OSTRACODE ASSEMBLAGES AND PALAEOENVIRONMENTAL EVOLUTION OF THE LATEST MESSINIAN LAGO-MARE EVENT AT PERTICARA (MONTEFELTRO, NORTHERN APENNINES, ITALY).

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ABSTRACT
The latest Messinian Lago-Mare event, which affected the whole Mediterranean area, is well constrained both lithostratigraphically and biostratigraphically. The sediments lie between the evaporite deposition related to the Messinian salinity crisis and the clayey deposition related to the Early Pliocene transgression and it is marked by the appearance of ostracode assemblages with Paratethyan affinity. The Perticara section (Montefeltro, northern Apennines, Italy), characterised by a high sedimentation rate, has been sampled every 50 cm. Ostracode assemblages have been analysed from the topmost portion of the sedimentary succession, with the aim of reconstructing the palaeoenvironmental evolution of the last 15-20.000 years of this event and investigate possible environmental changes on a millennial scale.

Statistical analyses have been performed on the relative abundance in percentages of the species identified in 31 sediment samples. Community structure has been studied through several indexes such as Margalef, Shannon and equitability. Both species (R-mode) and samples (Q-mode) were grouped by cluster analyses and detrended correspondence analyses (DCA) using the software package PAST (ver. 1.06). The DCA analysis has shown that, during this short period, several environmental changes have been recorded. A short interval, 14 m below the Mio-Pliocene boundary, testifies to a shallow mesohaline waterbody dominated by Leptocytherinaceae and Loxoconchidae (Loxoconcha (Loxocorniculina) djafarovi and Loxoconcha (Loxoconcha) eichwaldi n. ssp.). Within the upper intervals, salinity slowly shifts to oligo-freshwater conditions since Loxoconchidae and Leptocytherinaceae progressively decrease and Candoninaceae increase (with dominant Caspiocypris pontica). A few meters below the Mio/Pliocene boundary, Candoninaceae are still dominant but Leptocytherinaceae species increase again in frequency together with Loxoconchidae. These changes point to the restoration of oligo-mesohaline or mesohaline conditions. The uppermost 2 m of clays below the Mio-Pliocene boundary are barren of ostracodes preventing an investigation of the very late Miocene palaeoenvironment, but the first Lower Pliocene samples show clearly the abrupt restoration of fully marine conditions.
KEYWORDS: ostracodes, latest Messinian Lago-mare event, northern Italy, palaeoenvironmental evolution, statistical analyses.

INTRODUCTION

The Lago-mare facies, characteristic of the Mediterranean area during the latest Messinian, has been widely investigated from a paleogeographic and paleontological point of view. Ostracode faunas, typical of this facies are characterised by an important contingent of ostracodes of Paratethyan affinity (Grekoff & Molinari, 1963; Gramann, 1969; Molinari Paganelli, 1975; Benson, 1976; Roep & Van Harten, 1979; Krstic & Stancheva, 1989; Bossio et al., 1996; Gliozzi, 1999; Cipollari et al., 1999a,b; Bonaduce & Sgarrella, 1999; Gliozzi et al., 2002). Their migration into the Mediterranean area was due both to the western closure of the Mediterranean-Atlantic connection (Weijermars, 1988; Benson et al., 1991; Cita & Corselli, 1993) and to the subsequent humid climate phase (Griffin, 2002) which diluted the hyperhaline Mediterranean waters after the Messinian “salinity crisis” (McCulloch & De Deckker, 1989). Ostracode assemblages mirror the dilution to oligo-mesohaline waters, being characterised by the presence of several Candoninae, Cyprideis and Amnicythere species. In the present paper the Lago-mare palaeoenvironment has been analysed in a new perspective: the detailed palaeoenvironmental reconstruction of the last 15-20,000 years before the marine ingression testifies to the restored Mediterranean-Atlantic connection and marks the beginning of the Pliocene.

GEOLOGICAL SETTING

The northern Apennines are part of the circum-Mediterranean orogen, developed through the convergence between the European and African plates mainly during Neogene times. The tectonic units of the northern Apennine chain derive from the deformation of both the Neotethyan oceanic realm and the Adria continental realm. In the Montefeltro area (Fig. 1), the oceanic-derived allochthonous Ligurian Complex overthrust the “autochthonous” succession of the Umbro-Marchean-Romagna domain, sedimented on the Adria continental microplate. Here, the allochthonous Ligurian Complex (Val Marecchia thrust sheet) is represented by the Mesozoic and Paleogene sedimentary cover of part of the Ligurian oceanic domain. In the northern Apennines, as well as on the Val Marecchia thrust sheet, Epiligurian deposits rest
unconformably on the allochthonous Ligurian units. Epiligurian succession sedimented in wedge-top basins, above the forelandward migrating allochthonous Ligurian Complex. (Ricci Lucchi, 1986; Roveri et al., 1999).

The Umbro-Marchean-Romagna “autochthonous” succession is characterised mainly by Meso-Cenozoic deep-water deposits (pelagic basin). The Neogene terms of this basinal succession extensively crop out at the footwall of the Val Marecchia thrust sheet (Fig. 2).

Close to the Val Marecchia thrust sheet the uppermost part of the “autochthonous” Umbro-Marchean Romagna succession crops out (Roveri et al., 1999). The upper turbiditic lobes of the Marnoso-Arenacea Fm. (Late Tortonian) are capped by the Ghioli di letto Fm. (Late Tortonian – Messinian), a thick fine-grained unit made up by thin bedded-turbidites, hemipelagites and submarine slide deposits. This fining-upward sequence (T2 sequence sensu Ricci Lucchi, 1986) is abruptly overlain by the Gessoso-Solfifera Fm, here exclusively made up by reworked evaporites. In turn, the evaporites are capped by the late Messinian Lago-Mare “Colombacci” Fm. and by the Peliti grigio-azzurre Fm., which mark the re-establishment of marine conditions in the Mediterranean basin during the Early Pliocene.

In the Montefeltro area the Messinian terms of the autochthonous succession crop out, resting on the Tortonian Marnoso-Arenacea Formation. The Perticara section (Fig. 3), studied in detail in the present paper, includes the “Colombacci” Fm. and the Early Pliocene Peliti grigio-azzurre Fm. which conformably overlying them. The “Colombacci” Fm. is represented by the association of several lithofacies: varicoloured, thin laminated pelites bearing abundant brackish ostracodes; intercalated sandstones and conglomerate lenses (not found at Perticara), black sandy-clays and chemically precipitated white limestones (“colombaccio” s.s.) of variable thickness from 30 to 80 cm. These lithofacies, included the “colombacci” levels, are repeated at least five times along the “Colombacci” Fm. which reaches its maximum thickness of about 250 m at the Cello section (Romagna Apennines) (Casati et al., 1978; Colalongo et al., 1978). In the studied portion of the Perticara section only one “colombacci” level is included.

The Peliti grigio-azzurre Fm., on the contrary, is characterised by bluish-grey clays with rare intercalation of yellowish-grey sandy levels. The formation bears rich planktic foraminiferal assemblages which testifies to the fully restored marine conditions during the Early Pliocene (Sphaeroidinellopsis seminulima Zone).
Nineteen meters of sedimentary succession have been sampled every 50 cm (being each samples around 8-10 cm of thickness), 17 m below the Mio/Pliocene boundary and 2 m above it (Fig. 4). At the base, grey-greenish clays are intercalated with thin reddish silty laminations (7.5 m of thickness). They are covered by ca. 1 m of alternating marls and clayey marls with a 20 cm thick limestone level (“colombaccio”). Green and grey clays follow (40 cm thick) overlain by ca 1 m of varicoloured (greenish, whitish and reddish) clays. Above the varicoloured clays an alternation of grey and greenish clays (5 m of thickness) is followed by ca 2 m of “black marls” (dark marly clays), rich in organic matter. Taking into account a sedimentation rate of about 1m / 1000 year (this figure is based on the maximum thickness of the “Colombacci” Fm. in the Romagna area (Colalongo et al., 1978) and on the duration of the Lago-Mare event of 260,000 years deduced from Krijgsman et al., 1999 and Lourens et al., 1996) it is possible to assume that the investigated seventeen meters of the “Colombacci” Fm. were deposited during a period of about 15-20ka. Thus each sample possible correspond to a sedimentation interval of about one hundred years and the sampling frequency is about every five hundred years.

The Peliti gigoazzure, which conformably rest upon the “black marls” are easily distinguished and characterised by a decimetric alternation of light and dark grey clays.

MATERIAL AND METHODS

Each sample has been desegregated in a 5% H_2O_2 solution, washed using a 0.125 mm mesh sieve and dried. Not less than 300 ostracode valves for sample where handpicked under the stereomicroscope. Ostracodes were mainly represented by carapaces whereas loose valves were few. On the whole they were medium to well-preserved, except for the samples collected from the upper portion of the “Colombacci” Fm. characterised by a high amount of deformed specimens, probably due to the tectonic stress linked to the overthrust which settled the Val Marecchia thrust sheet. Some samples were barren of ostracodes (PE 32-PE 35 from the “Colombacci” Fm. and PE 36-PE 39 from the Peliti gigoazzure Fm.), others yielded few valves (PE 16-PE 19, corresponding to the “colombaccio” limestone) but, in general, the majority of the samples were characterised by high frequencies. Each species frequency was normalised to 10 g of dried sieved sample and the relative abundance in percentage was calculated for each taxon. Community structure analyses [frequency, Margalef index Shannon index and equitability index (Dodd & Stanton, 1990)] and multivariate analyses (cluster analysis and Detrended Correspondence Analysis (DCA) in Q-mode...
and in R-mode) have been used. These latter analyses have been performed using the software package PAST – Palaeontological Statistics (ver. 1.06) (Hammer et al., 2003).
PALEONTOLOGICAL ANALYSES

The ostracode fauna collected at Perticara contains 22 species referable to 12 genera: 
Amnicythere sp. 1., Amnicythere sp. C Miculan in Bassetti et al. (2003), Amnicythere sp. D 
Miculan in Bassetti et al. (2003), Amnicythere costata (Olteanu, 1989), Amnicythere idonea 
(Markova, 1962) vel pontica (Sheydaeva, 1951), Amnicythere multituberculata (Liventals, 
1929), Amnicythere palimpsesta (Liventals, 1929), Amnicythere propinqua (Liventals, 1929), 
Amnicythere subcaspia (Liventals in Agalarova et al., 1940), Euxinocythere (Maeotocythere) 
praebaquina praebauna (Liventals in Agalarova et al., 1940), Euxinocythere sp. 1, Cyprideis 
sp. 5, Cyprideis anlavauxensis Carbonnel, 1979, Acanthocythereis cf. A. hystrix (Reuss, 1950), 
Tyrrhenocythere cf. T. taurica Krstic, 1977, Loxoconcha (Loxoconcha) eichwaldi Livental, 
1929 (ssp.), Loxoconcha (Loxocorniculina) djafarovi Schneider in Suzin, 1956, Pseudocythere 
limata Schneider in Agalarova, Djafarov, Halilov, 1940, Camptocypris sp. 1, Lineocypris sp. 1, 
Caspiocypris pontica (Sokac, 1972), Pontoniella pontica Agalarova, 1961 ssp. and Zalanyiella 
venusta (Zalanyi, 1929).

Six of these genera (Euxinocythere, Camptocypris, Caspiocypris, Lineocypris, Pontoniella 
and Zalanyiella) are widespread during Miocene in the Paratethys domain and migrated into the 
Mediterranean area only during the latest Messinian Lago-mare event (Loxoconcha 
(Loxocorniculina) djafarovi Zone as defined by Carbonnel, 1979) (Bonaduce & Sgarrella, 1999; 
Carbonnel, 1979; Gliozzi, 1999; Gliozzi et al., 2002 cum bibl.). Four genera are widespread in 
the Neogene/Quaternary of both the Paratethyan and Mediterranean domains (Loxoconcha, 
Pseudocythere, Tyrrhenocythere, Amnicythere), but here at Perticara they are represented only 
by Paratethyan species which migrated in the Mediterranean exclusively during the latest 
Messinian Lago-mare event (Bonaduce & Sgarrella, 1999; Carbonnel, 1979; Gliozzi, 1999; 
Gliozzi et al., 2002 cum bibl.; Gliozzi et al., in press). Finally, the genus Cyprideis is here 
represented only by Mediterranean species, although widespread in both the Paratethyan and 
Mediterranean realms. At Perticara, The genus Acanthocythereis widely represented in the 
Mediterranean area during the Late Tortonian is considered as reworked since it is represented 
by a single fragment of A. cf. A. histrix.

At the species level, the taxa recognised at Perticara were characteristic of the late Pontian 
(sensu Neveskaya et al., 1984; Papp, 1985; Pantic, 1989; Marinescu, 1989, 1995; 
Stevanovic, 1989; Krstic & Stancheva, 1989) of the Eastern Paratethys (Euxinic and Caspian-
Aral basins), the early Dacian (Getian) sensu Marinescu (1989; 1995; Sacchi & Horvath, 1997) of the Central Paratethys (Dacian Basin) and of the early Pontian (Novorossian) (sensu Stevanovic, 1989; Krstic & Stancheva, 1989) of the Western Paratethys (Pannonian basin) which, on the whole, correspond to the latest Messinian. In particular, A. subcaspia, A. palimpsesta, E. (Maetocythere) praebaquana praebaquana and L. (Loxocorniculina) djafarovi are widespread in all the four Paratethyan basins, P. limata and A. idonea vel pontica are distributed only in the Euxinic and Caspian-Aral basins, whereas A. costata, Z. venusta and C. pontica are present in the Pannonian and Dacian basins and A. multituberculata has been collected in the Dacian, Euxinic and Caspian-Aral basins. Only A. propinqua seems to be reported exclusively in the Pannonian basin during latest Messinian. Anyway this species is widespread in the Euxinic and Caspian-Aral basin from Early Pliocene to Recent. Thus, it seems that the Paratethyan species able to spread into the Mediterranean realm during the latest Messinian Lago-mare event were those living in the Dacian and Euxinic areas. Those areas represented the more probable areas in connection with the Mediterranean, according to the palaeogeographic reconstruction proposed by several authors (Hámor, 1988; Cipollari et al., 1999a; Cipollari et al., 1999b; Gliozzi et al., in press).

Since few of the studied species are extant, little data exists on their ecology. At present, A. multituberculata and A. palimpsesta live in the Caspian Sea, A. propinqua, lives in the Caspian Sea, the Aral Sea, the Pahlavi Lagoon (Iran), the Black Sea and in the Azov Sea (Gofman, 1966; Schornikov, 1966; Naydina, 1970, Yassini & Ghahreman, 1976; Boomer et al., 1996). All three species seem to be characteristic of shallow waters (around 10-12 m depth) and oligomesohaline waters (12-13.25‰ for A. multituberculata and A. palimpsesta, 4-13.25‰ for A. propinqua). No ecological data have been found regarding the Candoninae species collected at Perticara, but at a generic level it seems that the living species of Caspiocypris and Pontoniella in the Caspian Sea are characteristic of less saline and deeper waters (down to few hundred meters) (Gofman, 1966; Schornikov, pers. com.). The fresh/oligohaline conditions for the latest Messinian Lago-mare Candoninae seem to be supported by the stable isotopic analyses performed by Casati et al. (1978) on the “colombacci” limestones of the “Colombacci” Fm. outcropping in the Romagna Apennines.

COMMUNITY STRUCTURE ANALYSES
Community structure analyses have been performed on the ostracode assemblages collected at Perticara in the “Colombacci” Fm. samples. Three community structure indices were calculated for each sample: Margalef index (richness), Shannon index (diversity) and equitability index. (Fig. 5).

The samples show a medium richness coupled with a rather high equitability. These parameters mirror rather stable environments, which lead to the establishment of several mature ostracode communities. In particular, the first two samples (PE 1-PE 2) and the samples from the upper portion of the Perticara Messinian succession (PE 19-PE 31) show the presence of several species with high equitability and high diversity. On the contrary, in the interval PE 3-PE 12, low values of equitability and Shannon indexes, coupled with a rather low richness mirror rather unstable environments, with low-diversity communities dominated by Caspiocypris pontica. Although in samples PE 16-PE 19 (corresponding to the “colombaccio”), few species have been collected, they show rather high equitability and diversity values, pointing to a rather stable but specialised environment able to support a mature, but oligotypic community (made only by Candoninae species).

MULTIVARIATE ANALYSES

A Q-mode hierarchical cluster analysis of the total association was computed using the Morisita distance measure and the un-weighted pair-group method using arithmetic average (UPGMA). By selecting a cut-off value of 0.6 for the across-cluster similarity, samples were statistically discriminated into three groups (Fig. 6). The first cluster is represented by the basal PE 1- PE 2 and PE 4 samples, the second by samples PE 25, PE 29-PE 31 taken near the top of the “Colombacci” Fm. and the third cluster includes all the remaining samples, mirroring the high similarity of their ostracode assemblages.

It is worth noting the partial coincidence of community analyses results and cluster analysis results, particularly for the basal and the higher samples in the Perticara succession. This is in accordance with the results of the paleontological analyses and was rather predictable taking into account that the different ostracode assemblages come from sediments deposited in a short time interval (probably not more than 20 ka) inside the latest Messinian Lago-mare Event.
For a more detailed statistical analysis of the structure of the ostracode assemblages, DCA was performed on the data set both in Q- and R-mode (Figs. 7 and 8). The eigenvalues are 36.7% for Axis 1 and 17.1% for Axis 2.

The Q-mode DCA further subdivides the samples into nine different groups (Fig. 7). The overlapping species distribution indicates that only three groups are characterised by “typical” taxa: Group IX characterised by A. palimpsesta (in Fig 7: pal), A. multituberculata (mul) and A. idonea vel pontica (ido); Group VII, characterised by the presence of all the Candoninae [Lineocypris sp. 1 (LIN), Camptocypria sp. 1 (CAMP), P. pontica ssp. (PON), Z. venusta (ZAL), and C. pontica (CAS)]; Group III, characterised by C. pontica (CAS), Amnicythere sp. D (spD), A. costata (cos) and L. eichwaldi ssp. (eich). Some groups seem to be characterised by a low ostracode frequency rather than a different taxonomic composition. For example, Group VI, whose samples (PE 16-PE 18) correspond to the “colombaccio”, shows a taxonomic composition very similar to that of Group VII (dominant Candoninae) but with much lower frequencies. Most of the species are located in the central area of the plot of Fig. 7, pointing to a more or less similar distance from all the groups and further emphasising the high grade of similarity of the Perticara ostracode assemblages. Particularly significant is the central position of Caspiocypris pontica, characteristic of Group IV (where it is dominant) but always present in all the analysed samples with rather high frequencies.

The R-mode DCA plot (Fig. 8), shows the distribution of the 20 species (except Acanthocythereis and Tyrrhenocythere, considered reworked or displaced) in four groups (A-D). The species C. pontica and Amnicythere sp. 1 are isolated. The first, probably because it shows high frequencies in all the samples (it seems to be an euryplastic taxon). The second, on the contrary, because is represented by very few valves in scattered samples.

Considering the few ecological data relating to the Perticara species, it is possible to suggest that Group C (which includes A. multituberculata, A. palimpsesta, A. idonea vel pontica and Amnicythere sp. C) represents a mesohaline (12-13‰) assemblage, while Group B (with A. propinqua, Z. venusta, C. anlavauxensis and P. limata) clusters taxa of a low mesohaline/oligohaline environment. If this interpretation is true, Group A (Camptocypria sp. 1, Lineocypris sp. 1 and P. pontica ssp.) should be the less saline assemblage and Group D (with L. eichwaldi ssp., Amnicythere sp. D, A. costata, A. subcaspia, E. (M.) praebaquana praebaquana, L. (L.) djafarovi and Cyprideis sp. 5) an oligo-mesohaline assemblage. Thus,
Axis 1, which accounts for 36.7% of the relative variance, should represent the ecological parameter “salinity”. Group D and Group B, both characterised by species tolerating similar salinities, are separated on the basis of their different behaviour respect to the Axis 2. According to the few ecological parameters found in the literature (Gofman, 1966; Schornikov, 1966; Naydina, 1972, Yassini & Ghahreman, 1976; Boomer et al., 1996) Candoninae (Group A) and Leptocytherinae (distributed in the other groups) inhabit different water depths: up to few hundred meters for the first and few tens of meters for the second. Thus, Axis 2, which account for 17.1% of the relative variance, should represent the ecological parameter “depth” and Group D should be represented by oligo/mesohaline shallow-water species, while Group B would include oligo/mesohaline deeper species. If this interpretation is the correct one, the ostracode assemblages are more significative for the paleosalinity fluctuations.

DISCUSSION

Paleontological, community and multivariate analyses have been used to depict the detailed palaeoenvironmental evolution of the last 17 m thick portion of the “Colombacci” Fm., corresponding to the last 15-20ka of the latest Messinian Lago-mare event. The 20 ostracode species collected at Perticara are not simultaneously present in the same samples but are associated in various assemblages each one with different frequencies. Although the cluster analysis indicates the high level of similarity of the different sample assemblages, DCA and community analyses have given important informations that distinguish several palaeoenvironmental intervals within the “Colombacci” Fm. succession. Tab. 1 and Fig. 9 summarize the palaeoenvironmental evolution recorded by the analysed section. It is worth to note the similar conclusions arised by independent methods (paleontological geochemical and mineralogical) concerning the palaeoenvironmental interpretation of Interval F (PE 16-PE 18), which corresponds to the “colombacci” limestone lithofacies. In these samples Candoninae are the absolutely dominant taxa, with all the genera recovered at Perticara (Pontoniella, Zalanyiella, Camptocypria, Caspiocypris and Lineocypris). L. eichwaldi ssp., and Leptocytherinae valves are very few, probably displaced. From the paleontological analyses, this interval most likely records a true fresh water and deep waterbody mirroring an environment rather different than those previously recorded, characterised by brackish and
rather shallow waters. This palaeoenvironmental interpretation is supported by the results of stable isotopes analyses performed by Casati et al. (1978) on the “colombacci” limestones cropping out in the Romagna (northern Apennine) area. The authors report low δ¹⁸O values (from -5.03 to 1.63) which are explained, at an average temperature of 20-25°C, as the result of CaCO₃ precipitation in a freshwater environment. Moreover, the mineralogical analyses carried out by Colalongo et al. (1978) on the “colombacci” levels show the dominance of calcite over dolomite, pointing to a freshwater depositional environment.

Two metres below the Messinian/Zanclean boundary, i.e. the topmost part of the Lago-mare interval, samples are barren of ostracodes. The sedimentary succession here is characterised by “black marls”, i.e. clays and marly clays rich in organic matter. Such organic matter accumulation suggests very shallow marshy or palustrine environment characterised by low pH conditions, unfavourable to ostracode life. Black marl levels have been found elsewhere in the northern Apennine “Colombacci” Fm. Mineralogical analyses carried out by Colalongo et al. (1978) support evidences of a pH lowering: these dark levels are characterised by a lower crystallinity degree of the illite (that point to a decreasing of alkalinity) and an abrupt lowering of smectite, a clay mineral which is typical of medium/high alkaline environments.

The palaeoecological analyses carried out on the upper portion of the “Colombacci” Fm. cropping out at Perticara reveals several palaeoenvironmental changes of the waterbody linked mainly to salinity and, to a less degree, to depth variations. The lower 9 m of the studied succession testifies to a continuous progressive trend of salinity reduction, from a mesohaline to an oligohaline/fresh waterbody. At the same time, a less marked but still progressive deepening is recorded, from few meters to several tens of meters. The maximum salinity decrease and waterbody depth is reached during the deposition of the colombaccio limestone. In the upper portion of the succession, however, the salinity increase and the depth decrease is reached through several short-time oscillations.

Bassetti et al. (2003) studied from a sedimentological and paleontological point of view a portion of the “Colombacci” Fm below the one studied in the present paper, cropping out in the same area, a few km to the NW of the Perticara section (Sapigno section, Fig. 1). Here, two colombacci limestones crop out along the “Colombacci” Fm., the topmost corresponding to the colombaccio of Perticara section. The ostracode taxonomic composition, revealed in the
Sapigno section, is very similar to those recovered at Perticara. From Bassetti et al. (2003) data it is possible to recognise a similar palaeoenvironmental trend below and above the lower *colombaccio* level, thus confirming a cyclicity in the palaeoenvironmental changes. Within the Sapigno section below and above the first *colombaccio* the ostracode assemblages are dominated by Leptocytherinae and Loxoconchidae, while close to the *colombaccio* level, the assemblages become progressively dominated by Candoninae. It is also interesting to mention that, in the Romagna-Marche area (northern Apennine) the “Colombacci” Fm. is characterised by high thickness (up to 260 m) (Casati et al., 1978; Colalongo et al., 1978) and, on the whole, along the entire succession up to five *colombacci* levels have been recognised. Ostracode assemblages studied in different Romagna-Marche outcrops point everywhere to palustrine/marshy waterbodies with alternate salinities. On the basis of the results of the detailed palaeoenvironmental study of the Perticara section it is possible to suggest that, during the late Messinian *Lago-mare* event at least 5 complete mesohaline/freshwater cycles are represented which are probably driven by cyclic climatic variations. Although the present palaeoenvironmental analysis has been carried out at a very small temporal scale (about five hundred years) at present it is not possible to detail neither the cyclicity period nor the nature of the climatic variations. More investigations are needed which are in the aims of the authors: a longer and better constrained paleontological record and, possibly the integration with palinological analyses.

**CONCLUSIONS**

The ostracode analyses carried out on the upper part of the late Messinian “Colombacci” Fm. cropping out at Perticara (Montefeltro, northern Apennines), indicate a lagoon/marshy brackish environment typical of a *lago-mare* facies. The taxonomical composition, dominated by taxa of Paratethyan affinity, confirms the stratigraphical correlation of this facies to the late Messinian “*Lago-mare*” event.

Detailed palaeoecological analyses on ostracode assemblages, using community structure analyses and multivariate analyses (UPGMA and DCA) lead to the recognition of a complete cyclical palaeoenvironmental change from mesohaline to fresh and deep to shallow waterbodies. These changes took place progressively in the lower portion of the studied succession and with short-living pulses in its upper part. The “*colombaccio*” level proved to
be deposited in fresher and deeper palaeoenvironmental conditions. Other literature data record the presence of at least 5 “colombacci” limestones within the “Colombacci” Fm., cropping out in the Romagna-Marche area. This suggests that the late Messinian Lago-Mare event was generally characterised by a lago-mare environment subject to cyclical changes in water salinity and depth, probably linked to astronomically driven minor climatic oscillations.

ACKNOWLEDGMENTS

We wish to thank D. Cosentino, I. Mazzini and C. Faranda for the useful and pleasant discussions and for their valuable suggestions and Ian Boomer whose comments improved this paper.

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FIGURE CAPTIONS

FIGURE 1 – Location map of the study sections and geological sketch-map of the Perticara area. Legend: MARECCHIA SHEET LIGURID COMPLEX – 27. Sillano Fm. (Upper Cretaceous-Lower Eocene); 19. Campaolo Fm. (Upper Oligocene-Aquitianian); UMBRO-MARCHEAN-ROMAGNA SUCCESSION – 3. Yellowish-grey limestones (Lower Pliocene, G. punticulata Zone); 32. Peliti grigio-azzurre Fm. (Lower Pliocene, Sphaerodinellopsis spp. to G. punticulata Zone); 34,35,36. “Colombacci” Fm. (Upper Messinian); 44. Gessoso-solfifera Fm. (Upper Messinian); 45. Ghioli di Letto Fm. (Tortonian-Lower Messinian) (from Conti, 1989, modified).


FIGURE 3 – Panoramic view of the Perticara section.


FIGURE 5 – Diagrams of the community structure indexes.

FIGURE 6 – Dendrogram resulting from cluster analysis using UPGMA method and Morisita distance applied to the Perticara samples.

FIGURE 7 – DCA ordination plot (Axis 1/Axis 2) of sites and species (Q-mode).
**Figure 8** - DCA ordination plot (Axis 1/Axis 2) of species (R-mode).

**Figure 9** – Palaeoenvironmental evolution (salinity and depth changes) of the upper portion of the “Colombacci” Fm. cropping out at Perticara.
TABLE CAPTION

TABLE 1 – Palaeoenvironmental interpretation of ostracode assemblages from Perticara samples.