New faunistic data on the Pleistocene environmental evolution of the south-western edge of the Hyblean Plateau (SE Sicily)

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Abstract: Faunistic associations of the Lower Pleistocene sediments, out-cropping at Cartiera Molino along the true right bank of the Ippari River (Vittoria, SE Sicily), have been investigated. This study integrates data obtained from the analysis of ostracods, foraminifers, bryozoans and serpulids found within a six metre thick sedimentary section. This multiproxy approach allowed us to reconstruct the palaeoenvironmental evolution of this south-western sector of the Hyblean Plateau (Comiso-Vittoria area) from fluvially-influenced shallow marine settings, recorded in the lower portion of the succession, to progressively shallower, transitional and brackish environments, testified in mid levels, up to freshwater environments at the top of the section.

Key Words: Palaeoenvironmental evolution; marine environment; brackish environment; freshwater environment; benthos; Pleistocene; Sicily.

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Riassunto: ***Evoluzione ambientale pleistocenica nel settore sud-occidentale del Plateau ibleo (Sicilia SE).-*** Sono state studiate le associazioni ad ostracodi, foraminiferi, briozoi e serpulidi riscontrate in una successione sedimentaria pleistocenica, affiorante in località "Cartiera Molino" nei pressi di Vittoria (RG), lungo la riva destra del Fiume Ippari. L'analisi faunistica effettuata lungo la sezione ha consentito di definire l'evoluzione pleistocenica del settore sud-occidentale del Plateau Ibleo (area di Comiso-Vittoria) da paleoambienti marini del piano infralitorale, testimoniati nei livelli basali della successione, ad ambienti progressivamente meno profondi di transizione e salmastri, testimoniati nei livelli intermedi, fino ad ambienti francamente dulcicoli individuati nei livelli sommitali della sezione.

Parole chiave: Evoluzione paleoambientale; ambiente marino; ambiente lagunare; ambiente lacustre; benthos; Pleistocene; Sicilia.

Résumé : ***Nouvelles données faunistiques sur l'évolution environmentale pléistocène de la bordure sud-ouest du Plateau Hybléen (Sud-Est de la Sicile).-*** Nous avons étudié les associations d'ostracodes, de foraminifères, de bryozoaires et de serpulidés d'une succession sédimentaire d'âge Pléistocène inférieur qui affleure sur la rive droite de la rivière Ippari, à "Cartiera Molino" près de Vittoria (RG). L'analyse a permis de définir l'évolution pléistocène d'un secteur sud-ouest du Plateau Hybléen (secteur de Comiso-Vittoria) depuis un milieu marin peu profond accusant quelques influences fluviatiles, observé à la base de la succession, en passant par des environnements progressivement moins profonds, de transition et puis saumâtres, tels qu'enregistrés dans les niveaux médians, jusqu'aux environnements d'eau douce, rencontrés au sommet de la section.

Mots-clefs : Évolution paléoenvironmentale ; milieu marin ; milieu lagunaire ; milieu d'eaux douces ; benthos ; Pléistocène ; Sicile.

1. Introduction

The ecological distribution of marine benthic organisms depends not only on biotic factors, but also on several environmental physico-chemical and climatic parameters. In coastal-deltaic environments, ostracod distribution depends almost exclusively on salinity (Carbonel *et al.*, 1972; Hoibian *et al.*, 2000; Smith & Horne, 2002, *inter alias*), while in fully marine environments depends on several other factors largely varying with depth, such as temperature, texture of the bottom sediments and local hydrodynamic energy, availability of food and oxygen. Consequently, particular ostracod associations can be considered as indicative of specific environmental conditions and used as tools to reconstruct palaeoenvironments.

Among the benthic organisms employed to define environmental and palaeoenvironmental conditions, ostracods have been used for a long time in various geological research fields, particularly in oceanographic (Benson, 1984, *inter*

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Figure 1: Geographical location of the Cartiera Molino section in South-Eastern Sicily.
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alias) and ecological studies (Babinot & Lethiers, 1984; Carbonel, 1987; Guernet & Lethiers, 1989, *inter alias*). These organisms have been shown to be particularly important for these purposes in deep-marine environments (Ayress *et al.*, 1997; Majoran & Dingle, 2001, *inter alias*) as well as in shelf, marginal and non marine environments.

Indeed, like a few other taxonomic groups, ostracods exhibit a wide range of ecological adaptations and include typically marine, brackish and freshwater species allowing the evolution from marine to transitional and/or continental environments to be traced (Frenzel & Boomer, 2005; Gliozzi & Grossi, 2008; Mischke & Holmes, 2008; Zaîbi *et al.*, 2011, *inter alias*). Ostracods are a useful tool for palaeoenvironmental interpretation in addition to other marine benthic faunistic groups in a multidisciplinary study performed by Messina *et al.* (2009) on a section from the Pleistocene Barcellona Pozzo di Gotto Basin (NE Sicily). In that study, data provided from several benthic organisms (molluscs, bryozoans, serpuloideans, crustaceans, foraminifers) were integrated with sedimentological, taphonomic, and biostratigraphic observations.

In the present study, a similar methodological approach is adopted to detail the palaeobasin evolution recorded in a Pleistocene sedimentary succession out-cropping along the south-western edge of the Hyblean Plateau, SE Sicily (Fig. 1).

2. Material and methods

The present analysis focuses on a sedimentary succession, six metres thick (Figs. 1-3), cropping out at Cartiera Molino (F. 276, IV NW; Lat. 36°56'58"; Long. 2°07'00") along the true right bank of the Ippari River, near Vittoria (RG). In this area the Quaternary sedimentary succession lies unconformably on Miocene carbonate formations and/or on Lower Pliocene calcareous marls, locally known as "Trubi" (Figs. 1 - 2). Pleistocene sediments consist predominantly of yellow calcareous sands, sands and silts and/or calcarenites with *Arctica islandica* (Linnaeus, 1767) and *Hyalinea balthica* (Schroeter, 1783) evolving laterally and upward to marine whitish silts and sands locally capped by lacustrine white calcareous silts and travertine deposits, which locally show discontinuous breccias and conglomerates intercalations. This succession is truncated by an erosive surface, on which early-mid Pleistocene sandy sediments are present. This sedimentary succession represents the transition from the marine whitish silts and sands to the white calcareous silts and continental travertines.

The white calcareous silts of the Cartiera Molino section were described in a short note by Ruggieri (1961), who recorded some freshwater ostracods, and in a geological study by Conti *et al.* (1979) reporting the presence of the freshwater gastropods *Bithynia leachi* (Shepard), *Planorbis planorbis* (Linnaeus) and *Lymnaea peregra* (Müller).

The molluscan faunas were susequently studied by Costa (1989), who indicated the presence of shallow-water marine species among which *Flexopecten hyalinus* (Poli, 1795), *Loripinus fragilis* (Philippi, 1836), *Loripes lacteus* (Linnaeus, 1758), *Cerithium vulgatum* Bruguière, 1792, *Conus mediterraneus* (Gmelin, 1791) and *Bittium reticulatum* (Da Costa, 1778).

Due to the lack of species stratigraphically significant, these sediments have been referred to the early Pleistocene on the basis of their stratigraphic position. Indeed, they overlay calcarenites containing *A. islandica* (Linnaeus) and *H. balthica* (Schroeter).

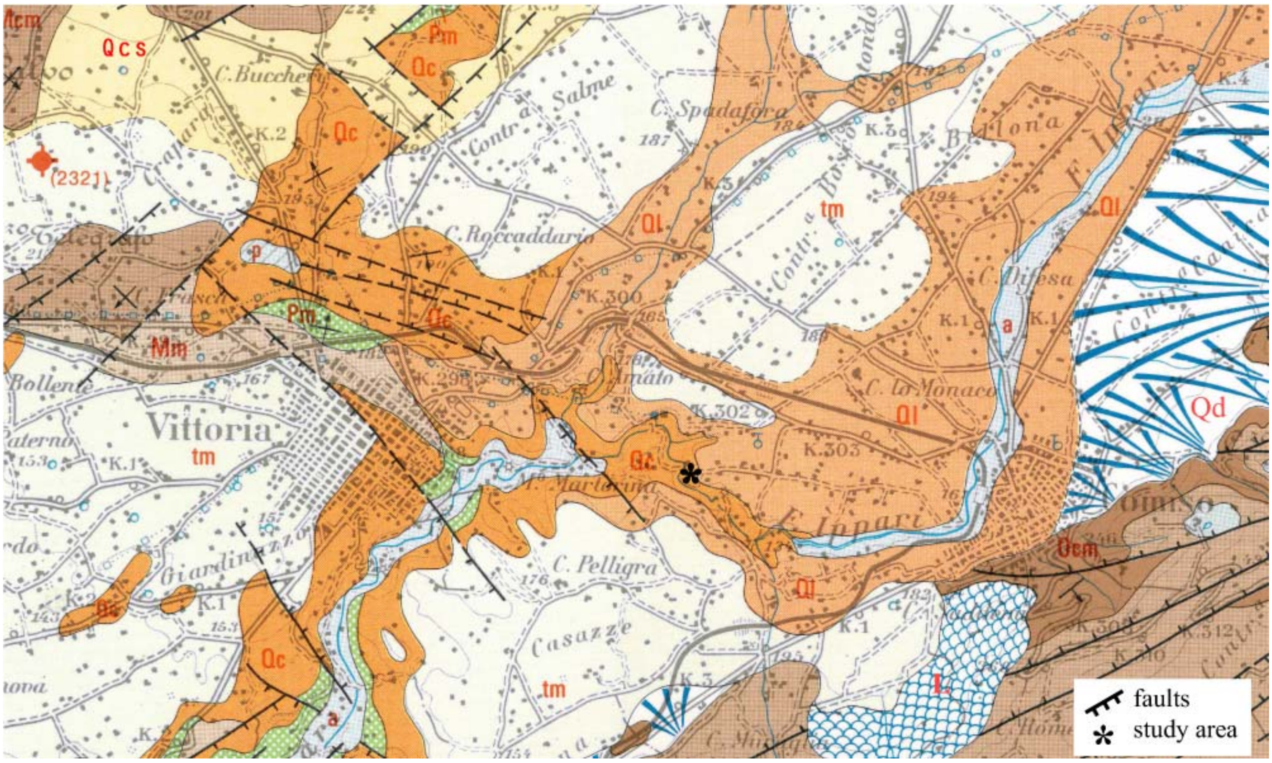


Figure 2: Geological map of the Cartiera Molino section area (excerpt from Lentini *et al.*, 1984, Carta geologica della Sicilia SE alla scala 1:100.000, modified). a) Alluvium. Recent; L) Landslide; Qd) Detritus deposits; tm) Sands, calcarenites and marine terraces. Middle-Upper Pleistocene; Ql) Silts and travertine, Qc) calcarenites, Qcs) sands and clays. Lower Pleistocene; Pm) Calcareous marls of Trubi. Lower Pliocene; Mn) Mudstones and marls of Tellaro Fm. Upper Miocene; Mcm) Calcarenites of Ragusa Fm (Irminio Member). Lower Miocene; Ocm) Calcarenites of Ragusa Fm (Leonardo Member). Upper Oligocene.

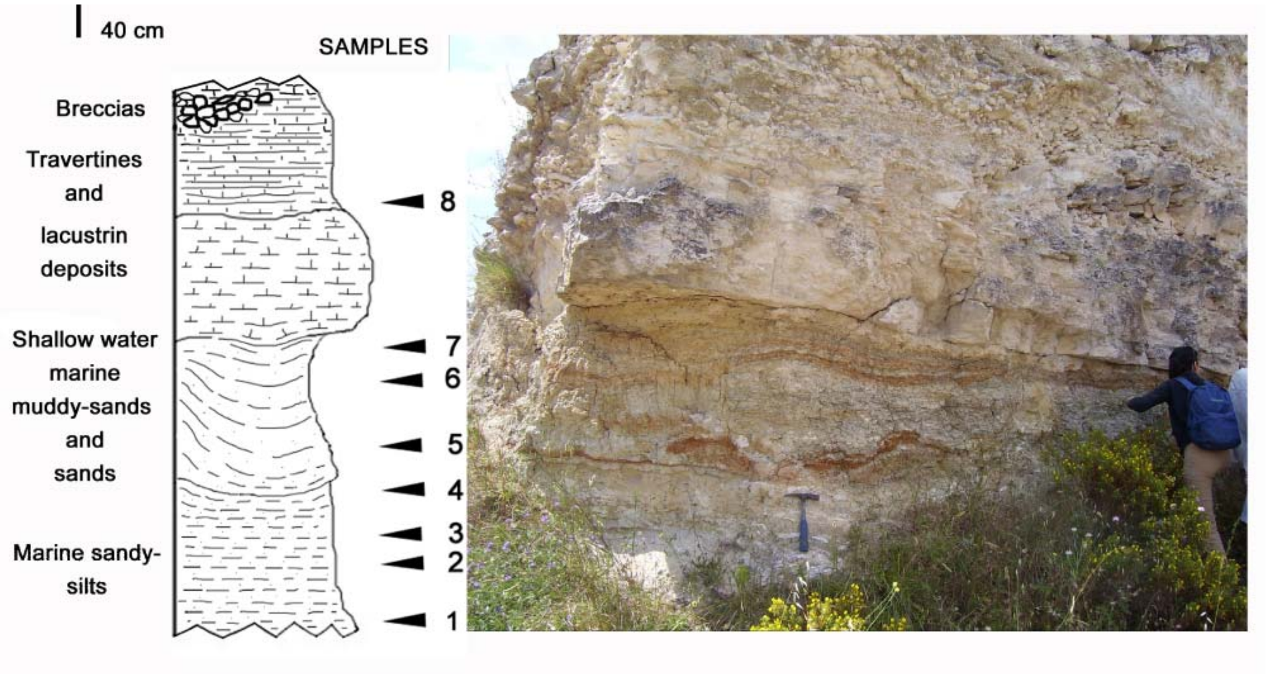


Figure 3: The sedimentary succession cropping out at Cartiera Molino and the corresponding stratigraphical log with sampling location.

The examined section (Fig. 3) exposes at the base 1.5 metres of sandy silts followed by 1.5 m of more or less cemented muddy sands and sands that are capped by about 3 metres of travertine precipitates. Within travertines a 45 centimetres thick layer of whitish carbonate limestone is interbedded, at 45 centimetres from its wavy basal contact.

For this study, a total of eight samples was collected (Fig. 3) with samples 1-3, coming from the sandy silts from the basal part of the section, samples 4-6 from sands in the intermediate part of the section, and samples 7-8 from the whitish limestones.

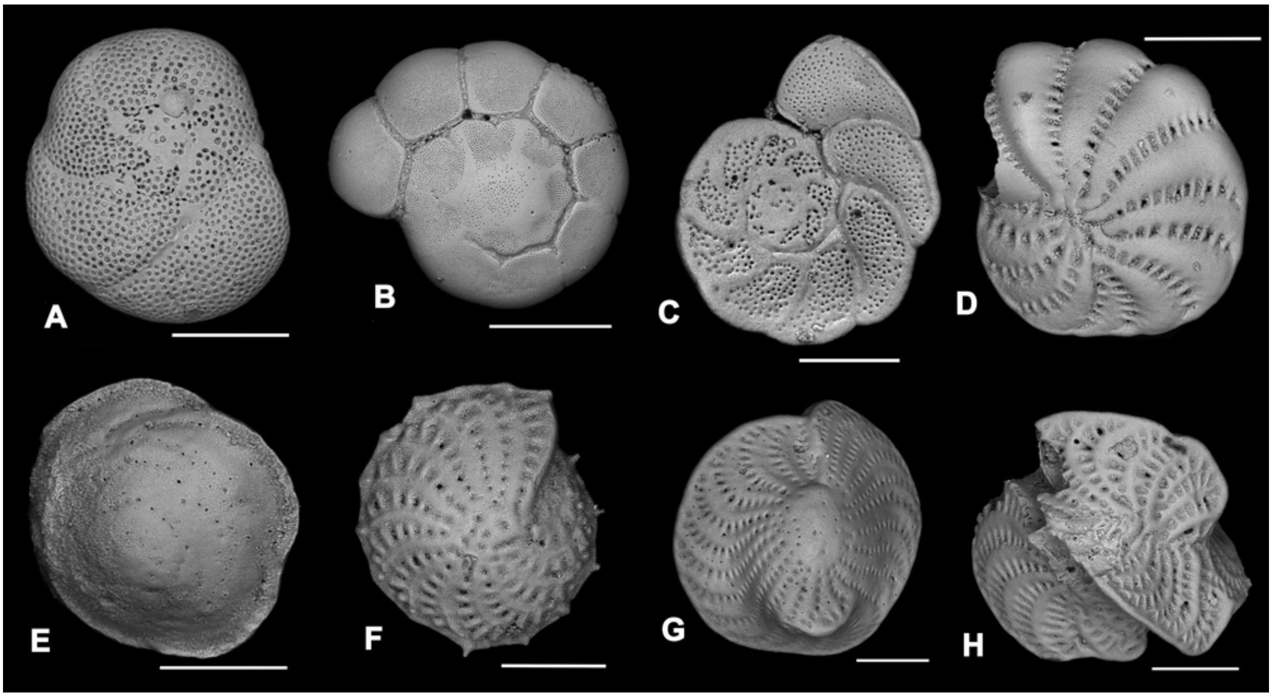


Figure 4: Foraminifers. A) *Rosalina globularis* ORBIGNY, 1826. Scale bar 200 µm; B) *Ammonia beccarii* (LINNAEUS, 1758). Scale bar 200 µm; C) *Cibicides lobatulus* (WALKER & JACOB, 1798). Scale bar 200 µm; D) *Elphidium* sp. Scale bar 200 µm; E) *Asterigerinata mamilla* (WILLIAMSON, 1858). Scale bar 200 µm; F) *Elphidium aculeatum* (ORBIGNY, 1846). Scale bar 200 µm; G) *Elphidium* sp. (teratologic specimen). Scale bar 250 µm; H) *Elphidium* sp. (teratologic specimen). Scale bar 250 µm.

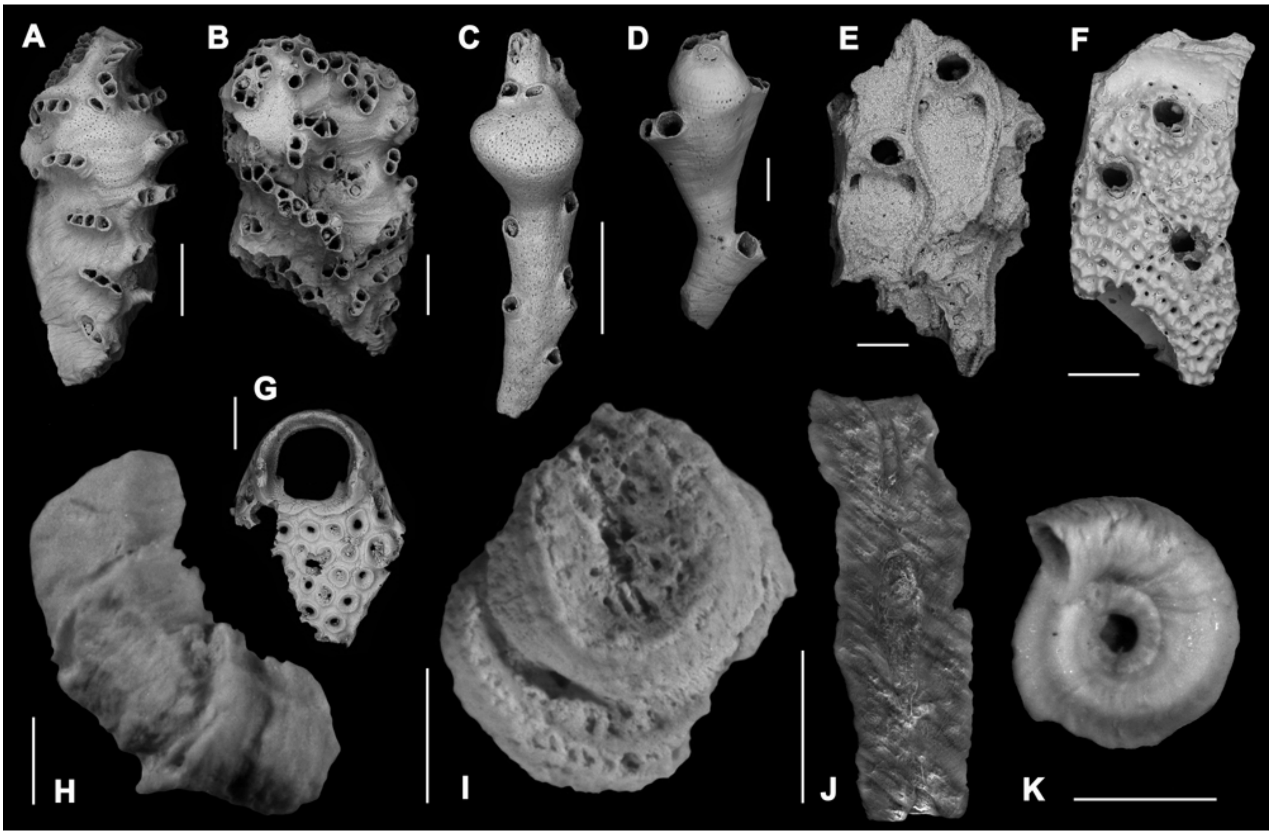


Figure 5: Serpuloideans, bryozoans and bioimmuration casts. A) *Platonea stoechas* HARMELIN, 1976. Scale bar 500 µm; B) ? *Tubulipora plumosa* HARMER, 1898. Scale bar 500 µm; C) ? *Crisia pyrula* HARMELIN, 1990. Scale bar 500 µm; D) *Crisia fistulosa* (HELLER, 1867). Scale bar 200 µm; E) *Calpensia nobilis* (ESPER, 1796). Scale bar 200 µm; F) *Schizomavella* sp. Scale bar 200 µm; G) ? *Watersipora* sp. Scale bar 200 µm; H) *Vermiliopsis striaticeps* (GRUBE, 1862). Scale bar 500 µm; I) *Spirobranchus polytrema* (PHILIPPI, 1844). Scale bar 1 mm; J) Undersurface of an encrusting portion of a serpulid skeleton exposing the mould of a *Posidonia* leaf. Scale bar 500 µm; K) *Neodexiospira pseudocorrugata* (BUSK, 1905). Scale bar 500 µm.

From each sample 300 cc of sediment was washed routinely, as reported in SCIUTO (2003, 2005). All specimens of ostracods, foraminifers, bryozoans and serpuloideans were picked from the > 63 µm fraction. They were determined to species level when possible. Ostracod species were particularly examined (see below in the taxonomic section) and their specimens measured under a stereo microscope and some photographed using an LMU Tescan Vega II Scanning Electron Microscope. The fossil material is housed at the Paleontological Museum of the University of Catania (PMC).

3. Results

3.1. Benthic associations found in the samples collected are characterised by highly variable specimen abundance and species richness for each of the studied taxa (Tables 1-4)

In the ostracod fauna, 41 species, belonging to 27 genera, have been found (Table 1, Pl. 1). A gradual decrease in the number of both species and genera from the lower part of the section to the top has been observed. Benthic foraminifers are present with a total of 15 species (Table 2, Fig. 4). They are common and diverse in the basal samples, decrease in the central part of the section and disappear in the upper part. Serpuloideans and bryozoans (Tables 3 - 4, Fig. 5) are represented by a total of 8 and 10 species, respectively. They occur mostly in samples from the basal part of the section, sporadically in the middle part and are completely absent from the top part.

The basal sandy-silty layers (samples 1-3) contain abundant and diversified benthic associations. Ostracods range from 14 to 23 species per sample. The most abundant species are *Aurila* gr. *A. convexa* (BAIRD, 1850), *A.* cf. *A. cruciata* (RUGGIERI, 1950), *Urocythereis sororcula* (SEGUENZA, 1880), *Loxoconcha gibberosa* TERQUEM, 1878, *Neonesidea mediterranea* (MÜLLER, 1894), *Costa batei* (BRADY, 1880), *Urocythereis margaritifera* (MÜLLER, 1894), *Graptocythere hscripta* (CAPEDER, 1900) and *Carinocythereis whitei* (BAIRD, 1850). Benthic foraminifers are common with 4-7 species per sample. Associations are dominated by *Ammonia beccarii* (LINNAEUS, 1758) (Fig. 4.B), *Rosalina globularis* ORBIGNY, 1826, *Cancris auriculus* (FICHTEL & MOLL, 1798), *Asterigerinata mamilla* (WILLIAMSON, 1858) (Fig. 4.E), *Cibicides lobatulus* (WALKER & JACOB, 1798) (Fig. 4.C) and by some species belonging to *Elphidium* (Fig. 4.F-H).

Serpuloideans and bryozoans are relatively abundant and diversified, although extremely fragmented. Serpuloideans are usually found as less than 1mm tube fragments and bryozoans consist of no more than 2-4 associated zooids (Fig. 5.E-F) and even single broken zooids (Fig. 5.G). The internodes of jointed species (*Crisia* spp.) are broken (Fig. 5.C-D) and exceptionally a few larger cyclostome bryozoan colony fragments (Fig. 5.A-B) have been found. Dissolution is often evident. For these reasons several specimens were identified to species level, or even to genus level, only tentatively.

Serpuloideans include 9 species, but they are all present in sample 3 whereas they are absent in sample 1 and represented by a single species in sample 2. Specimens belonging to the genus *Hydroides*, particularly to *H. dianthus* (VERRIL, 1873) and *H. elegans* (HASWELL, 1883), as well as to the species *Vermiliopsis striaticeps* (GRUBE, 1862) (Fig. 5.H). Other species, such as *Serpula vermicularis* LINNAEUS, 1767, *Neodexiospira pseudocorrugata* (BUSK, 1905) and *Janua pagenstecheri* (QUATREFAGES, 1866) are subordinate.

Bryozoans total 10 species. Species richness per sample ranges from 4 to 9. Internodes of *Crisia*, including those of the species *C. fistulosa* (HELLER, 1867) (Fig. 5.D) and ? *C. pyrula* HARMELIN, 1990 (Fig. 5.C) dominate the fossil associations. *Platonea stoechas* HARMELIN, 1976 (Fig. 5.A) is also abundant whereas all other species are represented by very few or even a single fragment, as is the case for ? *Watersipora* sp. (Fig. 5.G).

Bioimmuration casts have been observed on the basal surfaces of some encrusting specimens, that were better preserved, belonging to both serpuloidean and bryozoans taxa (Fig. 5.J).

Samples 4-6 from the muddy sands and sands, of the intermediate part of the section, contain benthic associations decidedly poorer than those of the basal part. Furthermore, both species richness and specimen abundance decrease markedly upward and fossil content is nearly completely absent in the topmost sample 6 (Tables 1 - 4). Ostracods are restricted to sample 4, where only 6 species occur, 5 of which share with associations from the previous samples. Three of them, namely *Aurila* gr. *A. convexa* (BAIRD, 1850), *A.* cf. *A. cruciata* (RUGGIERI, 1950) and *Costa batei* (BRADY, 1866), are abundant in the basal part, and still predominate.

Benthic foraminifers slightly reduce their diversity in samples 4-5 (6 species) and completely disappear in sample 6. *Ammonia beccarii* (LINNAEUS, 1758), *Cibicides lobatulus* (WALKER & JACOB, 1798) and *Elphidium crispum* (LINNAEUS, 1758) are more frequent than other species, such as *Asterigerinata mamilla* (WILLIAMSON, 1858), *Elphidium* spp. *Bolivina alata* (SEGUENZA, 1862), *Bulimina marginata* (ORBIGNY, 1826) and *Cassidulina carinata* SILVESTRI, 1896, are only present in sample 5. Serpuloideans and bryozoans are only sporadically present with a single species each, and very few specimens, in sample 4 or 5, whereas they are absent from sample 6.

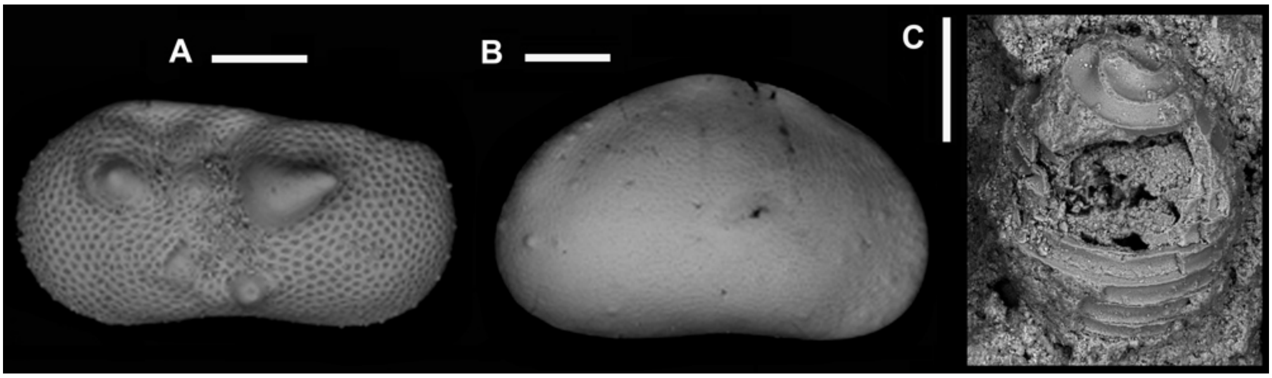


Figure 6: Freshwater faunas and floras. A - *Ilyocypris monstrifica* (Norman, 1862). LV external lateral view. Scale bar 200 µm; B) *Eucypris virens* (Jurine, 1820). RV external lateral view. Scale bar 200 µm; C) Characean oogone. Scale bar 250 µm.

Samples 7-8 are from the marly sediments collected from the top part of the section; they contain only ostracods, whereas all other investigated groups are lacking. Ostracods include a total of 7 species with a species richness ranging from 3 to 7. *Ilyocypris gibba* (Ramdohr, 1808) (Pl. 1, fig. U), *I. monstrifica* (Norman, 1862) (Fig. 6.A), *Cypridopsis vidua* (O.F. Müller, 1776), *Eucypris virens* (Jurine, 1820) (Fig. 6.A), *Candona neglecta* Sars, 1887, *C. angulata* Müller, 1900 (Pl. 1, figs. V & Z), and *Herpetocypris* sp. have been detected. Rare characean oogones (Fig. 6.C) have been found in these samples.

3.2. Planktonic foraminifers

Planktonic foraminifers are very rare along the section. In the basal samples (1-2) only three species have been recognized: *Globigerinoides ruber* (Orbigny, 1839), *Globigerinoides elongatus* (Orbigny, 1839) and *Globorotalia inflata* (Orbigny, 1839). Samples 3-4 do not contain planctonic foraminifers. Sample 5 shows higher diversity with *Globigerinella calida* (Parker, 1962), *Neogloboquadrina pachyderma* (Ehrenberg, 1861), *Globorotalia inflata* (Orbigny, 1839), *Globigerinoides ruber* (Orbigny, 1839), *Globigerinoides trilobus* (Reuss, 1850) and *Orbulina* spp. The association is indicative of the early Pleistocene (Calabrian). Samples 6-8 bear only few planktonic species (Table 2) and the globorotaliids *Globorotalia margaritae* Bolli & Bermudez, 1965, and *G. puncticulata* Deshayes, 1832, reworked from the Lower Pliocene chalks (Trubi Formation).

4. Discussion and conclusion

Benthic associations from the lower part of the Cartiera Molino section (Samples 1-3) point to shallow-water marine habitats falling within the inner shelf and the infralittoral zone of the benthic zonation scheme proposed by Pérès and Picard (1964) and successfully applied to the interpretation of palaeocommunities (Di Geronimo, 1985; Di Geronimo *et al.*, 1994, *inter alias*).

Particularly, the ostracod fauna characteristically consists of species thriving in Infralittoral environments to which a subordinate number of rare, more euryecious ubiquitous species add, whose distributions extends also to the circa-littoral zone. This latter group includes both relatively common-to-abundant species belonging to the genera *Aurila*, *Neonesidea*, *Loxoconcha*, *Carinocythereis* and *Paracytheridea*, as well as rare species, such as *Cytherella alvearium* (Bonaduce *et al.*, 1975) and *Tetracytherura angulosa* (Seguenza) (Montenegro *et al.*, 1998; Guernet & Lethiers, 1987, *inter alias*).

Typically infralittoral species are *Urocythereis sororcula* (Seguenza), *U. margaritifera* (Müller), *Costa batei* (Brady), *Graptocythere hscripta* (Capeder), *Cytheretta* spp., *Caudites calceolatus* (Costa), *Leptocythere lagunae* Hartmann and *Semicytherura* spp., that have been usually reported from many authors.

The presence of *Cytherelloidea beckmanni* Barbeito-Gonzales has a considerable palaeoenvironmental significance, as this species is characteristic of very shallow water environments (Aranki, 1987, *inter alias*). Analogously, *Aurila arborescens* (Brady) is a shallow marine species, characteristically associated to vegetate bottoms (Athersuch *et al.*, 1989). Furthermore, *A. arborescens* can be found also in brackish lagoonal and estuarine environments. Consequently, the presence of this latter species, as well as of some taxa, such as *Leptocythere lagunae*, *Semicytherura paradoxa* and *Loxoconcha* spp. point to the possible (at least temporary) presence in the area of freshwater inputs. Indeed, all the above reported species are known as able to tolerate salinity fluctuations and to be also widely distributed in brackish waters (Smith & Horne, 2002; Frenzel & Boomer, 2005).

Therefore, ostracod association from this part of the section, indicate a shallow-water marine environment very close to the coast and possibly in the upper Infralittoral (probably less than 20 m deep) that was affected by freshwater river inputs, in agreement with the environmental assignment scheme proposed by Guernet & Lethiers (1986), Montenegro *et al.* (1998) and supported by the autoecological features of individuals species.

Benthic foraminifera associations concur to this hypothesis because most species (*e.g.*, *Ammonia beccarii*, *Elphidium crispum*) are typical of inner shelf environments (MURRAY, 1991).

Analogously, serpuloideans and bryozoans support the same inferences. Associations consist of typical infralittoral species. They are the serpulids *V. striaticeps*, *Hydroides* spp., *S. polytrema* and the spirorbids *J. pagenstekeri* and *N. pseudocorrugata*, with these latter two species more typical of the upper horizon of the infralittoral zone (ROSSO *et al.,* 2013). Also several bryozoans, and particularly *P. stoechas*, *C. fistulosa*, *Tubulipora* spp. and *C. nobilis* are typical representatives of infralittoral habitats where they are often associated to soft algae and *Posidonia oceanica* meadows (GAUTIER, 1962; HARMELIN, 1976; ZABALA, 1986). The euryecious ubiquitous species found, such as the serpulid *S. vermicularis* and the bryozoans *C. pyrula* (HARMELIN, 1990), have distributions including infralittoral habitats (SANFILIPPO *et al.*, 2013; HARMELIN, 1990). Last but not least, the serpulid *H. elegans* may indicate water with low salinity value (BIANCHI, 1981).

Furthermore, some taphonomic features contribute to strengthen this environmental attribution. Some bioimmuration evidences on the undersurfaces of encrusting portions of serpulid (Fig. 5.J) and bryozoan skeletons concur to testify to the presence of algae and plants that probably represented the substratum for most of the taxa recovered.

This environmental attribution is in agreement with previous inferences obtained through malacofaunas that suggest shallow marine environments ranging from the *Posidonia* meadows assemblage (HP) to the Muddy-Sand Assemblages in Sheltered Areas (SVMC), up to a transition to the Euryhaline and Eurytherm Assemblage (LEE) *sensu* PÉRÈS & PICARD (1964) and PÉRÈS (1982), as suggested by COSTA (1980).

The palaeoenvironmental interpretation of the middle part of the section (samples 4-6) is less supported owing to the extremely scant fossils found in these layers. This is particularly apparent for the macroinvertebrates and subordinately for ostracods, but not for foraminifers, except in the uppermost layer.

Ostracod association from sample 4 consists exclusively of species that are typical infralittoral representatives and could therefore point to a palaeoenvironment roughly comparable to those from previous samples. Nevertheless, it is oligospecific and extremely impoverished when compared to associations from the underlying layers, although nearly all species from the association of sample 4 are shared with those from previous samples. The progressive decrease in richness observed along the section at both species and genus level could be interpreted as related to a progressive shallowing, following SMITH & HORNE (2002).

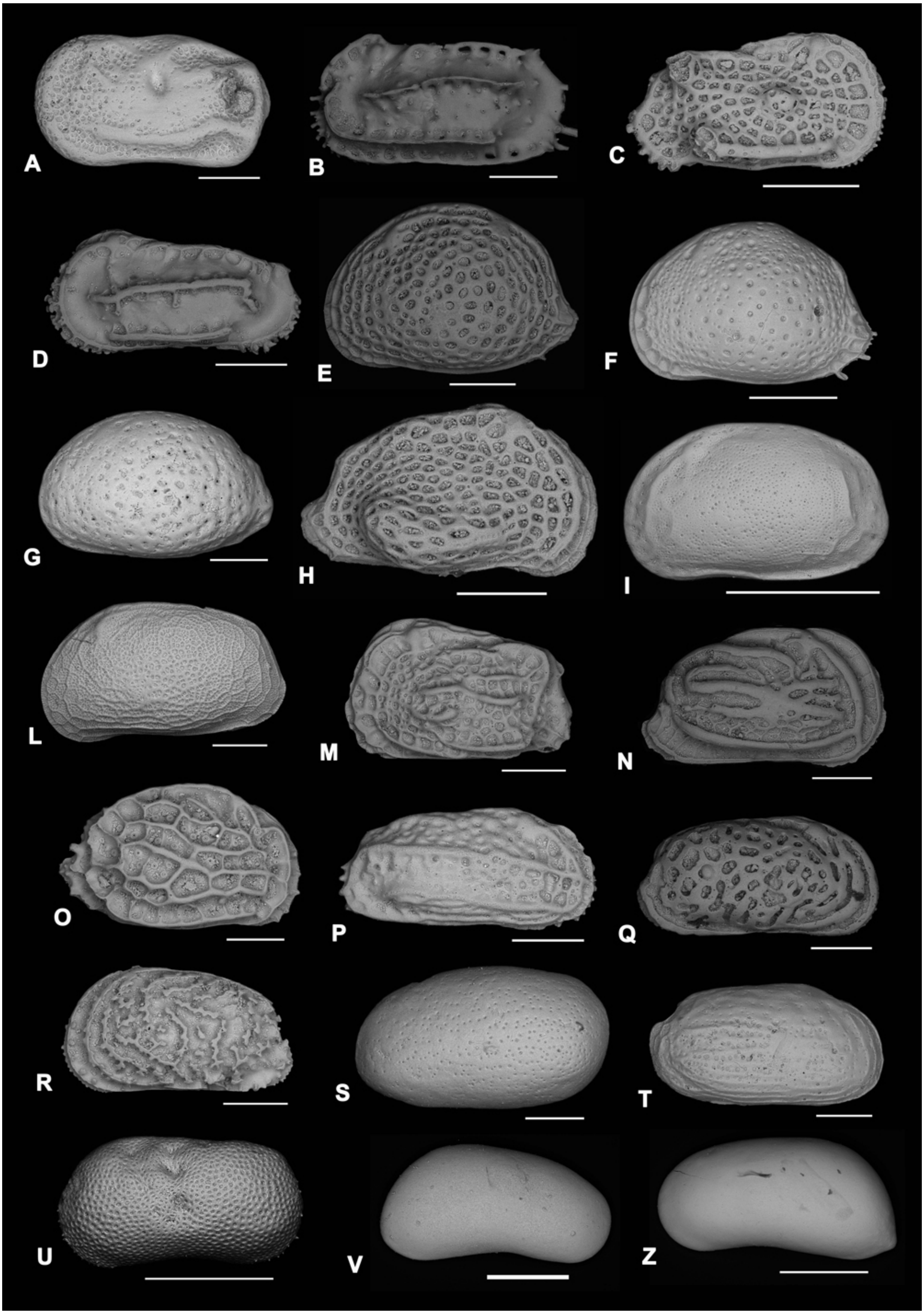
Of special interest is also the relevant number of teratologic specimens of *Elphidium* sp. (Fig. 4.G-H) whose occurrence could indicate environmental stress (YANKO *et al.*, 1998; GESLIN *et al.*, 2000; SAMIR & EL-DIN, 2001) that may be caused by lower salinity induced by freshwater inputs (TRIANTAPHYLLOU *et al.*, 2005).

Although a certain similarity in inferred palaeoenvironments for associations from the lower and central part of the sections, the strong oligotypy of the latter ones point to strong changes in palaeoenvironmental features and parameters and particularly to stressed conditions (AAA). In the present instance a possible explanation for the progressive reduction of taxa could have been caused by the increase of freshwater inputs, already present but probably only temporarily active in previous times. An additional source of disturbance can be foreseen in the occurrence of high sedimentation episodes consistent with a fluviatile input. Local/temporary high sedimentation events are also suggested by the occurrence of discontinuous layers of breccias and conglomerate intercalations in corresponding layers, from neighbouring areas.

In Sample 5 the association is composed of species living in lagoons and /or inner shelf environments (*e.g.*, *Elphidium*, *Ammonia*, *Cibicides*) together with *Bulimina marginata*, *Bolivina alata* and *Cassidulina laevigata*. These species are present in the Atlantic Ocean and Mediterranean Sea in mud and muddy sandy substrata at variable depth from few tens to hundreds meters. The presence of these taxa, the increasing diversity and the lithological features suggests an upward increasing content in mud within a shallow, fluvial-influenced marine setting.

Fossil associations from the highest stratigraphic levels of the succession (samples 7-8) point to a lacustrine palaeoenvironment or, at least, to the inner confined portion of a lagoon. This hypothesis is supported by the absence of any taxon thriving in marine environments. Serpuloideans and bryozoans, as well as foraminifers are completely absent. Only ostracods occur but none of the species found in the associations from these layers are shared with those of the underlying layers. Associations are relatively diversified and exclusively consist of species that presently live within lakes, ponds and canals, such as *C. vidua*, *E. virens*, *I. gibba* and *I. monstrifica* (HENDERSON, 2002, *inter alias*) or whose distribution extends also to inner lagoons and other brackish coastal waters, such as *C. angulata* and *C. neglecta* (AA). The recovery of oogones of characeans (Fig. 6.C), plants specially adapted to colonise freshwater settings (MAGNY *et al.*, 2006), is consistent with the above inferences.

In these continental basins a large amount of sediments, coming from the erosion of the neighbouring Pliocene outcrops (Trubi), was deposited as demonstrated by the finding of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specimens of *Globorotalia margaritae* and *G. puncticulata*.

The Cartiera Molino section, with its sediments and the palaeontological content, testifies to the transition from marine shallow water settings to lagoon environments up to continental lacustrine environments, contributing information to a better understanding of the evolution of the western sector of the Hyblean Plateau.

◀ **Plate 1: Ostracoda**

A) *Cytherelloidea beckmanni* Barbeito-Gonzalez, 1971. LV external lateral view. Scale bar 200 µm;

B) *Carinocythereis whitei* (Baird, 1850). LV external lateral view. Scale bar 250 µm;

C) *Hermanites haidingeri* (Reuss, 1850). RV external lateral view. Scale bar 350 µm;

D) *Costa batei* (Brady, 1866). LV external lateral view. Scale bar 250 µm;

E) *Aurila* gr. *punctata* (Münster, 1830). LV external lateral view. Scale bar 200 µm;

F) *Aurila* gr. *convexa* (Baird, 1850). LV external lateral view. Scale bar 300 µm;

G) *Aurila* sp. 1. LV external lateral view. Scale bar 250 µm;

H) *Aurila balanoides* Ruggieri, 1983. RV external lateral view. Scale bar 200 µm;

I) *Aurila* sp. 2. LV external lateral view. Scale bar 500 µm;

L) *Aurila arborescens* (Brady, 1865). LV external lateral view. Scale bar 200 µm;

M) *Quadracythere prava* (Baird, 1850). LV external lateral view. Scale bar 250 µm;

N) *Graptocythere hscripta* (Capeder, 1900). RV external lateral view. Scale bar 200 µm;

O) *Mutilus* cf. *laticancellatus* (Neviani, 1928). RV external lateral view. Scale bar 200 µm;

P) *Cistacythereis rubra* (Müller, 1894). RV external lateral view. Scale bar 250 µm;

Q) *Urocythereis* cf. *sororcula* (Seguenza, 1880). RV external lateral view. Scale bar 250 µm;

R) *Urocythereis* sp. 1. LV external lateral view. Scale bar 200 µm;

S) *Cytheretta subradiosa* (Roemer, 1836). LV external lateral view. Scale bar 200 µm;

T) *Cytheretta adriatica* Ruggieri, 1952. RV external lateral view. Scale bar 500 µm;

U) *Ilyocypris gibba* Ramdohr, 1808. LV external lateral view. Scale bar 500 µm;

V) *Candona angulata* Müller, 1900. RV (female) external lateral view. Scale bar 500 µm;

Z) *Candona angulata* Müller, 1900. LV (female) external lateral view. Scale bar 500µm.

5. Systematics

Some species of ostracods found in the stratigraphic section of Cartiera Molino, that are rare and/or little known from Sicily are briefly commented below. They are mostly freshwater taxa, and among the less reported as fossils owing to the rare preservation in these palaeoenvironments.

Class Ostracoda Latreille, 1806

Order Platycopida Sars, 1866

Family Cytherellidae Sars, 1866

Genus *Cytherelloidea* Alexander, 1929

Cytherelloidea beckmanni Barbeito-Gonzalez, 1971

(Pl. 1, fig. A)

1971 *Cytherelloidea beckmanni* Barbeito - Gonzalez, p. 262, Pl. 2, figs. 1c, 2c, 3c; Pl. 45, figs. 14-15;
1972 *Cytherelloidea beckmanni* Barbeito - Gonzalez: Sissingh, p. 72, Pl. 2, fig. 3;
1975 *Cytherelloidea beckmanni* Barbeito - Gonzalez: Bonaduce & Pugliese, p. 2, Pl. 1, fig. 7;
1987 *Cytherelloidea beckmanni* Barbeito - Gonzalez: Aranki, p. 45, Pl. 1, figs. 1-2;
1997 *Cytherelloidea beckmanni* Barbeito - Gonzalez: Barra, p. 74. Pl. 1, fig. 1;
2005 *Cytherelloidea beckmanni* Barbeito - Gonzalez: Dall'antonia *et al.*, p. 74.

Remarks: This species is known from the Miocene (Aranki, 1987) to the Recent (Barra, 1997). In the Recent, *C. beckmanni* Barbeito-Gonzalez, as well as other species of the genus *Cytherelloidea* are considered to be characteristic of very shallow-water environments (Bonaduce & Pugliese, 1975; Aranki, 1987; Guernet & Lethiers, 1989). Consequently, the finding of this species as fossil could be confidently used as a good palaeoenvironmental indicator. Few specimens of this species were found, restricted to the lower levels of the section (samples 1-2).

Order Podocopida Sars, 1866

Family Hemicytheridae Puri, 1953

Genus *Aurila* Pokorni, 1955

Aurila arborescens (Brady, 1865)

(Pl. 1, fig. L)

1865 *Cythere arborescens* Brady, p. 190, Pl. 9, figs. 5-8;
1868 *Cythere woodwardii* Brady, p. 93, Pl. 10, figs. 19-21;
1963 *Aurila woodwardii* (Brady): McKenzie, p. 8, Pl. 1, figs. 1-3;
1975 *Aurila woodwardii* (Brady): Bonaduce, Ciampo & Masoli, p. 44, Pl. 20, figs. 8-11;
1975 *Aurila woodwardii* (Brady): Ruggieri, p. 30;
1985 *Aurila arborescens* (Brady): Athersuch, Horne & Whittaker, p. 156, Pl. 1, figs. 5-8; Pl. 2, figs. 1-4;

1989 *Aurila arborescens* (BRADY): ATHERSUCH, HORNE & WHITTAKER, p. 158, Fig. 63; Pl. 4, fig.10;
2005 *Aurila arborescens* (BRADY): SCHNEIDER *et al.*, p. 93, Pl. 1, figs. 11-12.

Remarks - This species is known from the late Pliocene of Forlì (RUGGIERI, 1975) and of NW France and Cornwall (ATHERSUCH *et al.*, 1985). It has been also reported from the present-day Mediterranean Sea (BONADUCE *et al.*, 1975), the SW Wales and in the Thames estuary (ATHERSUCH *et al.*, 1989). Presently, *A. arborescens* is a shallow marine phytal species, found also in brackish lagoonal and environments. Only a few specimens were found in sample 3.

Suborder Cypridocopina JONES, 1901

Superfamily Cypridoidea BAIRD, 1845

Family Candonidae KAUFMANN, 1900

Subfamily Candoninae KAUFMANN, 1900

Genus *Candona* BAIRD, 1845

Candona neglecta SARS, 1887

1887 *Candona neglecta* SARS, p. 279, Pl. 15, figs. 5-7; Pl. 19;
1900 *Candona neglecta* SARS: MÜLLER, p. 17;
1957 *Candona neglecta* SARS: WAGNER, p. 21, Pl. 3 figs 1-5;
1998 *Candona* (*Candona*) *neglecta* SARS: GLIOZZI & MAZZINI, p. 78, Pl. 1, fig. E;
2000 *Candona neglecta* SARS: MEISCH, p. 77, Fig. 26;
2003 *Candona neglecta* SARS: MEISCH & WOUTERS, p. 15, Fig. 2;
2006 *Candona neglecta* SARS: HUSSEIN, p. 331;
2008 *Candona neglecta* SARS: BEKER *et al.*, p. 13, Pl. 2, fig. 1.

Remarks - *C. neglecta* is presently distributed throughout the Holarctic biogeographical region (MEISCH, 2000; MEISCH & WOUTERS, 2003), where it has a long and nearly continuous stratigraphic record. The earliest occurrence of the *C. neglecta* group is from the Late Cretaceus of Mongolia (MEISCH & WOUTERS, 2003). In the Recent the species is widespread in all permanent or temporary freshwater habitats, such as lakes, rivers, deltaic settings, springs and streams but, being able to live in waters with salinities ranging from 0.5 to 16 ‰, it also colonises brackish waters. Nevertheless, it is rare in such environments. *C. neglecta* prefers cool waters and tolerates low oxygen content in the water.

The species was not known as fossil from Sicily, whereas it probably thrives in present-day lakes. Specimens of *Candona lindneri* PETKOVSKI, 1969, have been recorded as living from this region by PIERI *et al.* (2006). This latter species has been distinguished from *C. neglecta* SARS, owing to the presence of tubercles and spines, but its validity and distinction from *C. neglecta* has been questioned by MEISCH & WOUTERS (2003).

Several valves of *C. neglecta* were found in sample 7.

Candona angulata MÜLLER, 1900

(Pl. 1, figs. V & Z)

1900 *Candona angulata* MÜLLER, p. 18, Pl. 1, figs. 1-17.
1963 *Candona angulata* MÜLLER: DECIMA, p. 76, Pl. 3, figs. 1-8.
1996 *Candona angulata* MÜLLER: JONES & SIMMONS, p. 40.
2011 *Candona angulata* MÜLLER: HAJEK-TADESSE, p. 69.

Remarks - This species lives in coastal ponds and occasionally in brackish lagoons (HENDERSON, 1990). *Candona angulata* has already been reported in the Pleistocene of Sicily by DECIMA (1963). Unlike the previous species, it has not yet been reported from present-day freshwater environments of this region.

Family Cyprididae BAIRD, 1845

Genus *Eucypris* VÀVRA, 1891

Eucypris virens (JURINE, 1820)

(Fig. 4.B)

1820 *Monoculus virens* JURINE, p. 174, Pl. 18, figs. 15, 16.
1900 *Cypris virens* (JURINE): MÜLLER, p. 62, Pl. 15, figs. 1-4, 7-10, 16-18.
1996 *Eucypris virens* (JURINE, 1820): CUSMINSKI & WHATLEY, p. 148, Pl. 1, fig. 16.
2006 *Eucypris virens* (JURINE, 1820): PIERI *et al.*, p. 5.
2013 *Eucypris virens* (JURINE, 1820): UÇAK *et al.*, p. 4

Remarks - *E. virens* lives in ponds and even temporary pools (HENDERSON, 1990). This species was already been reported from the Recent of Sicily by PIERI *et al.* (2006). It is here reported as fossil for the first time from this region.

Family Ilyocyprididae KAUFMANN, 1900

Subfamily Ilyocypridinae KAUFMANN, 1900

Genus *Ilyocypris* BRADY & NORMAN, 1889

Ilyocypris gibba (RAMDOHR, 1808)

(Pl. 1, fig. U)

1808 *Cypris gibba* RAMDOHR, p. 91, Pl. 3, figs. 13-14, 17;
1965 *Ilyocypris gibba* (RAMDOHR): DEVOTO, p. 345, Fig. 50;
1979 *Ilyocypris gibba* (RAMDOHR): CARBONNEL & PEYPOUQUET, p. 195, Pl. 1, fig. 2;
1998 *Ilyocypris gibba* (RAMDOHR): GLIOZZI & MAZZINI, p. 80, Pl. 2, fig. A;
1999 *Ilyocypris gibba* (RAMDOHR): MAZZINI *et al.*, p. 297, Pl. 2, fig. 5;
2000 *Ilyocypris gibba* (RAMDOHR): MEISCH, p. 245, Fig. 104;
2005 *Ilyocypris gibba* (RAMDOHR): RODRIGUEZ-LÀZARO & MARTIN-RUBIO, p. 40, Pl. 1, figs. 1-3, 7;
2006 *Ilyocypris gibba* (RAMDOHR): ROSSETTI *et al.*, p. 124, Fig. 2 (I-K);
2006 *Ilyocypris gibba* (RAMDOHR): PIERI *et al.*, p. 5;
2008 *Ilyocypris gibba* (RAMDOHR): AKDEMIR, p. 109, Fig. 3;

- **2008** *Ilyocypris gibba* (Ramdohr): Beker *et al.*, p. 12, Pl. 1, figs. 10-11;
- **2013** *Ilyocypris gibba* (Ramdohr): Uçak *et al.*, p. 4.

Remarks: *I. gibba* (Ramdohr) is a Holarctic species, known from a very wide area in Europe and Asia, as well as from East Africa and North America (Henderson, 1990). In Sicily it has been recently recorded in Recent deposits by Pieri *et al.* (2006). The stratigraphical distribution of *I. gibba* (Ramdohr) is wide, ranging from the Tortonian to the Recent (Beker *et al.*, 2008). The species is widespread in all freshwater environments, in a wide temperature range.

***Ilyocypris monstrifica* (Norman, 1862)**

(Pl. 1, fig. Z)

- **1862** *Cypris monstrifica* Norman, p. 45, Pl. 3, figs. 4-5;
- **1970** *Ilyocypris monstrifica* (Norman, 1862): Mckenzie, p. 109-110;
- **1988** *Ilyocypris monstrifica* (Norman, 1862): Meisch, p. 153, Fig. 3;
- **2001** *Ilyocypris monstrifica* (Norman, 1862): Altinsaçli, p. 346;
- **2003** *Ilyocypris monstrifica* (Norman, 1862): Rossi *et al.*, p. 3;
- **2006** *Ilyocypris monstrifica* (Norman, 1862): Rossetti *et al.*, p. 124;
- **2006** *Ilyocypris monstrifica* (Norman, 1862): Hussein, p. 331;
- **2008** *Ilyocypris monstrifica* (Norman, 1862): Akdemir, p. 110;
- **2011** *Ilyocypris monstrifica* (Norman, 1862): Savatenalinton, p. 174.

Remarks: *I. monstrifica* (Norman) is widely distributed in Europe from lakes, canals and large rivers (Henderson, 2002). It has also been reported from the floodplain of the Chi River basin in Thailand (Savatenalinton, 2011) and from Syria (Hussein, 2006). Nevertheless, this species has rarely been reported from Italy and the present record is the first one from Sicily.

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Table 1: List of the ostracods found in the Cartiera Molino section (X = rare, XX = abundant, XXX= very abundant).

SPECIES	**SAMPLES**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Candona angulata Müller, 1900								x	
Candona neglecta (Sars, 1887)								x	x
Cypridopsis vidua (O.F. Müller, 1776)								x	
Eucypris virens (Jurine, 1820)								x	
Herpetocypris sp.								x	x
Ilyocypris monstrifica (Norman, 1862)								x	x
Ilyocyris gibba (Ramdohr, 1808)								x	
Loxoconcha tumida Chapman, 1902					x				
Xestoleberis dispar Müller, 1894				x					
Aurila sp.				x					
Aurila arborescens (Brady, 1865)				x					
Aurila cf. *cruciata* (Ruggieri, 1950)			xx		xx				
Urocythereis sororcula (Seguenza, 1880)			xx	xx	x				
Urocythereis sp.1			x	x					
Loxoconcha gibberosa Terquem, 1878			xx						
Loxoconcha bairdi Müller, 1894			x						
Loxoconcha stellifera Müller, 1894			x						
Carinocythereis whitei (Baird, 1850)			xx						
Cytheretta subradiosa (Roemer, 1838)			x						
Cytheretta adriatica Ruggieri, 1952		x		x					
Mutilus cf. *laticancellatus* (Neviani, 1928)		x		x					
Aurila gr. *convexa* (Baird, 1850)		xx	xx	xx	xx				
Costa batei (Brady, 1866)		x	xx	xx	xx				
Graptocythere hscripta (Capeder, 1900)		x	xx	xx	x				
Neonesidea mediterranea (Müller, 1894)		x	xx	xx					
Urocythereis margaritifera (Müller, 1894)		x	xx	x					
Semicytherura paradoxa (Müller, 1894)		x	x	x					
Paracytheridea gr. *depressa* Müller, 1894		x	x	x					
Semicytherura sp. 1		x	x	x					
Sagmatocythere napoliana (Puri, 1963)		x	x						
Callistocythere lobiancoi (Müller, 1894)		x	x						
Cytherelloidea beckmanni Barbeito-Gonzales, 1971		x	x						
Cytherella alvearium Bonaduce, Ciampo & Masoli, 1976		x	x						
Hemicytherura defiorei Ruggieri, 1953		x							
Aurila balanoides Ruggieri 1983		x							
Aurila prasina Barbeito-Gonzales, 1971		x							
Loxoconcha rhomboidea (Fischer, 1855)		x							
Caudites calceolatus (Costa, 1853)		x							
Leptocythere lagunae Hartmann, 1958		x							
Tetracytherura angulosa (Seguenza, 1880)		x							
Grinioneis haidingeri (Reuss, 1850)		x							
Kangarina abyssicola (Müller, 1894)		x							
total number of species		23	19	14	6	0	0	7	3

Table 2: List of the foraminifers found in the Cartiera Molino section (X = rare, XX = abundant, XXX= very abundant).

SPECIES	SAMPLES	1	2	3	4	5	6	7	8
Benthos									
Ammonia beccarii (Linnaeus, 1758)		x	x	x	x	x			
Ammonia tepida (Cushman, 1926)				x					
Asterigerinata mamilla (Williamson, 1858)		x	x		x				
Bolivina alata (Seguenza, 1862)						x			
Bulimina marginata (Orbigny, 1826)						x			
Cancris auriculus (Fichtel & Moll, 1798)			x						
Cancris sp.				x					
Cibicides lobatulus (Walker & Jacob, 1798)		x	x		x	x			
Cribroelphidium sp.					x				
Elphidium aculeatum (Orbigny, 1846)		x	x		x				
Elphidium complanatum (Orbigny, 1839)		x	x						
Elphidium crispum (Linnaeus, 1758)		x	x		x	x			
Elphidium sp.				x					
Paracassidulina neocarinata (Thalmann, 1950)						x			
Rosalina globularis Orbigny, 1826		x	x						
total number of species		7	8	4	6	6			
Plankton									
Globigerina calida Parker, 1962						x	x		
Globigerinoides elongatus (Orbigny, 1839)			x						
Globigerinoides ruber (Orbigny, 1839)		x	x			x	x		
Globigerinoides trilobus (Reuss, 1850)						x			
Globorotalia inflata (Orbigny, 1839)		x	x			x		x	
Globorotalia margaritae Bolli & Bermudez, 1965 (R)							x		x
Globorotalia puncticulata Deshayes, 1832 (R)							x		x
Neogloboquadrina pachyderma (Ehrenberg, 1861)						x			
Orbulina suturalis (Bronnimann, 1951)						x			
Orbulina universa Orbigny, 1839						x			
total number of species		2	3			7	4	1	2
(R)= reworked									

Table 3: List of the serpuloideans found in the Cartiera Molino section (X = rare, XX = abundant, XXX= very abundant).

SPECIES	SAMPLES	1	2	3	4	5	6	7	8
Serpula vermicularis Linnaeus, 1767				x					
Hydroides dianthus (Verril, 1873)				x					
Hydroides elegans (Haswell, 1883)				x					
Hydroides sp.				xxx					
Vermiliopsis labiata (O.G. Costa, 1861)				x					
Vermiliopsis striaticeps (Grube, 1862)			x	xxx	x				
Spirobranchus polytrema (Philippi, 1844)				x					
Janua pagenstecheri (Quatrefages, 1866)				x					
Neodexiospira pseudocorrugata (Bush, 1905)				x					
total number of species			1	9	1				

Table 4: List of the bryozoans found in the Cartiera Molino section (X = rare, XX = abundant, XXX= very abundant).

SPECIES	**SAMPLES**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Platonea stoechas Harmelin, 1976		x	xxx	x					
? *Tubulipora liliacea* (Pallas, 1766)		x							
? *Tubulipora plumosa* Harmer, 1898		x	x						
? *Annectocyma* sp.		xx	xx	x		x			
Crisia fistulosa (Heller, 1867)		xxx	xxx	x					
? *Crisia pyrula* Harmelin, 1990		xxx	xx						
Crisia spp.		xxx	xx	x					
Calpensia nobilis (Esper, 1796)		x	x						
Scrupocellaria sp.		x	x						
? *Watersipora* sp.			x						
Schizomavella sp.			x	x					
total number of species		8	9	4		1			