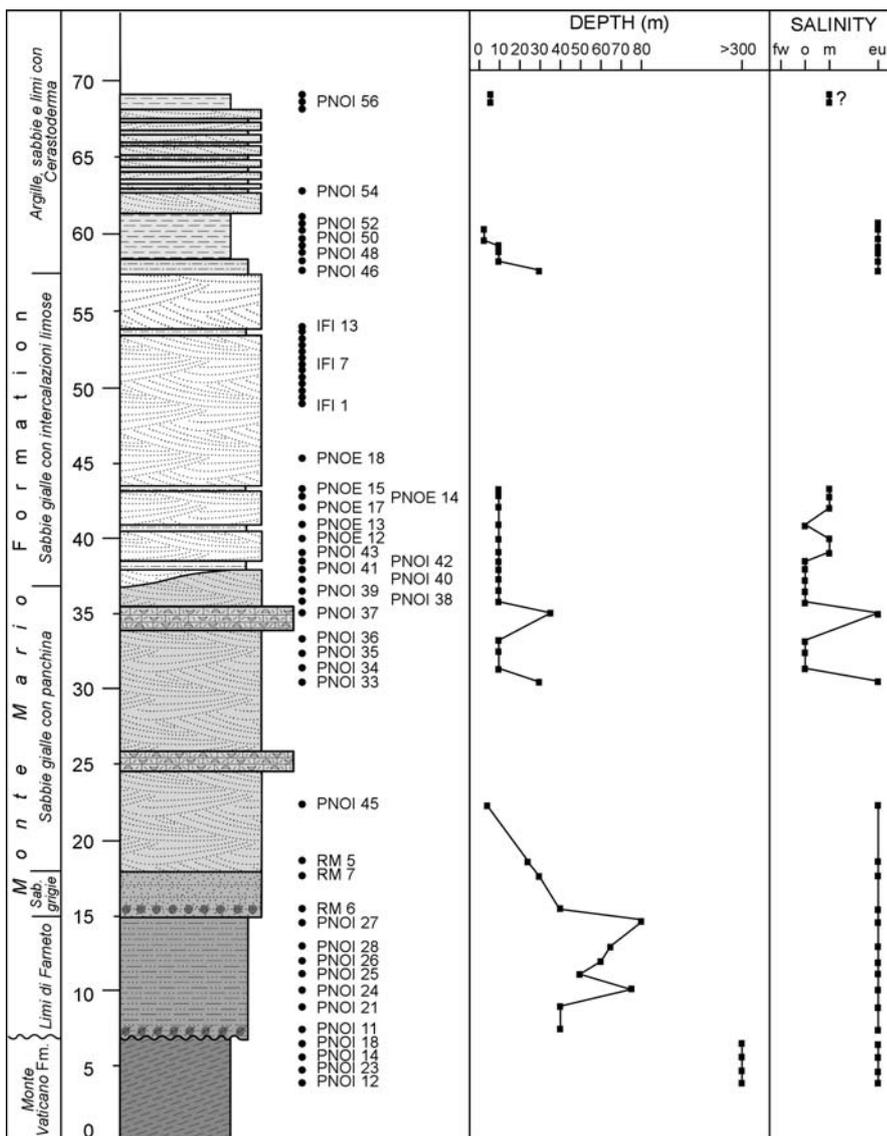


Fig. 6 - Palaeodepth and palaeosalinity scheme of the Marne Vaticano and Monte Mario Fms. samples (eu=euhaline, m=mesohaline, o=oligohaline, fw= freshwater).

Mario Fms. has given important inputs to the knowledge of the palaeoenvironmental and palaeoecological evolution of the Monte Mario succession, mainly concerning variations in depth, temperature and salinity (Fig. 6).

The upper part of the Monte Vaticano Fm. corresponds to a marine bathyal environment 300–350 m of depth, characterised by the presence of *Henryhowella sarsii profunda*, *Krithe compressa*, *Parakrithe ariminensis*, *Parakrithe dimorpha*, *Bairdoppilata profunda*, *Cytherella robusta* and *Cytherella gibba*. Water-temperatures, as shown by the PCoA plot, are in agreement with such depths.

Immediately above the Acquatraversa Erosional Phase, an infralittoral environment has established. At the base of the Monte Mario Fm., in the lowest “Limi di Farneto” sample (PNOI 11), a first pulse of climate deterioration is testified by the occurrence of *Arctica islandica*. The sudden disappearance of this northern guest in the upper “Limi di Farneto” samples, which are partly referred to the same littoral environment, is most likely linked to variations in water temperatures. As a matter of fact, a general warming of 2–3°C in the surface water layers (above the thermocline) would expose invertebrates to temperatures near or beyond their thermal tolerances causing, directly or indirectly, lethal consequences (Romano et al. 2000). The ostracod fauna recovered in the remaining “Limi di Farneto” samples is typical of temperate waters, without any indication of cold species. For this reason, the “Limi di Farneto” above the 1st *A. islandica* level are referred to a temperate depositional littoral environment, with water temperatures exceeding 20°C. The PCoA plot shows that the second pulse of climatic deterioration, more intense than the first, is represented by the 2nd *A. islandica* level, occurring within the “Sabbie grigie ad *Arctica islandica*” Member. Here the mollusc assemblage includes three “northern guests”: *A. islandica*, *Cochlodesma praetenuae* and *Buccinum humphreysianum* (Malatesta & Zarlenga 1986). The ostracod assemblage includes four “northern guests”: *Cytheropteron depressum*, *Bythocythere zetlandica*, *Paradoxostoma ensiforme* and *Paradoxostoma abbreviatum*. These species occur in the northern Atlantic Ocean, in the North Sea and along the coast of the British Islands; they were never found before, fossil or living, in the Mediterranean area, except for *P. ensiforme*, already signaled by Cappelli (1905) in the Monte Mario sands. On the basis of the age provided by calcareous nannoplankton and benthonic foraminifer data (Cosentino et al. in press), which constrain the sedimentation of the whole Monte Mario Fm. within 1.60–1.59 Ma, these cold pulses can be referred to the transition from the Oceanic Isotopic Stage 55 to the OIS 54 (Shackleton 1995).

Ostracod assemblages have shown that the Monte Mario Fm. deposited in a littoral sea, which underwent several sea-level oscillations. The “Limi di Farneto” member is characterised by high diversified ostracod assemblages, dominated by *Aurila (Cruciaurila) cruciata*, *Palmoconcha turbida*, *Leptocythere transiens*, *Leptocythere ramosa*, *Carinocythereis carinata*, *Cytheridea neapolitana*, *Costa edwardsii*, *Pterygocythereis jonesii*, *Cytheropteron sulcatum* and *Henryhowella partenopea*. At the very base of the “Limi di Farneto”, the PCoA analysis showed the existence of an outer infralittoral environment (around 40 m of depth), which gradually became deeper, within the inner circalittoral, down to 70–75 m of depth (sample PNOI 24) (Fig. 4). Moving upwards, the ostracod assemblages record the restoration of infralittoral conditions (around 50 m of depth, sample PNOI 25) and again a progressive deepening down to 80 m of depth (sample PNOI 27). The ostracods of the “Sabbie grigie ad *A. islandica*” and “Sabbie gialle con panchina” record three shallowing up oscillations of the sea. The first one goes from an outer infralittoral environment (40–30 m, samples RM 6–7) (dominant *Cimbourila cimbaeformis*, *Semicytherura inconguens* and *Xestoleberis communis*) to an inner infralittoral, vegetated environment (25–few meters, samples RM 5, PNOI 45) (dominant *X. communis*, *X. erecta*, *Loxoconcha ovulata*, *Cytheretta adriatica*, *Cytheridea neapolitana*, *Costa edwardsii*, *Semicytherura ruggierii*, *Semicytherura inconguens*, *Pontocythere turbida* and occurrence of the northern guests *Cytheropteron depressum*, *Bythocythere zetlandica*, *Paradoxostoma ensiforme* and *Paradoxostoma abbreviatum*). The second one goes again from an outer infralittoral environment (30 m, PNOI 33) to an inner infralittoral environment (around 10 m, PNOI 33–PNOI 36). Finally, the third one goes from an outer infralittoral environment (35 m, PNOI 37) to an inner infralittoral environment (around 10 m, PNOI 38–40). The shallowest portions of the last two oscillations were probably characterised by a salinity decrease; in fact, the assemblages are less rich and diversified, characterised by low equitability due to the dominance of *Cyprideis torosa* and *Pontocythere turbida*. In the “Sabbie gialle con intercalazioni limose”, divided by an erosional surface from the underlying “Sabbie gialle con panchina”, the ostracod assemblages record very scarce *Cyprideis torosa* and *Pontocythere turbida*, testifying a shallow (less than 10 m) and brackish environment. In correspondence of the silty intercalations (PNOI 41–42 and PNOE 13) oligohaline episodes are recorded by the presence of freshwater/oligohaline species such as *Ilyocypris gibba*, together with juveniles of *Candona (Neglecandona) neglecta*, *Pseudocandona marchica*, *Trajanicypris clavata*, *Potamocypris zschokkei* and *Potamocypris fallax*. The uppermost samples (PNOE 18–IFI 13) are barren.

The ostracod assemblages of the “Argille, limi e sabbie con *Cerastoderma*” records the restoration of inner infralittoral marine conditions (samples PNOI 46-51) (dominant *Cytheridea neapolitana*, *Costa edwardsii*, *Palmoconcha turbida*, *Pontocythere turbida*, *Carinocythereis carinata*, *Xestoleberis communis* and *Semicytherura ruggierii*). Above, a short interval (PNOI 52-55) records scanty and badly preserved ostracods, mainly represented by juveniles of *Cyprideis*, *Pontocythere* and Candoninae. At the top of the investigated succession, two samples (PNOI 56-57) made by mono-specific *Cyprideis torosa* assemblages probably record the setting of a brackish, poorly oxygenated and very shallow marginal marine environment.

Conclusions

The detailed study on the ostracod assemblages collected from the Monte Mario succession provided new insights about the palaeoenvironmental evolution of the Monte Mario area:

1. The Monte Mario Fm. (Early Pleistocene, Santernian p.p.) unconformably overlies the Monte Vaticano Fm. dated Early Pliocene p.p. The discordance is well visible in the outcrops and it is very well detectable from a palaeoenvironmental point of view. In fact, os-

tracod assemblages indicate depths around 300-350 m for the Monte Vaticano Fm. (inner batial marine environment) and depths around 40 m (outer infralittoral marine environment) for the lowest Monte Mario Fm. samples.

2. Within the Monte Mario Fm three marine shallowing-up sequences can be recognised, the last two recording upwards, marginal marine conditions with low depths and reduced salinities.

3. Water temperatures inferred from the mollusc and ostracod assemblages show the existence of two cold pulses. The first one at the base of the Monte Mario Fm. (“Limi di Farneto” member), in correspondence of the 1st *A. islandica* level, immediately above the discontinuity. The second, colder pulse, in correspondence of the “Sabbie grigie ad *A. islandica*” member and the 2nd *A. islandica* level, which is also characterised by the occurrence of four ostracod species, the “northern guests” *Cytheropteron depressum*, *Bythocythere zetlandica*, *Paradoxostoma ensiforme* and *Paradoxostoma abbreviatum*.

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