

## TAPHONOMIC EFFECTS ON THE PALEOECOLOGICAL RECORD OF THE LOWER PLEISTOCENE SHALLOW BENTHIC FORAMINIFERA ASSEMBLAGES (WESTERN EMILIA, ITALY)

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**ABSTRACT:** Stefanelli S., *Taphonomic effects on the paleoecological record of the lower Pleistocene shallow benthic foraminifera assemblages (Western Italy)*. (IT ISSN 0394 – 3356, 2004).

Taphonomic and paleoecological quantitative analyses are drawn from benthic foraminiferal assemblages from four lower Pleistocene marine sections (Western Emilia). Then, the data are used to perform the Cluster Analysis (by means SPSS Program) in order to group samples and benthic foraminifera on the basis of their taphonomic and paleoecological similarities.

The sections are arranged in meter to tens-of-meters thick sedimentary cycles. The lower part of each cycle represents the sedimentological transport of shelly material from shallow sandy bottoms to slightly deeper settings (20-40m depth range) due to catastrophic flooding events. The upper part of the cycles represents the return to normal, muddy deposition in an inner shelf setting.

For the taphonomic analysis, foraminifera specimens are classified into taphonomic categories on the basis of their state of preservation: (1) fresh tests, (2) opaque tests, (3) light orange to dark brown iron-stained tests, (4) black or black-striped tests filled with or replaced by pyrite (including partial dissolution of the tests), (5) breakage of the tests.

In both the lithological intervals of the cycles, the high number of specimens grouped into "breakage tests" category leads to suppose the destruction of the tests as the principal taphonomic process affecting the foraminiferal assemblages. In the mudstone partings of the sandstone interval, the mechanism that caused the destruction of the tests is the transport in a shallow-high hydrodynamic setting where benthic foraminifera are put into suspension in water and collide each other and/or with sediment grains. In the same interval, paleoecological results points out that the specimens grouped into "fresh tests" category belong to displaced taxa coming from shallow sediments due to the transport. As a consequence, a correct paleoecological interpretation from the assemblages of the lower part of the cycles is not possible.

In the high-bioturbated mudstones, the "breakage tests" category consists in fragments of hyaline specimens. In these lithological intervals of the cycles, the destruction of the tests may well be due to a strong dissolution activity that causes, in the typical dissolution sequence of pore-boaring species, the corrosion and amplification of the pores and, then, the destruction of the chambers. Though the taphonomic activity, a paleoecological interpretation is possible. It reconstructs a sedimentary deposition in a shallow-quiet environment and changes in oxygen bottom-water content.

**RIASSUNTO:** Stefanelli S., Effetti tafonomici sul significato paleoecologico delle associazioni a foraminiferi bentonici di mare basso del Pleistocene inferiore (Emilia Occidentale, Italia). (IT ISSN 0394 – 3356, 2004).

Due analisi quantitative, una tafonomica e una paleoecologica, sono state condotte su associazioni a foraminiferi bentonici di quattro sezioni marine. I dati ottenuti sono stati successivamente utilizzati per effettuare l'Analisi Cluster (mediante programma SPSS) per raggruppare i campioni ed i foraminiferi sulla base delle loro analogie tafonomiche e paleoecologiche.

Le sezioni in esame, affioranti nella parte occidentale dell'Emilia Romagna, si sono depositate nel Pleistocene inferiore e consistono in cicli sedimentari di alcune decine di metri di spessore. La parte inferiore di ciascun ciclo (sabbiosa) rappresenta il trasporto di materiale conchigliare proveniente da aree superficiali e depositatosi in aree profonde (20-40 metri di profondità), in seguito a piene fluviali. La parte sommitale di ciascun ciclo (argillosa) rappresenta, invece, la deposizione di sedimenti in regime marino di maggiore tranquillità.

Per l'analisi tafonomica, i foraminiferi sono stati raggruppati in categorie sulla base dello stato di preservazione dei gusci: 1) gusci intatti, 2) gusci opachi, 3) gusci ossidati, 4) gusci piritizzati (inclusa la parziale dissoluzione del guscio), 5) gusci rotti.

In entrambi gli intervalli litologici dei cicli, la categoria "gusci rotti" raggruppa un numero alto di individui suggerendo, così, la distruzione dei gusci come il principale processo tafonomico che ha interessato le associazioni a foraminiferi.

Nella porzione basale dei cicli, la distruzione dei gusci è causata dal trasporto in un ambiente poco profondo e di alta energia. In un simile ambiente, i foraminiferi, portati in sospensione e urtandosi l'uno con l'altro e/o con le particelle di sedimento, si distruggono. Nello stesso intervallo, l'analisi paleoecologica ha evidenziato che le specie raggruppate nella categoria "gusci intatti" appartengono a foraminiferi alloctoni, trasportati da un ambiente più superficiale a causa di eventi di trasporto. Di conseguenza, per questi intervalli, una corretta interpretazione paleoecologica sulla base delle associazioni esaminate non è stata possibile.

Negli intervalli sommitali e bioturbati dei cicli, la categoria "gusci rotti" raggruppa frammenti di gusci di forme ialine. Si ipotizza, quindi, che la distruzione dei gusci possa essere causata da un forte processo di dissoluzione. Nella tipica sequenza, la dissoluzione dei gusci porosi comporta la graduale corrosione e allargamento dei pori ed, infine, la rottura delle camere. Per questi intervalli l'analisi paleoecologica ha ricostruito un ambiente di deposizione tranquillo e superficiale, nel quale ci sono state variazioni del contenuto di ossigeno al fondo.

Keywords: benthic foraminifera, early Pleistocene, taphonomy, paleoecology

Parole chiave: foraminiferi bentonici, Pleistocene inferiore, tafonomia, paleoecologia

### 1. INTRODUCTION

Benthic foraminifera represent an important tool in ecological research. A vast literature established the existence of a strong relationship between the distribu-

tion of these organisms and oceanographic properties (Phleger, 1960; Chierici, Busi & Cita, 1962; Blanc-Vernet, 1969; Corliss, 1985; Caralp, 1989; Hermelin & Shimmield, 1990; Murray, 1991; Barmawidjaja *et al.*, 1992; Jorissen *et al.*, 1992). Changes in their faunal

composition are dependent on the responsiveness of each particular species, whose presence can be attributed to changes in environmental factors such as dissolved oxygen, nutrient input, water temperature and salinity, and bathymetry. Hence, analyses on the composition of benthic foraminiferal assemblages provide information about the properties of the ocean bottom-waters and their variations through time.

The modern-day distribution of benthic species is widely used to reconstruct the environmental conditions recorded by the fossil assemblages. Murray (1991) argued that the better paleoecological interpretations are extrapolated from the "ideal dead assemblage" that reflects, with fidelity, the living assemblage. However, the dead/fossil assemblage represents many generations accumulated over a long period of time (time averaging, Staff *et al.*, 1996). Furthermore, through the time, because of the relatively small size of benthic foraminifera, the dead assemblage is, potentially, very susceptible to post-mortem processes, i. e. transport and destruction of the tests, abrasion, dissolution and bioerosion (Murray & Alve, 1999, Martin, 1999). Consequently, a fossil assemblage can be relatively modified with respect to a living fauna and important information can be lost, and this may have negative implications in the paleoecological interpretation of the fossil assemblages. Hence, it is important to know the manner in which the fossils are preserved, i. e. taphonomy. The type of fossil preservation can, in fact, provide important insights and contribute to a better understanding of past ecology.

The present work represents a small contribution to the preservation history of the benthic foraminiferal fauna. Still little, in fact, exists on the taphonomy of fossil foraminifera (Murray, 1973; 1976a; 1983; Douglas *et al.*, 1980; Loubere & Gary, 1990; Murray & Alve, 1999; Walker & Goldstein, 1999; Barbieri, 2001) and probably less is known about the rate of taphonomical alteration suffered by tests in modern settings.

A quantitative taphonomical analysis is attempted on the benthic foraminiferal assemblages from four lower Pleistocene marine sequences. The aim is to compare the taphonomic data with the paleoecological results and to verify to what degree the taphonomic history obliterated the paleoecological signal. Moreover, since taphonomic and paleoecological results drawn from the mollusk assemblages are also available, a further purpose is to compare the response of such different taxonomic groups to taphonomic effects and paleoenvironmental changes.

## 2. GEOLOGICAL AND STRATIGRAPHICAL SETTING

The Lower Pleistocene studied sequences outcrop in western Emilia, along the external Apennine margin and form part of the infill of the Po Plain-Adriatic fore-deep (Fig. 1a). The Northern Adriatic is a collisional basin, characterized by active thrusting during the deposition, in which several basin-wide and unconformity-bounded sedimentary basins have been recognized (Ricci Lucchi *et al.*, 1982; Pieri, 1983; Ricci Lucchi, 1986). Sedimentologic data suggest that the Lower Pleistocene cycles were formed by changes in clastic

input, controlled by tectonics and the climate (Mutti, 1996; Molinari, 1997). In the Early Pleistocene, a phase of tectonic uplift increased the slope of the nearby mountain front and the sediment availability. Simultaneously, the local climate conditions in the form of heavy rain fall triggered hyperpycnal flows and turbidite currents that caused the delivery of large amounts of sands that deposited in the shallow shelf. This hypothesis is substantiated by data from the modern Mediterranean, where turbidity currents generated during river floods are recognized as important means of sediment delivery from the continent, across the shelf, and down to abyssal regions (Mulder *et al.*, 2001). Conversely, during times of widespread forestal cover of the nearby mountain fronts, in meteorological conditions similar to present ones, the mud deposition prevailed (Dominici, 2001).

The four Lower Pleistocene studied sections outcrop along the flanks of the Arda river (Castell'Arquato - Piacenza area) and the Stirone river (Salsomaggiore - Parma area), the Enza river (S. Polo - Reggio area), and the Tiepido river (Castelnovo - Modena area). The sequences are arranged in meter to tens-of-meters thick sedimentary cycles (Fig. 1b). The lowest part of each cycle is formed by stratified fine and coarse bioclastic sandstones intercalated with thin mudstone beds and flasers, followed upward by thoroughly bioturbated mudstones. Taphonomical data (Dominici, 2001) based on macrofaunal assemblages from the sandstone intervals are suggestive of the sedimentological transport of shelly material from shallow sandy bottoms (a 0-35m depth range is proposed on the basis of modern occurrences of the characterizing taxa), to slightly deeper settings (20-40m depth range), where these remains got mixed with local bivalves from dysaerobic bottoms. In this context, the upper mudstone part of each cycle represents the return to normal deposition in an inner-shelf setting. The near-monospecific assemblages dominated by *Arctica islandica* from the sandstone intervals are interpreted as diagnostic of dysaerobic conditions. Conversely, assemblages from the mudstone intervals, with a more diverse fauna dominated by *Venus multilamella*, show normal aerobic conditions.

## 3. MATERIAL AND METHODS OF ANALYSIS

For the benthic foraminiferal study, a total of thirty-nine samples were analyzed (see again Fig. 1b). The samples were collected in the mudstone beds intercalated in the sandstone intervals and in the bioturbated mudstones forming the upper part of each cycle. For each sample 300 gr. were washed over a set of sieves with mesh widths of 500, 250, 125 and 63  $\mu\text{m}$ . At least 300 individuals were counted. The benthic foraminifera counted belong to the species commonly distributed in the Mediterranean basin in the infralittoral zone (0-40m: Sgarrella & Moncharmont Zei, 1993), in accordance with the paleodepth determined through macrofaunal data (Dominici, 2001). In Appendix A the list of the taxa encountered in this study is shown.

For the taphonomic quantitative analysis, the entire washed residue > 125  $\mu\text{m}$  and < 500  $\mu\text{m}$  was examined in its benthic foraminifera content. The specimens were classified in the following taphonomic categories of

Wang & Chappell (2001), slightly modified for this study. These categories are: (1) fresh tests, (2) opaque tests, (3) light orange to dark brown iron-stained tests (including partially corroded tests), (4) black or black-striped tests filled with or replaced by pyrite (including partial dissolution of the tests). To these, another two categories have been added: (5) breakage of the tests (Murray & Alve, 1999) and (6) pitting (Boltovskoy & Wright, 1976). Finally, the percentages of frequency were calculated.

For the paleoecological quantitative analysis, the fraction 125-250 µm was examined in its benthic foraminifera content and the percentages of frequency calculated.

Then, Hierarchical Cluster Analysis, a statistical approach particularly indicated in presence of heteroge-

neous data set, was performed. Those taxa with a frequency of more than 2% as well as those of particular environmental significance were selected for this analysis. Finally, a raw data matrix, made up of 39 samples (rows) x 19 taxa (columns), was used. Hierarchical Cluster Analysis was performed on the relative percentage of frequencies per sample by means of SPSS program, version 9.0. The hierarchical clustering routine produces a dendrogram, a two-dimensional plot that shows how the data points (frequencies of taxa) can be clustered. For this work, the Q-mode and R-mode clustering were performed. The Q-mode clustering obtains a dendrogram that allows the recognition of samples with similar faunal compositions.

In the taphonomic analysis the R-mode clustering constructs a dendrogram that allows the grouping of the

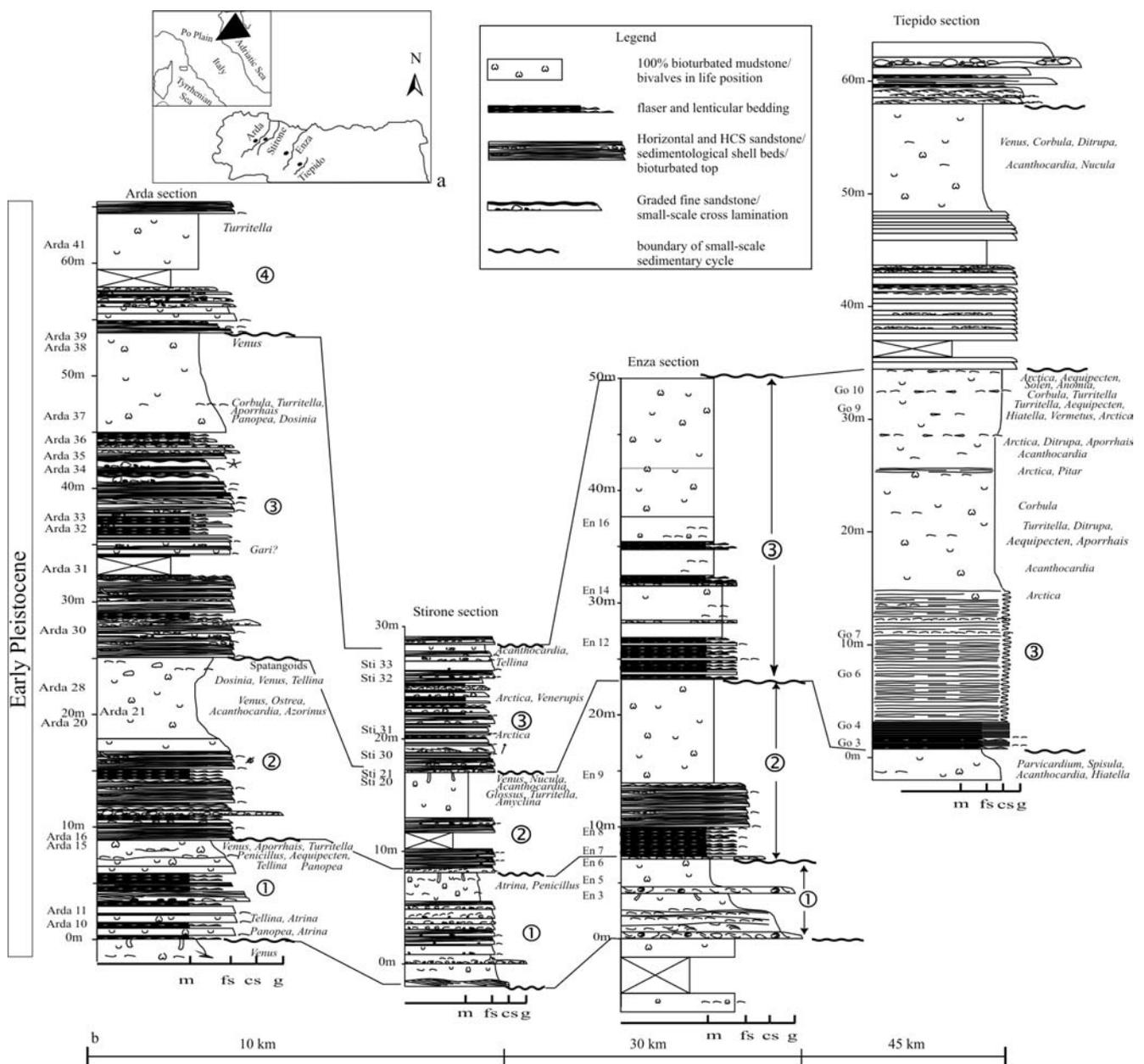


Fig. 1 - Location of the studied area and stratigraphic correlation of the small-scale sedimentary cycles detected in the four sections. Localizzazione dell'area studiata e correlazione stratigrafica dei cicli sedimentari a piccola scala riconosciuti nelle quattro sezioni.

taphonomic categories.

In the paleoecological analysis the R-mode clustering groups foraminifera with a similar ecological meaning.

The most significant dendrograms were obtained using the Average-Linkage Between Group, Pearson correlation.

#### 4. RESULTS

##### 4.1 Taphonomic analysis

In the Q-mode dendrogram, the samples are grouped into two big clusters, named Cluster I and Cluster II (Fig. 2). In the R-mode dendrogram, the taphonomic categories of pitting, dissolution and breakage form one cluster. The other categories are treated as poorly correlated variables and the lower degree of correlation is shown by the fresh tests.

Cluster I groups together samples that present the highest percentages of fresh tests, most of which come from the sandstone intervals. Within this cluster, the subclusters 1a and 1c include samples with the highest values of "breakage" and "pyritization", up to 40%. Common, also, are the light orange to dark brown iron-stained tests. Moreover, in subcluster 1a the samples show slightly higher percentages of opaque tests.

Cluster II groups, above all, samples from the mudstone intervals. Within this cluster the subcluster 2a consists of samples that have a high percentage of light orange to dark brown iron-stained tests, all from the Enza section. The subcluster 2b groups samples with pyritized, pitted and broken tests. Finally, subcluster 2c groups together samples characterized by opaque tests.

Regarding the traces of oxidation and pyritization, substantial differences emerge between the tests grouped in Cluster I (sandstones) and the tests grouped in Cluster II (mudstones).

In the mudstones, the tests present an internal pyrite replacement evidenced by the partial dissolution and/or breakage of the shell wall. Beautiful dissolution effects manifested by foraminifera are the internal moulds of hyaline perforated calcareous tests, such as *Valvulineria*, *Elphidium*, *Nonion depressulum* and *Rosalina*, and of agglutinated tests, such as *Textularia* and *Dorothia*. Also a few individuals of *Quinqueloculina* show internal moulds due to the partial dissolution of the test. This taphonomic feature is particularly evident in the mudstone associations of cycle 2 in Arda and Stirone sections.

In the sandstone associations, the oxidation and/or pyritization are, generally, external. The tests assume an orange-brown and/or black staining and traces of test dissolution are rather rare. Exceptions are the base of the sandstone interval of cycle 1, in the Arda and Enza sections, and the sandstone interval of cycle 3, in Stirone section, where internal pyritized moulds of individuals of *Ammonia beccarii*, *Valvulineria* and *Quinqueloculina* are also observable.

Focusing on the stratigraphic distribution of the different taphonomic categories, the high proportions of intact tests characterize assemblages from the mudstone partings of sandstone intervals when compared with the mudstone intervals (Fig. 2). Percentages of fresh tests increase eastward, reaching maximum values in samples of the Tiepido section. On the contrary, the black or black-striped tests filled with or replaced by pyrite have higher percentages in the Arda section, and decrease eastward. Opacity of the tests is the dominant shell alteration in samples from the mudstone interval of cycle 1 and in basal samples of the mudstone interval of cycle 3 (the Arda section). Broken tests and/or fragmentation of the tests characterize the whole sedimentary cycles but show major frequencies in the mudstone intervals. A decrease in entity of this feature is observed in cycle 3 and eastward, with the exception

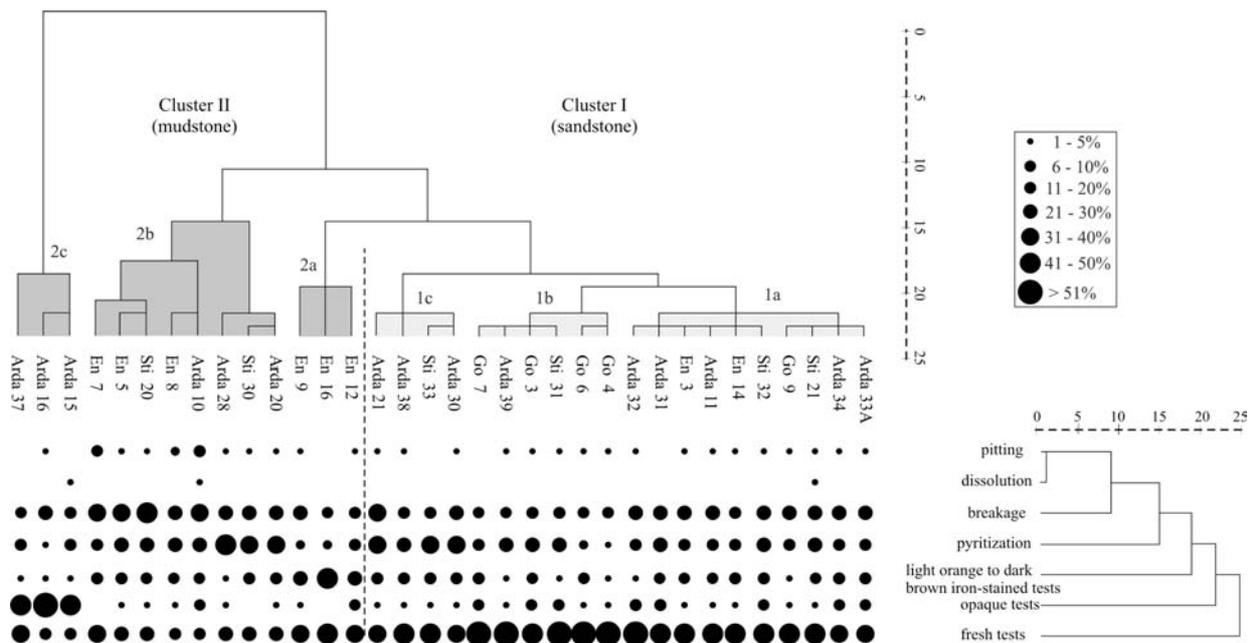


Fig. 2 - Q-mode and R-mode clustering of the samples from the Arda, Stirone, Enza and Tiepido sections for the taphonomic analysis. *Raggruppamento in Q-mode e R-mode dei campioni provenienti dalle sezioni Arda, Stirone, Enza e Tiepido per l'analisi tafonomica.*

of the Tiepido section. Iron-stained tests are more frequent in the mudstone intervals. Pitting shows its maximum effect at the base of cycle 1 in the Arda area, but is rare in other cycles and in the other sections.

**4.2 Paleocological analysis**

The assemblages are taxonomically homogeneous in all the sections. Differences concern the relative frequencies in the intervals of the sedimentary cycles. Assemblages from the Arda and Stirone sections show the strongest affinities. Similarity with the other sections, however, decreases eastward, across the Enza and Tiepido sections. Fauna compositions are dominated by species of the genera *Ammonia*, *Bulimina*, *Elphidium*, *Quinqueloculina*, *Textularia*, and by *Cassidulina carinata*, with percentages up to 50%. *Fursenkoina schreibersiana*, *Nonion depressulum*, *Triloculina gibba* and species of genera *Bolivina*, *Rosalina*, and *Valvulineria* are subordinated, with percentages ranging from 0% to 18%. *Asterigerinata mamilla*, *Bigenerina nodosaria*, *Buccella granulata*, *Cibicides lobatulus*, *Dorothia gibbosa*, *Planorbulina mediterranensis*, *Pyrgo bulloides*, *Reussella spinulosa*, *Sigmoilopsis schlumbergeri* and *Uvigerina* of the "forms costate" group are rare, with percentages always lower than 3%. Other taxa were scattered in the assemblages: *Astronion* sp., *Cibicoides pachydermus*, *Globocassi-*

*dulina subglobosa*, *Globobulimina affinis*, *Gyroidina umbonata*, *Hanzawaia rhodiensis*, *Hyalinea balthica*, *Lamarkina scabra*, *Lenticulina* sp., *Melonis* sp., *Nonionella turgida*, *Sigmoilina tenuis*, *Spiroloculina excavata*, *Stainforthia complanata*, *Trifarina angulosa*.

In Fig. 3, the Q-mode and R-mode dendrograms are displayed. The samples Arda 35 and Arda 36, since they are barren in foraminifera, have been omitted.

In Q-mode dendrogram we distinguish the large Clusters I and II, and the small subclusters 1, 2 and 3. In R-mode dendrogram, we distinguish the large Clusters A and B, and the minor subclusters C, D and E.

Cluster I groups samples belonging above all to the mudstone intervals. Conversely, Cluster II is composed by samples belonging to sandstone intervals. Subclusters within Cluster I suggest a further subdivision of mudstone assemblages. Subcluster 1 groups samples from cycle 2. Subcluster 2 consists in Tiepido samples. Subcluster 3 mostly consists in samples of cycle 3.

Cluster A includes *Quinqueloculina* gr. (the absolute dominating taxon in samples where it occurs), followed by *T. gibba*, *P. mediterranensis*, *A. mamilla*, and *C. lobatulus*. In Cluster B, subcluster C groups together *Bulimina* gr. and *N. depressulum*, subcluster D groups together *C. carinata*, *Bolivina* gr. and *S. schlumbergeri* and subcluster E groups together *Textularia* gr.,

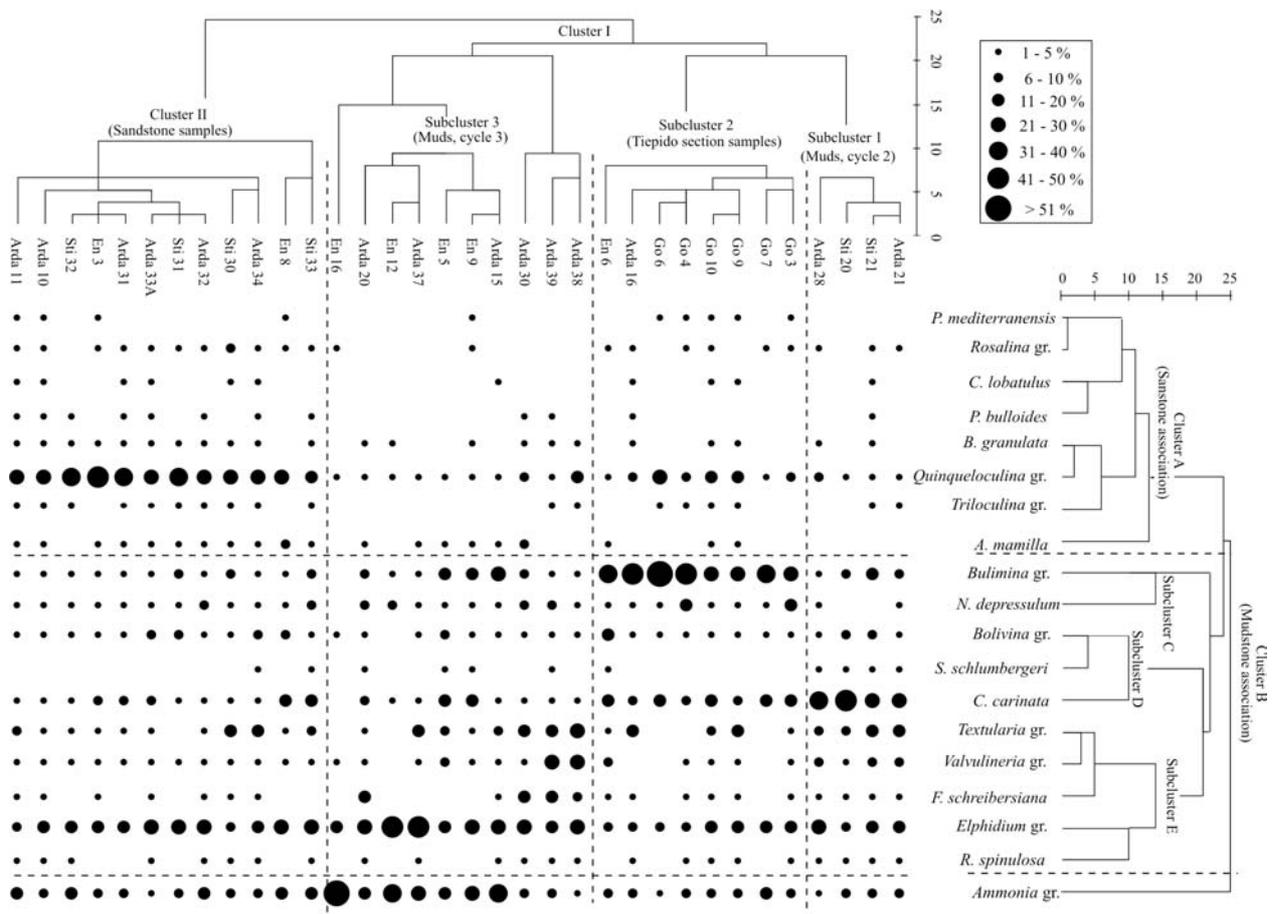


Fig. 3 – Q-mode and R-mode clustering of the samples from the Arda, Stirone, Enza and Tiepido sections for the paleocological analysis. *Raggruppamento in Q-mode e R-mode dei campioni provenienti dalle sezioni Arda, Stirone, Enza e Tiepido per l'analisi paleocologica.*

*Valvulineria* gr. and *Elphidium* gr.

Noteworthy, *Ammonia* gr. is a taxon common to all samples and so it is not associated to particular clusters.

## 5. DISCUSSION OF THE DATA

### 5.1 Taphonomy

The "fresh tests" category groups perfectly preserved intact tests (Plates, Figs. 1d, 3a, 5b, 7a, 8, 10, 12). The highest frequency of the "fresh tests" group is detected in the mudstone partings of the sandstone intervals of the Arda, Stirone and Enza sections. This feature, together with the lesser traces of fragmentation, abrasion and/or dissolution, indicates that the taphonomic processes were not active or their effects were minimized in the lower part of the cycles. Therefore, the taphonomic insights recorded may be suggestive of quiet paleoenvironmental settings, in which any transport at the bottom and any chemical process within the sediment involved the fauna. These taphonomic insights can also be suggestive of a different setting, strictly linked to poor oxygenated condition. The low oxygen availability may have, in fact, excluded the predatory fauna from the sediment itself thus limiting mechanical and digestive-chemical destruction. Furthermore, the low oxygen availability may also have limited the pH decrease within the sediment pore waters which results from aerobic oxidation, thus limiting pore water carbonate dissolution (Loubere, 1997). As a consequence, the tests are perfectly preserved.

The quiet environmental scenario seems to contradict the taphonomical results drawn from mollusk fauna of the same stratigraphic intervals (Dominici, 2001). The mollusk assemblages had, in fact, indicated catastrophic flooding events.

Focusing in detail on the shells included in the "fresh tests" category, it is observable that they belong, above all, to the order Miliolida. By contrast, the fragments belong, above all, to the infaunal hyaline tests, such as those of *Ammonia* sp., *C. carinata*, *Valvulineria* sp. and *Elphidium* sp. According to Martin (1999), the nature of the tests, i. e. shell mineralogy, architecture of the microstructure and size, well controls the different states of preservation of the tests in the same shallow high-energy regime. Therefore, the state of preservation of the microfauna detected in the sandstones may well be plausible with the shallow high-energy paleoenvironment. The porcelain tests of the order Miliolida, having thick walls and a low number of pores, resulted to be more resistant than the hyaline tests which, on the contrary, have thin walls and a larger number of pores.

Different is the taphonomic signal detected in the sandstones of the Tiepido section. The intact shells belong above all to the genus *Bulimina*, which has a hyaline and thin test. By contrast, *Quinqueloculina* group is less frequent. This can suggest that going eastward the hydrodynamic setting changed. No transport involved the lower part of the cycle 3, thus indicating quieter scenario.

The other taphonomic categories detected a group of tests coming above all from the mudstone parts of the cycles, whose original aspect is partially or totally modified. In these intervals, the great frequency of altered

and broken tests and the lesser frequency of fresh tests could be suggestive of the great activity of the mechanical and chemical processes within the sediment. The alteration of the tests in light orange to dark brown color implies an iron staining process that may be from  $\text{FeSO}_4$  or  $\text{Fe}(\text{OH})_2$  derived from oxidation of  $\text{FeS}_2$  (Wang & Chappell, 2001). The opacity of the tests, typical in forms whose walls were originally transparent, is indicative of the etching of calcite micro crystal edges in the tests under low pH condition (Wang & Chappell, 2001). Pyritized tests indicate a set of chemical reactions, rather common in reduced organic muds (Plates, Figs. 1b, 5a, 6, 9a, b). The process of pyritization, often followed by partial or total dissolution of the tests, indicates strong stressed environmental conditions related, principally, to lack of oxygen (Allison *et al.*, 1995). The pitting indicates the bioerosion activity (Plate 1, Fig. 2), the traces of which are expressed by rounded holes (Boltvskoy & Wright, 1976). The broken tests and/or fragments are the effects of destruction that can be related to several causes (Plates, Figs. 1c, 1e, 3c, d, 7b, 9a, c). In a high-energy hydrodynamic regime the shell accumulation was put into suspension, the tests battered into each other and/or into the particles of the sediment and, consequently, fragmented. Nevertheless, pitting is considered to be the initial phase of the dissolution of the foraminiferal carbonate by bacteria, which can lead, successively, to the disintegration of the chamber walls (Freiwald, 1995).

The bed preservation of the fauna in the mudstone intervals provides information about a paleoenvironment characterized by strong destructive effects.

The presence of internal pyritized moulds is indicative of oxygen-poor marine environments. In low oxygenated muddy bioturbated environments, pyrite does not form in the body of the sediment but forms in anaerobic microenvironments, commonly within shells, where it forms internal moulds (Martin, 1999). The absence, total or partial, of shells around the internal pyritized moulds is indicative of a dissolution process within the sediment. The total bioturbation state of the mudstone intervals of each cycle, in fact, supports the hypothesis of this process. Dissolution is greatest in areas of high bioturbation since alkalinity is impeded by increased fluid through burrows and this also enhances carbonic acid production mediated by aerobic respiration (Aller, 1982). Dissolution effects can, therefore, well explain the high degree of fragmentation in the microfauna. The typical sequence of dissolution of pore-bearing taxa consists, in fact, in the gradual increase of corrosion and amplification of the pores and, in the end, the breakage of the chambers (Martin, 1999). The relationship between the broken fraction with the dissolution process rather than hydrodynamics is well plausible with the interpretation of the mudstones as representing the return to the normal deposition after the catastrophic flooding events.

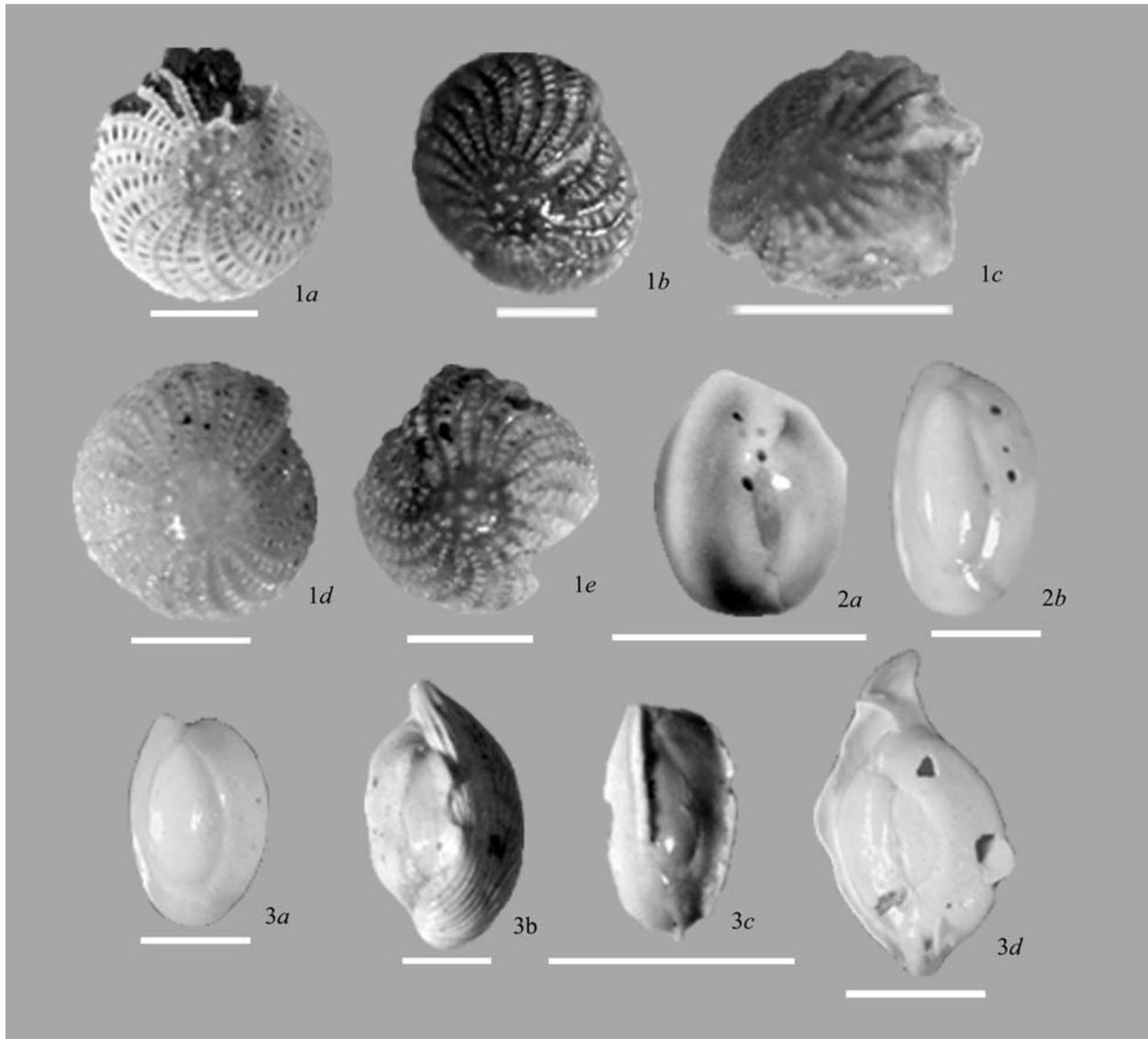
Unlike foraminifera, the mollusks, showing a more diverse fauna and dominated by *Venus multilamella*, suggest normal aerobic conditions at the bottom (Dominici, 2001). Moreover, bivalves show no traces of pyritization: the only pyrite coatings in bivalves are detected in the sandstone assemblages.

The different indications on the oxygen content given by these organisms may well be related to their

diverse style of life. *Venus multilamella* lives on the sea floor, while *Cassidulina*, *Bulimina*, *Valvulineria*, *Ammonia* and *Elphidium* live at a depth of 0.5 – 2 cm in the sediment column (Murray, 1991; Jorissen *et al.*, 1995). This means that *Venus multilamella* is influenced exclusively by dissolved oxygen content at the sea floor, unlike the infaunal foraminifera which are influenced by the oxygen concentration in sediment pore-water. Thus, the coexistence of these micro and macro organisms in the same stratigraphic interval is plausible: the pore-water sediment can be less oxygenated independently

by the dissolved oxygen regime on the bottom-water.

This is the same for the pyrite formation: it does not necessarily imply that the overlying water column was low oxygenated. Certain morphologies of pyrite can be formed under broadly oxic conditions within anaerobic micro-environments (Allison *et al.*, 1995), as the presence of internal pyritized moulds of foraminifera in the oxygenated mudstones clearly confirms. Still, the different effect of pyritization on the benthic organisms could be simply related to their taxonomical characteristics. In foraminifera, the pyrite formation depends on the ini-



#### Plate A

Different taphonomic aspects identified in the studied assemblages. The bar measures 0.25 mm.

Fig. 1 - *Elphidium crispum*. a: tests partially broken or dissolved showing the internal lining with pyrite; b: black stained test; c, e: broken shell; d: fresh test.

Fig. 2 - tests of *Quinqueloculina seminulum* showing the rounded holes, evident traces of pitting. a: dorsal side; b: ventral side.

Fig. 3 - Different states of preservation of tests of miliolids. a, b: fresh test of *Quinqueloculina seminulum* and *Adelosina mediterraneensis*; c: deformed test; d: flattened test.

*Differenti aspetti tafonomici riconosciuti nelle associazioni studiate. La barretta misura 0.25 mm*

*Elphidium crispum*. a: guscio parzialmente rotto o dissolto, con la cavità interna riempita di pirite; b: guscio nero; c, e: guscio rotto; d: guscio intatto.

*Gusci di Quinqueloculina seminulum mostranti i buchi rotondi, tracce evidenti di pitting.*

*Differenti stati di preservazione di gusci di miliolidi. a, b: gusci intatti di Quinqueloculina seminulum e Adelosina mediterraneensis; c: guscio deformata; d: guscio schiacciato.*

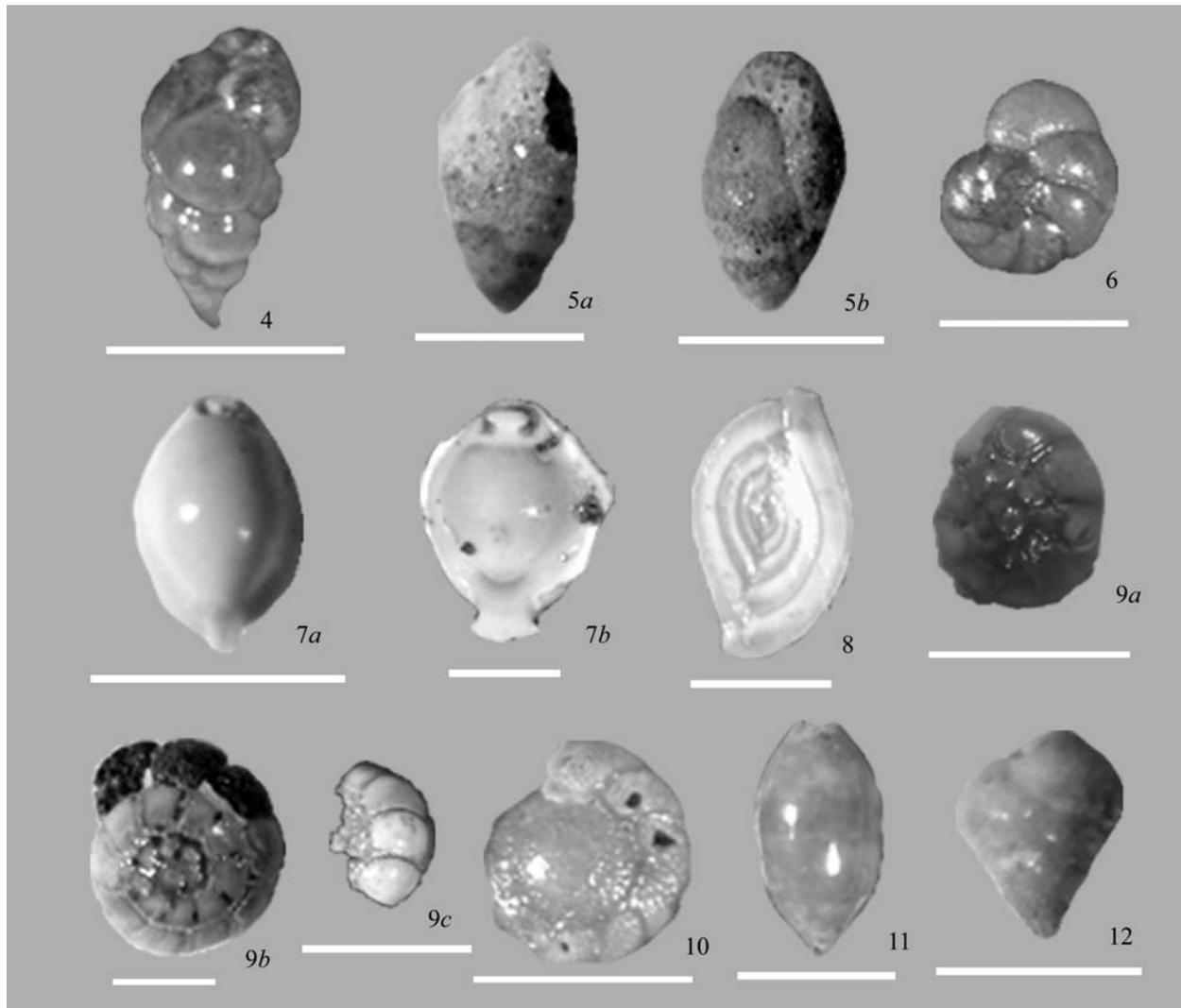
tial shell structure and the capacity of access of iron and sulfate ions into shells (Fischer, 1986), whilst only living mollusks, which get quickly buried under thick sandy beds, are not exposed to the complete degradation of the organic matter under aerobic conditions, and so, small pyrite coatings can form on the internal surfaces.

The higher level of alteration shown by foraminifera, a component of the benthic community, could be explained through a longer residence in the taphonomically active zone recorded in the mudstone intervals (TAZ; see Loubere, 1997; Walker & Goldstein, 1999). With this hypothesis, the mudstone intervals would represent a longer span of time with respect to muddy

strata of comparable thickness from the sandstone intervals, in accordance with the general sedimentological setting (Dominici, 2001). Mudstones from sandstone intervals are, in fact, interpreted as produced by the waning phase of turbidity currents (Dominici, 2001).

## 5.2 Paleoecology

Cluster A association can be considered representative of the mudstone partings of the sandstone intervals of each cycle, with the exception of the Tiepido section (Fig. 4). The association is formed by diverse and abundant individuals of *Quinqueloculina* spp. and *Triloculina* spp. Scattered permanently attached forms



### Plate B

Fig. 4, 6 - Black stained tests of *Bulimina elegans* and *Valvulineria brayana*.

Fig. 5 - *Dorothia gibbosa*. a: shell partially broken or dissolved showing the internal lining with pyrite; b: fresh test.

Fig. 7 - *Pyrgo bulloides*. a: fresh test; b: flatted test.

Fig. 8 - Fresh test of *Spiroloculina excavata*.

Fig. 9 - *Ammonia beccarii*. a: broken and black stained test; b: shell partially broken or dissolved showing the internal lining with pyrite; c: fragment of test.

*Gusci neri di Bulimina elegans e Valvulineria brayana.*

*Dorothia gibbosa*. a: *guscio parzialmente rotto o dissolto, con la cavità interna riempita di pirite*; b: *guscio intatto*.

*Pyrgo bulloides*. a: *guscio intatto*; b: *guscio schiacciato*.

*Guscio intatto di Spiroloculina excavata.*

*Ammonia beccarii*. a: *guscio rotto e nero*; b: *guscio parzialmente rotto o dissolto, con la cavità interna riempita di pirite*; c: *frammento di guscio*.

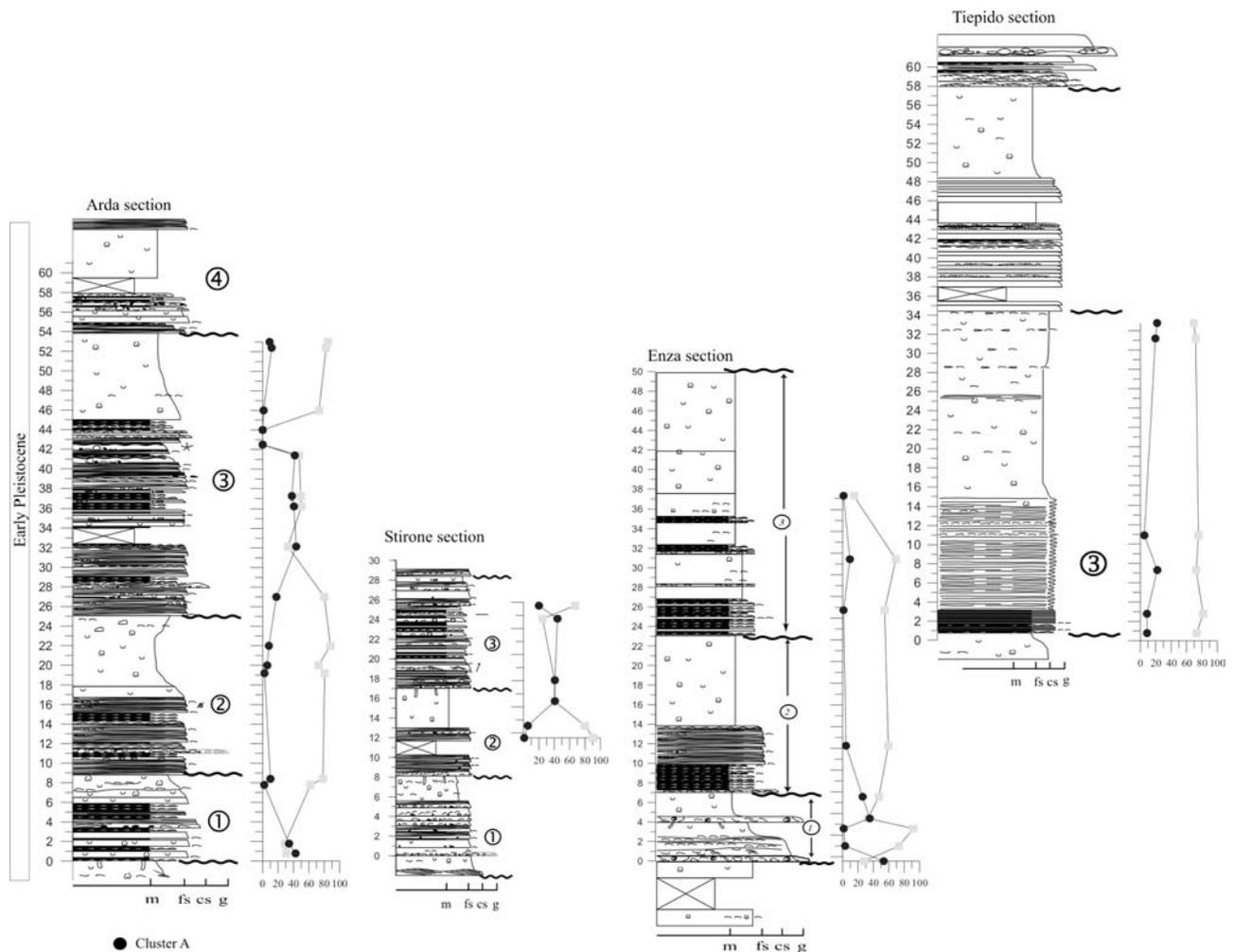


Fig. 4 - Stratigraphic distribution of the associations of Cluster A and Cluster B throughout the sections.  
*Distribuzione stratigrafica delle associazioni dei Clusters A e B lungo le sezioni.*

such as *C. lobatulus* and *P. mediterraneensis* and facultative mobile species such as *Asterigerinata* sp. are also included. All these species have an epifaunal microhabitat preference commonly in well-oxygenated marine environments (Murray, 1991).

This fauna composition shows a strong similarity with the seagrass assemblages of the Mediterranean, distributed at a depth of 2–40 m (Murray, 1991). So, the restriction of the seagrass association to samples coming from sandstone intervals, interpreted as the result of the shallow water turbidity currents triggered by catastrophic flooding events, induces us to consider Cluster A association as displaced, transported from shallower environments. This means that, since considered allochthonous, the taxa grouped in the association of Cluster A must be subtracted from the paleoecological investigation. Consequently, the fauna association is extremely poor, composed only of the taxa grouped in Cluster B. The general sedimentologic aspect of the mudstone intervals and the nature of the macrofaunal association that it contains (Dominici, 2001), allows, in fact, the interpretation of the fossil association of Cluster B as autochthonous or parautochthonous.

The scarcity of the fauna could well be related to the strongly stressed environmental condition in conse-

quence of the high input of organic matter from the river that caused the consumption of oxygenation at the sea floor. The stressed environmental conditions, in fact, are hostile to life. In this context, the two samples barren in foraminifera, Arda 35 and Arda 36, both from cycle 3 of the Arda section, would document an anoxic event. Thus, the above-mentioned interpretation could be in good accordance with the hypothesis of hypoxic conditions at the bottom as suggested by the analysis of macrofaunal remains in life position from the sandstone interval of cycle 3 (Dominici, 2001). However, the scarcity of the fauna could have been caused by the nature of the high hydrodynamic setting rather than the oxygen deficiency. The continuous impacts among the shells could have caused the destruction of a great part of the fossils. As, in fact, the taphonomic analysis indicated, the fragments belong to the delicate hyaline tests.

The Cluster B association can be considered diagnostic of the upper part of the cycles since it is better represented in mudstones (see always Fig. 4). In the Tiepido section this association characterizes also the lower part of cycle 3.

Within Cluster B, the distribution of the associations in the subclusters C, D and E allows a further differentiation of the mudstone association from the three

cycles (Fig. 5). In the muds of cycle 1 the fauna is dominated, above all, by diverse species belonging to the genus *Bulimina* (subcluster C association). *C. carinata* characterizes the muds of cycle 2 (subcluster D association). The species of the genus *Elphidium* are abundant in the mud interval of cycle 3 (subcluster E association). *Ammonia* gr. is abundant in samples from the Enza section, particularly in sample En16 where its abundance reaches 78%, and in cycle 1 of the Arda section. It decreases in the Tiepido section.

The taxa are common in modern muddy marine substrates from depths of 25 m downwards (Murray, 1991). Among them, *C. carinata*, *Valvulineria* sp. *Bulimina* gr., *Bolivina* gr., are shallow infaunal typical of sediments that display low quantity of dissolved oxygen and rich in organic matter (Murray, 1991; Bergamin *et al.*, 1992). *Ammonia* spp. and *Elphidium* spp. prefer well-oxygenated environments, though some species such as *Protelphidium granosum* and *Ammonia beccarii* var. *tiepida* show a moderate tolerance of lowered oxygen conditions (Jorissen, 1988; Murray, 1991).

By schematizing the stratigraphic distribution of

the subcluster associations, it is possible to reconstruct a fossil fauna replacement throughout the sedimentary cycles (Fig. 6).

In the upper part of cycles 1 and 2, the fossil association distribution suggests low oxygenated sediment pore-waters in shallow marine environment. In the upper part of cycle 3 the replacement by *Elphidium* spp. and *Ammonia* spp. seems to suggest a change in the environmental scenario, from a strictly shallow marine scenario to a lagoon one. Individuals of *Ammonia* and *Elphidium* are, in fact, very abundant in stressed environments such as brackish lagoons and estuaries (Murray, 1991). Associations characterized by more than 60% of *A. beccarii* and *A. tiepida*, as the frequency detected in the Enza section, have been observed in the Venice Lagoon (Albani & Serandrei Barbei, 1982).

In the Tiepido section, the replacement of *Bulimina* spp. association by the association rich in individuals of *Elphidium* spp. and *Quinqueloculina* spp. may well provide information about an increased dissolved oxygen content at the bottom-water surface towards the top of cycle 3.

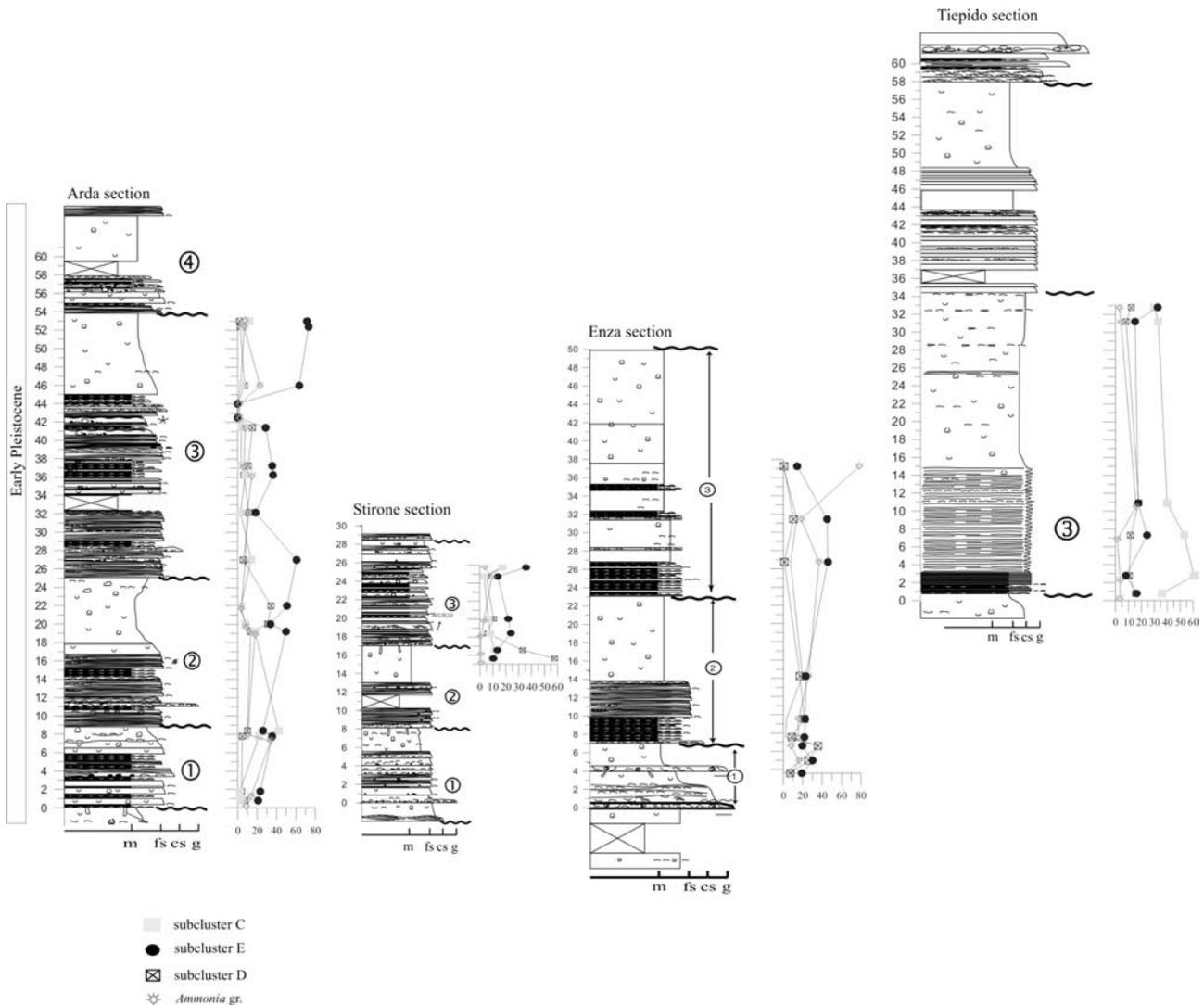


Fig. 5 - Stratigraphic distribution of the associations of subcluster C, subcluster D and subcluster E, and of *Ammonia* gr. throughout the sections.

Distribuzione stratigrafica delle associazioni dei subclusters C, D e E, e di *Ammonia* gr. lungo le sezioni.

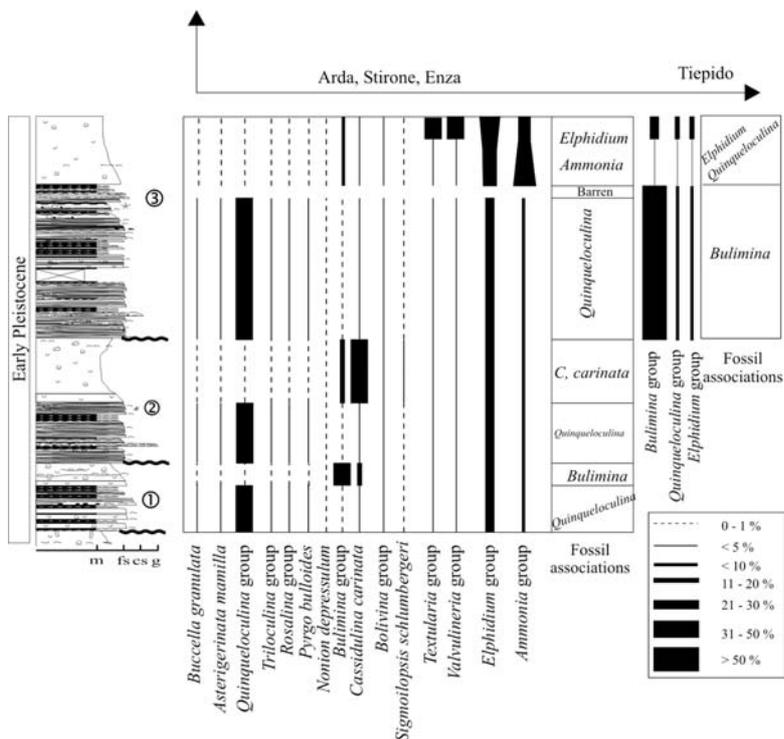


Fig. 6 - Schematic fauna replacement throughout the small-scale sedimentary cycles.

Sostituzione schematica delle fauna nei cicli sedimentari a piccola scala.

## 6. CONCLUSIONS

The foraminiferal taphonomic investigation represents a helpful tool in order to draw a correct paleoecological interpretation of the lower Pleistocene.

The investigation pointed out, in fact, that traces of paleoecological evidence had been lost over time. The destruction of the tests, the most evident post-mortem process, caused a substantial specimen loss in the fauna. Part of the allochthonous or parautochthonous components has been lost. In particular, in the mudstone partings of the sandstone intervals, this loss had negative implications in the reconstruction of the paleoecological history. The fauna detected in the samples from these intervals is not able to support the reconstructed hypoxia condition at the bottom as suggested by the mollusks. The scarcity of the fauna, although typical of a hostile environment, can not be strictly related, in this case, to strong low oxygen availability. The high-energy setting induces, in fact, the hypothesis that the tests might have been totally destroyed, and, hence, no trace of their presence was detected.

In the mudstone intervals, the low energy setting allowed the better preservation of the paleoecological signal. Although the substantial specimen loss in the fossil association, strictly related to dissolution effects, the paleoecological results drawn from the micro fauna are well in accordance with the paleoecological results drawn from the macro fauna.

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