

New reports of Paratethyan ostracods affinity from the Mediterranean Basin (Sicily, Italy)

Francesco Sciuto, Angela Baldanza, Rim Temani, and Giovanni Privitera

ABSTRACT

During the late Messinian post evaporitic phase, in the eastern region between the Alps and the Aral Sea, the Paratethys was reduced to a number of large independent basins (Pannonian Basin, Pontic Basin and Caspian-Aral Basin) separated by vast continental regions. At the same time, in the Paleomediterranean region, discontinuous shallow-water basins were formed on the existing substrate. In these basins predominantly siliciclastic sediments were deposited consisting of gravels, sands, marls and silts, and containing continental oligohaline faunas. These sedimentary facies, which are largely exposed in Italy and in other Mediterranean regions, are called "Lago-Mare". These sediments overlapping the Messinian evaporitic layers in apparent conformity have already been reported from western Sicily. Now they have been sampled and analyzed in five different localities in eastern Sicily. These sedimentary facies are called "*Congerina*" strata (marl containing oligohaline faunas) and "Arenazzolo" (reddish arkosic sands containing brackish or freshwater ostracods). From these levels, which correspond to two different sedimentation environments, an oligotypic ostracod fauna was extracted consisting of species belonging to the genera *Tyrrhenocythere*, *Loxoconcha* and *Cyprideis*. Among them, *Loxoconcha muelleri* (Mehes, 1908) and *Cyprideis anlavauxensis* Carbonnel, 1979, are reported for the first time from Sicily. Two other species are new to science; one is described as *Tyrrhenocythere pulcherrima* sp. nov. herein, whereas, the other one is left in open nomenclature as *Loxoconcha* n. sp.

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INTRODUCTION

The temporary restricted connection to complete closure of the communication with the Atlantic Ocean during the Messinian Stage determined the formation of euxinic environments in the Paleomediterranean Basin and gave rise to what is called Messinian Salinity Crisis (Hsü et al., 1973). During this short period, which lasted about 640 kyr (Krijgsman et al., 1999; Roveri et al., 2014), various and sometimes considerable thicknesses (from few to thousands of meters) of evaporites were deposited in virtually the entire Mediterranean Basin area (Rouchy and Caruso, 2006). In Sicily, the Messinian evaporitic succession is present in the Caltanissetta Basin where it is classically divided into two cycles: a lower cycle, comprising the primary evaporitic facies (the Lower Gypsum unit) and an upper cycle, lying unconformably on the lower one, comprising cyclic alternations of primary gypsum and calcareous sediments (Roveri et al., 2008). In eastern Sicily the Messinian evaporites, represented mainly by “The Calcare di Base” and gypsum, were deposited in pre-existing basins created by a synsedimentary tectonics (Pedley and Grasso, 1992; Caruso et al., 2015). This gypsum appears to be related to the “Primary Lower Gypsum” of the Central Sicily Basin (Di Geronimo et al., 1989; Pedley and Grasso, 1992; Roveri et al., 2006, 2008).

During the Late Messinian post evaporitic phase, several parts of the Mediterranean Basin were affected by intense continentalization with strong subaerial erosion phenomena and chemical dissolution of Messinian gypsum and Calcare di Base, and, in the widespread lower basin area, deposition of sedimentary facies characterized by brackish to fresh water fauna (Orszag-Sperber et al., 2000; Rouchy et al., 2007; Gliozzi et al., 2007). This sedimentary facies, called “Lago-Mare” sensu Ruggieri (1967), crops out discontinuously but widely in all the Mediterranean Basin from the Eastern to the Western Basin (Orszag-Sperber et al., 2000; Rouchy and Caruso, 2006).

In Sicily, but also in other geographical areas of the Mediterranean Basin, these sediments seem to have at least two different facies: the first one consists of marl containing oligohaline faunas (“*Congerina*”) (Di Geronimo et al., 1989), the second

one consists of reddish arkosic sands (“Arenazolo”) containing brackish to fresh water ostracods (Bonaduce and Sgarrella, 1999; Roveri et al., 2008; present paper). Sometimes these facies represent mesohaline to hyperhaline shallow water environments with low oxygen content (Grossi et al., 2015). The origin of this fauna was probably related to overflowing of the Pannonian-Pontian Paratethyan waters (Gliozzi et al., 2007; Stoica et al., 2016) or to the colonisation of shallow lakes formed at various altitudes, on the top of the Messinian strata and fueled by rainwater (Orszag-Sperber et al., 2000).

After the Late Messinian Mediterranean Lago-Mare phase (sensu Stoica et al., 2016), the early Pliocene is characterized by a rapid restoration of full marine environmental conditions with deposition unconformity on the evaporites of white chalk (Trubi Formation) (Pedley and Grasso, 1992). The depositional environment of this sediment is bathyal as documented by the presence of psychrospheric and deep water ostracods immediately on the top of the Messinian facies (F.S., personal observation). This seems to show a rapid and abrupt sea level rise due to the abrupt enlargement of the channel between the Atlantic Ocean and the Mediterranean Sea.

The present contribution focuses on the Lago-Mare ostracod fauna coming from upper Messinian stratigraphic levels cropping out in some localities of eastern Sicily above the evaporitic facies (Figure 1). The aim of the study is the taxonomic analysis of ostracod species belonging to the Lago-Mare facies in a period just before the restoration of fully marine conditions (post evaporitic phase). Some levels attributable to Lago-Mare facies were previously analyzed in SE Sicily but only with regard to mollusc fauna (Di Geronimo et al., 1989). Today the acquired knowledge on ostracods in the present study adds up to those of Eraclea Minoa (Bonaduce and Sgarrella, 1999) and Pasquasia (Colalongo, 1967).

GEOLOGICAL SETTING

The upper Messinian sedimentary levels sampled for this study belong to two different paleogeographic contexts: the Villafranca Tirrena Basin and the north-western border of the Hyblean Plateau.

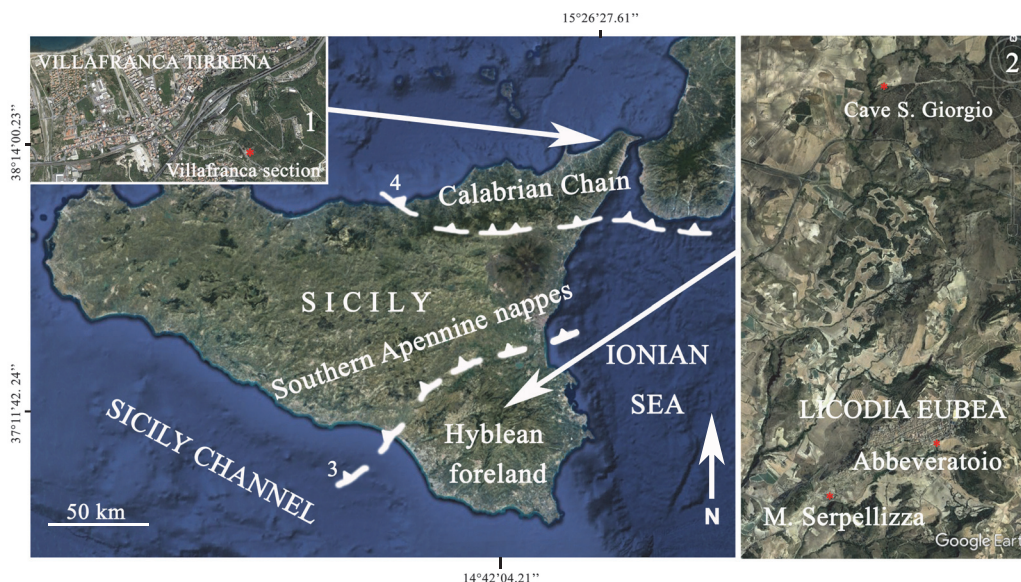


FIGURE 1. Geographical location of the sampling stations (red dots) in northeastern (1) and southeastern Sicily (2); and the external front of the Apenninic Chain (3) and overthrust of the Calabride Units (4). Some rights reserved: Imagery © 2015 TerraMe-trics, Map Data © 2015 Google. Note: The authors are the 'sole responsible' for the usage made of texts, illustrations (tables and drawings), photos and videos provided and used in their respective publications.

The Villafranca Tirrena Basin is situated in NE Sicily, along the Tyrrhenian coast (Figure 1.1). This area is structurally part of the Apennine-Maghrebian chain ("Aspromonte Unit" auct.), characterized by a metamorphic basement covered unconformably by a complicated series of Miocene and Plio-Pleistocene sediments with extremely variable thickness (from a few to tens of meters), frequent facies transitions, stratigraphic gaps and unconformities (Lentini et al., 1987). The sedimentary sequence started with polygenic conglomerates evolving laterally and upward to gray clayey marls with fine sand; these terms deposited during the early-middle Miocene. Upwards the Messinian sequence deposited, consisting of evaporitic carbonates (Calcare di Base), calcareous breccias and gypsum. During the post evaporitic, phase medium and coarse sands and breccias are deposited, called "Arenazzolo" (Mottura, 1871; Ogniben, 1957). The Pliocene Trubi Formation followed, evolving upwards to marls and sands. The sequence ended with the Pleistocene "blue clays" and calcarenites. The other upper Messinian sedimentary levels were sampled in three different localities ("Abbeveratoio", "Cave San Giorgio" and "Monte Serpellizza") in the surroundings of the village of Licodia Eubea (Figure 1.2).

Structurally, the area is a part of the Hyblean foreland, a prevalently calcareous plateau that

occupies the SE sector of Sicily. The outcropping stratigraphic sequence is characterized by mainly carbonate sediments intercalated with subaerial and submarine volcanic products at various levels. The oldest layers consist of pelagic calcareous marls with ammonites and belemnites (Hybla Formation) assigned to the Lower Cretaceous. Cretaceous-Eocene white cherty limestones (Amerillo Formation) followed. The Mesozoic-Cenozoic boundary is marked by intraformational breccias, re-sedimentation and slumping deposits, which were the result of a strong synsedimentary tectonic activity (Lentini et al., 1987). Carbonate sediments of shelf environment deposited in the Cenozoic followed during the Oligocene-early Miocene interval by calcarenites and calcisiltites of the Ragusa Formation, locally including re-sedimented layers with *Miogypsina* sp. These layers were overlain in the middle Miocene by grey marls of the more pelagic Tellaro Formation (Romeo and Sciuto, 1987), containing a nautiloid cephalopod *Aturia aturi* (Basterot, 1825). During the Messinian Stage a series of sediments deposited, which document the Messinian Salinity Crisis.

These sediments include confined and discontinuous siliceous laminated sediments (Tripoli Formation), evaporitic limestones (Calcare di Base) and Gypsum, which were deposited in semi-closed synsedimentary tectonic basins, at the

depth of 150–200 m (Pedley and Grasso, 1992). The Licodia Eubea gypsum has been interpreted as related to the “Primary Lower Gypsum” of the Central Sicily Basin (Di Geronimo et al., 1989; Pedley and Grasso, 1992; Roveri et al., 2006, 2008). Apparently paraconcordant post evaporitic upper Messinian sediments followed. They consisted of carbonate breccias, marls, sands and silts locally containing oligohaline to freshwater faunas (Lago-Mare facies). These facies are referred to as “*Congereria strata*” when constituted by marls containing oligohaline mollusc faunas (Di Geronimo et al., 1989; Pedley and Grasso, 1992), and “Arenazzolo” when consisting of reddish arkose containing brackish to fresh-water ostracods (Bonaduce and Sgarrella, 1999; Roveri et al., 2008; present paper). The succession is closed by lower Pliocene (Zanclean) remarkably thick white chalks, very rich in planktic foraminifers and nannofossils (Trubi Formation) representing the restoration of fully marine conditions. In the Licodia Eubea area, Pleistocene calcarenites and marls can be found on the top.

MATERIAL AND METHODS

Sampling Sites

Villafranca Tirrena section. The sampled layers crop out in the southern slope of the Guardiola hill along the road Galvaruso-Fondaco (38°14'02.42"N; 15°26'14.11"E; 43 m a.s.l.). The stratigraphic sequence analyzed (Figure 2) consists of 2 m of upper Messinian terrigenous medium and coarse sands and breccias (Arenazzolo) distributed in thick layers overlain by the lower Pliocene calcareous marls of the Trubi Formation. Four samples were taken from the upper Messinian levels and eight samples from the Trubi Formation.

Abbeveratoio section. This sampling station (Figure 3) is located a few dozen meters south of the Licodia Eubea village (37°09'20.11"N; 14° 42'33.81"E; 554 m a.s.l.). The stratigraphic sequence starts with 3 m of well-stratified gypsum crystals, followed, in apparent conformity, by a 50 cm thick layer of reddish sands and silty sands, known as “Arenazzolo”. These two terms refer to the Messinian (Di Geronimo et al., 1989; inter alias). The lower Pliocene sedimentary sequence (Di Geronimo et al., 1989; inter alias) follows upwards in paraconformity. It consists of a 7 m thick sequence of predominantly white marls and limestone marls (Trubi chalk), containing a bivalve *Neopycnodonte navicularis* (Brocchi, 1814) and ichnofossils attrib-

utable to *Zoophycos* sp. Four samples were taken from the Arenazzolo level and seven samples from the Trubi Formation.

Cave San Giorgio section. This sample station is located in the east side of the Mangalavite valley in the territory of Vizzini village (37°11'43.07"N; 14°42'04.90"E; 521 m a.s.l.). The studied sequence (Figure 4) consists of gypsum strata topped by about three meters of the upper Messinian white marls called “*Congereria strata*” (Di Geronimo et al., 1989), which are superimposed by three meters of subaerial basaltic lavas and, unconformably, by the lower Pliocene Trubi Formation. Several samples were taken from the *Congereria strata*, and from the lowest levels of the Trubi Formation.

Monte Serpellizza section. This section (Figure 5) is located on the southern slope of the Licodia Eubea hill (37° 08'53.71"N; 14°41'38.81"E; 435 m a.s.l.). The studied sequence begins with several meters of gypsum covered concordantly by the white marl of the Trubi Formation. No post evaporitic levels were found at this locality; the lower portion of the Trubi Formation was sampled.

Methods

Samples were analyzed for the ostracod content; the most significant planktic and benthic foraminifers and calcareous nannofossils were also identified. From each sample, 250 g of a sediment were washed using diluted hydrogen-peroxide for disaggregation. They were subsequently sieved through standard sieves (63/125/250/500 μ m). Less than 250 μ m residuals were picked out completely and ostracods were investigated taxonomically in detail. From the 125 μ m sieve-residual, 0.2 g/samples were picked and then quartered if necessary for foraminifers. The specimens were examined and measured under a stereomicroscope and photographed under LMU Tescan Vega II Scanning Electron Microscope of the Electronic Microscopy Laboratory, of the Earth Science Section (University of Catania). The specimens are housed in the Paleontological Museum of Catania University (PMC) with the following abbreviations: “OFS” = Ostracoda figured specimens and “Gt.FS” = Girogonite figured specimens.

RESULTS

Biostratigraphic Remarks

The calcareous nannofossil assemblages of Licodia Eubea and Villafranca Tirrena sections coming from the white chalks of the Trubi Formation, cropping above the Lago-Mare sedimentary

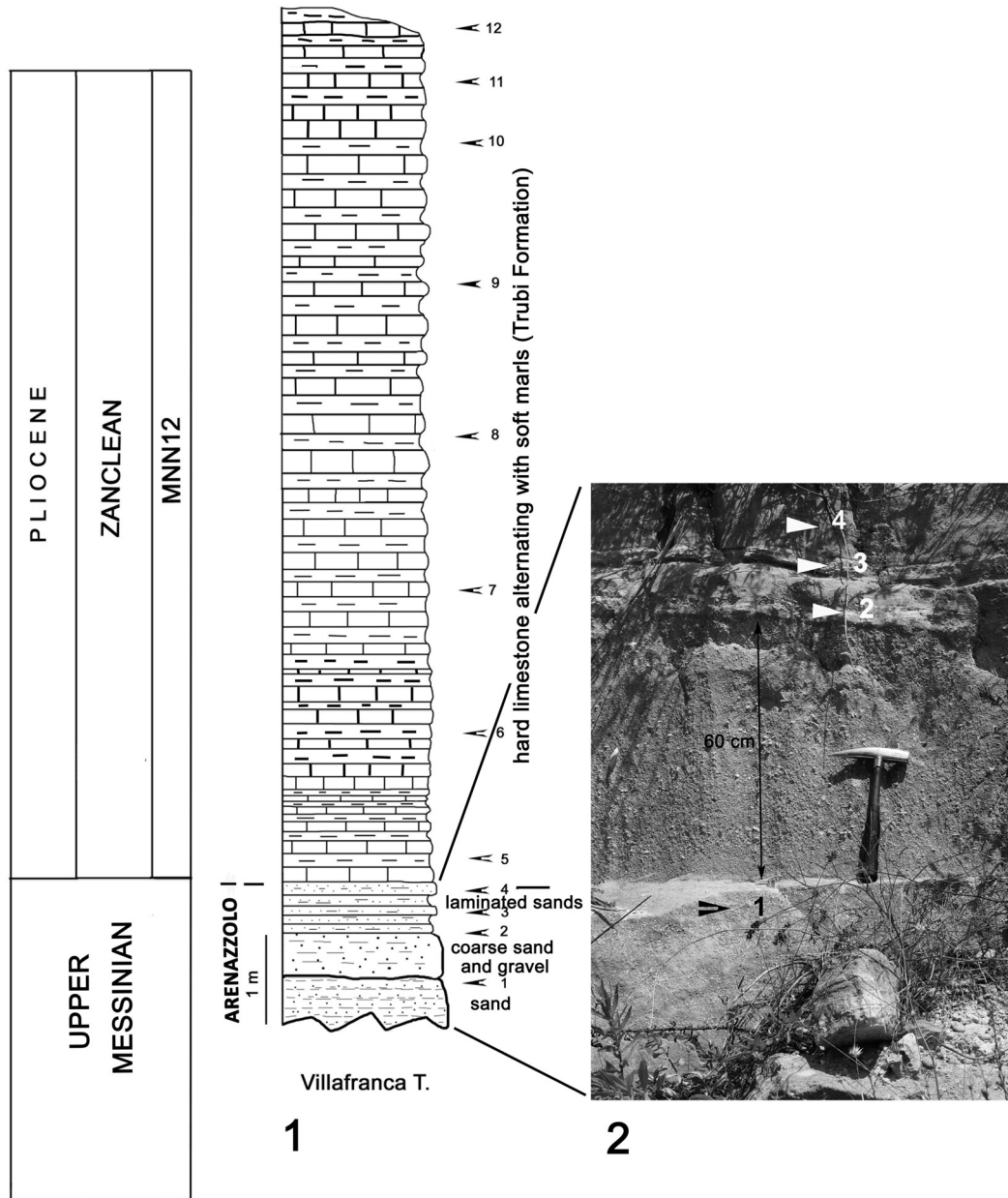


FIGURE 2. Stratigraphical log (1) with the position and number of samples of the Villafranca Tirrena section (2).

facies, are rich and the specimens are well-preserved. The assemblages collected from both sections are similar to each other and allow to identify many important markers for the Messinian-Zanclean boundary and to define better the age of the lowermost portion of the Trubi Formation. Two key events, such as the occurrence of *Ceratholithus acutus* Gartner and Bukry, 1974 and the presence of *Reticulofenestra zancleana* Di Stefano and Sturiale, 2010 in the assemblages, allow to attribute the

sediments of the Trubi Formation, overlying the upper Messinian levels studied here, to the basal Zanclean: CNPL1 Zone sensu Backmann et al. (2012) or MNN 12 biozone sensu Martini (1971). It is noteworthy that the occurrence of *R. zancleana*, as a characteristic marker of the *Reticulofenestra zancleana* Interval Subzone MNN12a with the FO into the Cycle 1 (5.332 Ma) and the LCO at Cycle 7 (5.199 Ma), determines a better stratigraphic resolution, demonstrating its importance for the Medi-



FIGURE 3. Stratigraphical log (1) with the position and number of samples of the Abbeveratoio section (2) and particular of the Arenazzolo outcrop (3).

terranean biostratigraphy. Few specimens of *Amaurolithus primus* (Bukry and Percival, 1971) Gartner and Bukry, 1975, are also found in the same samples. In the surrounding area of Vallone Scorciovitelli, just north of Licodia Eubea, the Messinian succession is closed by basaltic lavas, whose magnetostratigraphy highlighted an inverse magnetization referable to the Messinian-Zanclean boundary (Grasso et al., 1983). The Villafranca Tirrena samples also contain rare, but well-preserved *Scyphosphaera apsteinii* Lohmann, 1902, *Scyphosphaera piriformis* Kamptner, 1955, and common *Helicosphaera carteri* (Wallich) Kamptner, 1954.

According to Grossi et al. (2011) the contemporary recovery of *Cyprideis agrigentina* Decima, 1964, *Loxoconcha muelleri* (Méhes, 1908), *L. eichwaldi* Livental, 1929, and *Tyrrhenocythere pontica* (Livental) in Agalarova et al., 1961, as it happens in the underlying Lago-Mare facies of Cave San Giorgio section, allows to attribute these levels to the upper part of the *L. muelleri* Zone (lower post evaporitic phase of the Messinian stage).

Since the base of the Trubi Formation is referable to an age within the base of MNN12 biozone (early Pliocene, Zanclean), the Lago-Mare facies sampled and analyzed here is referred to as the final part of the Messinian stage.

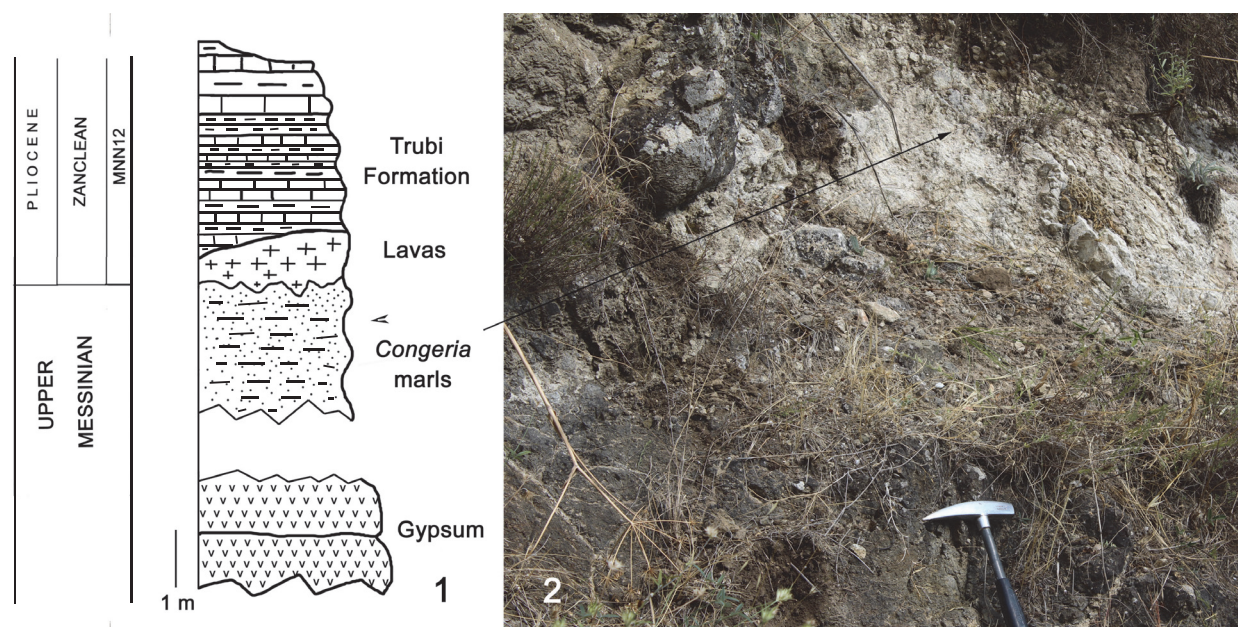


FIGURE 4. Stratigraphical log (1) with the position and number of samples of the Cave San Giorgio section (2).

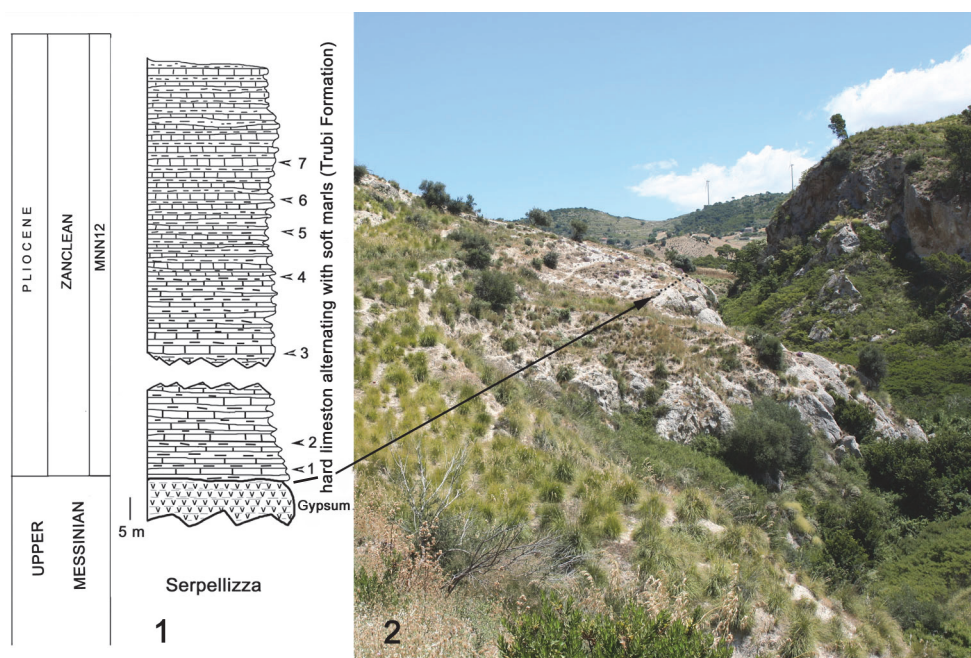


FIGURE 5. Stratigraphical log (1) with the position and number of samples of the Serpellizza section (2). The arrow indicates the boundary between the gypsum and the Trubi.

Ostracod Faunas

Villafranca Tirrena section. The ostracod fauna from the upper Messinian medium-coarse sand and gravel underlying the Trubi Formation is very poor and is represented only by species of the genus *Cyprideis*.

Abbeveratoio section. Some samples were taken from the “Arenazzolo” levels constituted by 50 cm of reddish sands and silty sands. The ostracod fauna is represented only by species of the genus *Cyprideis* and *Tyrrhenocythere*.

Cave San Giorgio section. The ostracod fauna taken from “*Congerina strata*” is slightly more abundant than other sampled stations and is represented by species belonging to the genus *Cyprideis*, *Tyrrhenocythere* and *Loxoconcha*.

Monte Serpellizza section. The gypsum strata are covered directly by the Zanclean Trubi Formation. There are no levels attributable to the upper Messinian Lago-Mare facies.

SYSTEMATIC PALEONTOLOGY

The species found in the post evaporitic sedimentary levels cropping out in the different sampling stations are listed systematically and commented on below.

Class OSTRACODA Latreille, 1806
Subclass PODOCOPA Sars, 1866
Order PODOCOPIDA Sars, 1866

Family HEMICYTHERIDAE Puri, 1953

Genus TYRRHENOCYTHERE Ruggieri, 1955

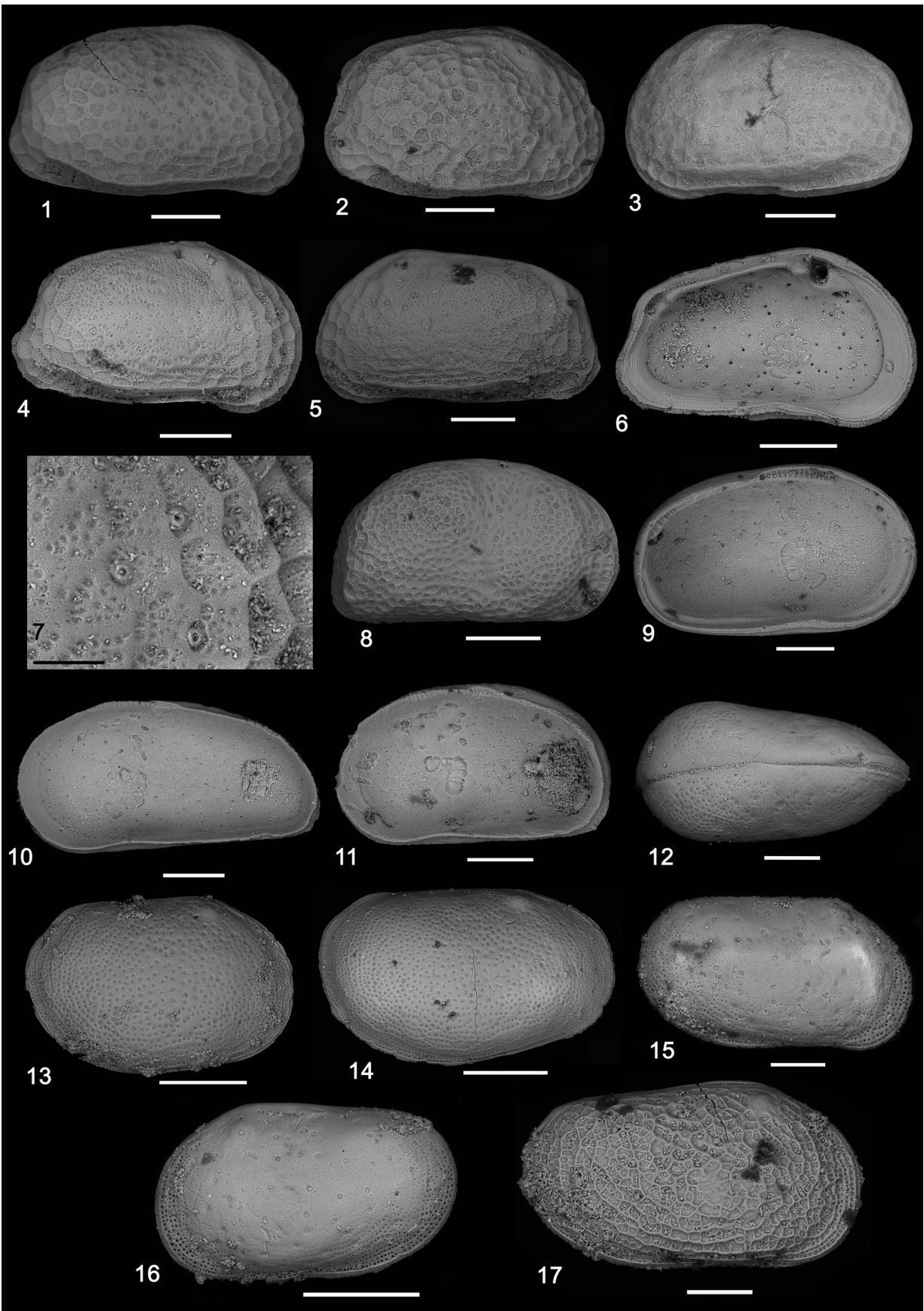
Type species. *Tyrrhenocythere pignatii* Ruggieri, 1955 by monotypy.

Tyrrhenocythere pontica (Livental) in Agalarova et al., 1961
Figure 6.1-3

- 1961 *Cythereis pontica* Livental; Agalarova, Kadyrova, and Kulijeva, p. 136, pl. 85, figs. 2, 3.
- 1979 *Tyrrhenocythere pontica* (Livental); Carbonnel, p. 109, pl. 2, fig. 17.
- 1999 *Tyrrhenocythere pontica* (Livental) in Agalarova, Kadyrova, and Kulijeva; Gliozzi, p. 201, pl. 2, figs. c-l, pl. 3, fig. d.
- 1999 *Tyrrhenocythere pontica* (Livental); Bonaduce and Sgarrella, pl. 1, fig. 9.
- 2007 *Tyrrhenocythere pontica* (Livental); Gliozzi, Ceci, Grossi, and Ligios, p. 331.
- 2008 *Tyrrhenocythere pontica* (Livental); Gliozzi and Grossi, p. 290.
- 2008 *Tyrrhenocythere pontica* (Livental); Bossio, Ciampalini, Colonese, Da Prato, Rafanelli, and Zanchetta, pl. 1, fig. 16.

The San Giorgio specimens although having more evident fossae are rather similar to that figured by Gliozzi (1999, pl. 2, fig. d); different height/length ratio may indicate sexual dimorphism.

Since the Pontian (sensu Snel et al., 2006; Pipik, 2007) species of *Tyrrhenocythere* are widely



distributed in brackish and freshwater environments within basins of the Paleomediterranean and Paratethyan regions (Boomer et al., 1996; Pipík, 2007). After rapid radiation in the Pontian, the genus began to decline and today appears to be represented by only one species, *T. amnicola* (Sars, 1887) (Pipík, 2007), which occurs at different depths and in hypohaline and mesohaline waters (Gliozzi, 1999) in the Black Sea, the Caspian Sea (Aladin et al., 2000) and the Aral Sea (Opresanu, 2004). In particular, the genus *Tyrrhenocythere* is not reported from Italy during the early Messinian while it is reported from the Paratethyan region (Pannonian Basin, Dacian Basin). Afterwards the genus is reported both in Paratethyan region and in Italy during the late Messinian, thus witnessing its immigration from Paratethyan region to the Paleomediterranean area (Carbonnel, 1980; Pipík, 2007).

Tyrrhenocythere pulcherrima sp. nov.

Figure 6.4-7

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2011 *Aurila arborescens* (Brady, 1865); Sciuto, p. 64, fig. 3.

2015 *Aurila arborescens* (Brady, 1865); Sciuto, Rosso, Sanfilippo, and Maniscalco, p. 49, pl. 1, fig. L.

Derivatio nominis. From the Latin word pulcherrima: very beautiful.

Type material. Three valves. Holotype: The right valve (length = 810 µm; height = 440 µm) PMC. O 20 H 19/5/2017 (Figure 6.4 and 6.7). Paratypes: Two left valves PMC. O 73–74 P 19/5/2017 (Figure 6.5 and 6.6).

Type locality. Cava San Giorgio in the east side of the Mangalavite valley (Tav. Vizzini, F. 645, IV, NO: 37°11'43.07"N; 14°42'04.90"E; 521 m a.s.l.) in upper Messinian white marls named "*Conger*

strata" (Di Geronimo et al., 1989) overlying the Messinian gypsum strata.

Stratigraphic range. Upper Messinian (lower part of the post evaporitic phase) to Zanclean. Other specimens have been found from lower Pleistocene shallow water sediments outcropping at Cartiera Mulino near Vittoria, southeast Sicily (Sciuto, 2011; Sciuto et al., 2015).

Other material. Some valves from lower Pleistocene shallow water sediments outcropping at Cartiera Mulino near Vittoria, southeast Sicily (Sciuto, 2011; Sciuto et al., 2015).

Diagnosis. The species is characterized by strong sub-trapezoidal carapace in lateral view with dense ornamentation constituted by polygonal muri and fossae.

Description. Carapace medium-sized, sub-rhomboidal in lateral view (Figure 6.4-7). Valves unequal, right valve slightly bigger than left. Anterior margin arched downwardly. Dorsal margin long and straight, posterior margin straight and angled. Caudal process small and arched. Ventral margin slightly sinuous, with a light oral convexity anteriorly, and regularly and steeply bending posteriorly. Outer surface ornamented by dense polygonal reticulation with well-marked muri, which delineate polygonal areas with another smaller and finer grid inside. Eye tubercles present. Normal pore canals simple, few and evenly distributed on the carapace.

Inner lamella: Anteriorly and postero-ventrally wide; there are a large anterior vestibulum and a narrower one in postero-ventral area (Figure 6.6). Marginal pore canals not visible.

Hinge: In the left valve is constituted by a straight groove parallel to the dorsal margin with, at the anterior and posterior extremities, two simple teeth and two sockets, one simple posteriorly and one double anteriorly (Figure 6.6); the right valve complementary. Muscle scars consisting of an

FIGURE 6 (left). Scanning electron microscope (SEM) photographs of Late Messinian "Lago-Mare" ostracods. **1-3**, *Tyrrhenocythere pontica* (Livental, 1929) from Cave San Giorgio, PMC. OFS 30, right valve in lateral view (**1**); PMC. OFS 31, right valve in lateral view (**2**); and PMC. OFS 32, left valve in external lateral view (**3**). **4-7**, *Tyrrhenocythere pulcherrima* sp. nov. from Cave San Giorgio, PMC. O 20 H 19/5/2017 (holotype), right valve in lateral view (**4**); PMC. O 73 P 19/5/2017 (paratype), left valve in lateral view (**5**); PMC. O 74 P 19/5/2017 (paratype), left valve in internal view (**6**); and PMC. O 20 H 19/5/2017 (holotype), right valve, close-up of normal pores (**7**). **8**, *Cyprideis* aff. *anlavauxensis* Carbonnel, 1979 from Cave San Giorgio, PMC. OFS 33, right valve in lateral view. **9**, *Cyprideis agrigentina* Decima, 1964 from Cave San Giorgio, PMC. OFS 34, left valve in internal view. **10-12**, *Cyprideis* ex *C. torosa* (Jones, 1850) group from Cave San Giorgio, PMC. OFS 35, right valve in internal view (**10**) and PMC. OFS 36, right valve in internal view (**11**); from Licodia Eubea, PMC. OFS 37, in dorsal view (**12**). **13-14**, *Loxoconcha eichwaldi* Livental, 1929 from Cave San Giorgio, PMC. OFS 38, female, right valve in lateral view (**13**) and PMC. OFS 39, male, right valve in lateral view (**14**). **15-16**, *Loxoconcha muelleri* (Méhes, 1908) from Cave San Giorgio, PMC. OFS 40, right valve in lateral view (**15**) and PMC. OFS 41, left valve in lateral view (**16**). **17**, *Loxoconcha* n. sp. from Cave San Giorgio, PMC. OFS 42, right valve in lateral view. Scale bars equal 200 µm except **7** (50 µm) and **17** (100 µm).

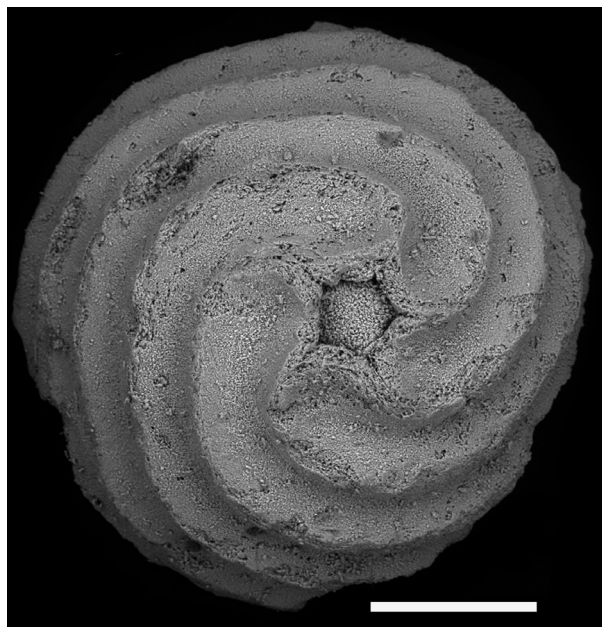


FIGURE 7. Scanning electron microscope (SEM) photographs of *Chara hispida* Linnaeus, 1753 from Cave San Giorgio, PMC. Gt.FS 48, basal view of gyrogonites. Scale bar equals 200 μ m.

inclined row of four scars centrally with three anterior and four posterior scars (Figure 6. 6).

Remarks. The species described herein has been assigned to the genus *Tyrrhenocythere* Ruggieri, 1955 because of morphological features such as the general shape of the carapace, the type of hinge and the muscle scars. *Tyrrhenocythere pulcherrima* sp. nov. is easily distinguishable from congeners *T. pignatii* Ruggieri, 1955 and *T. ruggierii* Devoto, 1967 by dense ornamentation. It can also be distinguished from *T. pontica* (Livental) in Agalarova et al., 1961, which is very similar, because of the different trend of the primary polygonal grip and the absence of secondary grip.

The new species is rather similar to *T. incerta* Olteanu, in Olteanu and Vekua, 1989 (Figure 7); nevertheless the comparison between the valves of the two species seen internally shows obvious differences, most importantly, the shape of the outer edge. The ventral margin of *T. pulcherrima* sp. nov. is long and almost straight, that of *T. incerta* is short and sinuous with a very pronounced oral convexity. The postero-ventral margin in *T. pulcherrima* sp. nov. is straight and oblique, while that of *T. incerta* is rounded. Also on the external surface of the valves there are differences such as greater density of the secondary reticulation and the primary reticulation also pres-

ent in the central part of the valve in *T. pulcherrima* sp. nov.

In the hinge area, the left valve of *T. pulcherrima* sp. nov. shows a long ridge parallel to the dorsal margin; while in *T. incerta* the ridge is oblique with respect to the dorsal margin. The anterior groove is circular in *T. pulcherrima* sp. nov., almond shaped in *T. incerta*. The muscle scars form a single rounded group in *T. pulcherrima* sp. nov., while forming two elongated groups in *T. incerta*.

Tyrrhenocythere pulcherrima sp. nov. has been found in the upper Messinian sequence above the gypsum formation, associated with an ostracod fauna dominated by *Cyprideis* spp. Therefore, as all the other species of the genus it can be related to the shallow water late Messinian Lago-Mare facies.

Tyrrhenocythere cf. *T. ruggierii* Devoto, 1967

These specimens, coming from the red sands "Arenazzolo" cropping out at Licodia Eubea (Abbeveratoio), are very similar to those figured by Stoica et al. (2016, pl. 3, figures 5-9). Compared to specimens described by Devoto in Colacicchi et al. (1967, figures 5-8) those of Licodia Eubea are not perfectly smooth.

This species is known since the upper Messinian from Sicily (Bonaduce and Sgarrella, 1999), Le Vicenne (Abruzzo, Italy) (Devoto in Colacicchi et al., 1967; Gliozzi, 1999), the Vera Basin (Spain) (Stoica et al., 2016), and since the Pontian from the Paratethys region (Olteanu, 1982).

Family CYTHERIDEIDAE Sars, 1925

Genus CYPRIDEIS Jones, 1857

Type species. *Candona torosa* Jones, 1850 by subsequent designation of Jones (1857).

Cyprideis anlavauxensis Carbonnel, 1979

Figure 6.8

- | | |
|------|---|
| 1979 | <i>Cyprideis anlavauxensis</i> ; Carbonnel, p. 112, pl. 1, fig. 8, pl. 2, figs. 10, 11. |
| 2006 | <i>Cyprideis anlavauxensis</i> ; Bassetti, Miculan, and Sierro, p. 287. |
| 2007 | <i>Cyprideis anlavauxensis</i> Carbonnel; Rouchy, Caruso, Pierre, Blanc-Valleron, and Bassetti, pl. IV, figs. 5, 6. |
| 2007 | <i>Cyprideis anlavauxensis</i> Carbonnel; Gliozzi, Ceci, Grossi, and Ligios, p. 331. |
| 2008 | <i>Cyprideis anlavauxensis</i> Carbonnel; Gliozzi and Grossi, p. 290. |
| 2012 | <i>Cyprideis anlavauxensis</i> Carbonnel; Ligios and Gliozzi, p. 180, pl. 2, figs. 1-6. |

The specimens, which come from Cave San Giorgio, are similar to *Cyprideis anlavauxensis*

Carbonnel figured by Cosentino et al. (2007, figure 5.4) and Ligios and Gliozzi (2012, pl. 2, figures 1-6) especially for the external ornamentation and to *Cyprideis* aff. *tuberculata* figured Gliozzi (1999, pl. 4, figure g); nevertheless the foveolae are wider and, the valve outline, especially in the posterior margin, is different: almost straight in the Cava San Giorgio specimen, arcuate in the other case. This species, which is reported for the first time in Sicily, is widespread in the Messinian post evaporitic facies of Lago-Mare in Mediterranean region (Italy, France, Spain and Algeria) (Carbonnel, 1979; Gliozzi et al., 2007).

Cyprideis agrigentina Decima, 1964
Figure 6.9

- 1964 *Cyprideis pannonica agrigentina*; Decima, pp. 108-111, pl. 29, figs. 4-8, pl. 30, figs. 1-10, pl. 31, fig. 1.2, pl. 37, figs. 16-21.
- 1964 *Cyprideis pannonica pseudoagrigentina*; Decima, pp. 111-113, pl. 31, figs. 3-7, pl. 32, figs. 1-2, pl. 38, figs. 1-2.
- 1978 *Cyprideis pannonica* (Méhes); Benson, p. 780, pl. 2, figs. 4-8.
- 1999 *Cyprideis "agrigentina"* Decima; Bonaduce and Sgarrella, pp. 84-86, pl. 1, fig. 1.
- 2007 *Cyprideis agrigentina* Decima; Rouchy, Caruso, Pierre, Blanc-Valleron, and Bassetti, pp. 392-393, 400, 407, 410-411, pl. 4, figs. 1-2.
- 2008 *Cyprideis agrigentina* Decima; Gross, Minati, Danielopol, and Piller, pp. 133, 135, 137-140.
- 2008 *Cyprideis agrigentina* Decima; Trenkwaller, Violanti, D'Atri, Lozar, De la Pierre, and Irace, p. 94.

According to Gliozzi (1999) the specific attribution of *Cyprideis* is rather complex. Indeed, the morphological characters of the carapace can be too diverse to justify the adoption of the term *Cyprideis* ex gr. *pannonica* by Gross et al. (2008) to indicate rather small and nearly smooth specimens of the genus found in upper Sarmatian and lower Pannonian sediments of the Central Paratethys. This character is so distinct that Ligios and Gliozzi (2012) still proposes to create the "*C. torosa* group", that includes species similar to each other as *C. agrigentina* Decima, 1964, *C. ruggierii* Decima, 1964, *C. torosa* (Jones, 1850), and in part *C. crotonensis* Decima, 1964 and *C. calabra* Decima, 1964 (Ligios and Gliozzi, 2012).

In this work we have relied not only on the general outline, but also on the internal characters of the carapace and particularly on muscle scars, hinge and duplicature. The specimen figured in

Figure 6.9 is very similar to *C. pannonica pannonica* (Méhes, 1908) figured by Decima (1964, pl. 26, fig. 9). Nevertheless, Krstić (1968) excludes in the Mediterranean area the presence of *C. pannonica* and *C. tuberculata* and afterwards, Ligios and Gliozzi (2012) compared the specimens of *C. pannonica* in the Decima collection with *C. pannonica* from Austria, showed that the specimens coming from Sicily were referable to *C. agrigentina*.

This species is widespread in all the brackish Mediterranean domain during the "Lago-Mare" phase of the Messinian Salinity Crisis, from the end of the evaporitic phase (about 5.6 Ma) to the Messinian-Zanclean boundary (5.33 Ma) (Cosentino et al., 2007; Gross et al., 2008; Guerra-Merchán et al., 2010; Cipollari et al., 2012). It seems to occur more frequently in the mesohaline-high mesohaline facies, where it made up oligotypic assemblages together with *Ammonia tepida* (Bonaduce and Sgarrella, 1999; Grossi and Gennari, 2008; Guerra-Merchán et al., 2010), while in the oligomesohaline environment it seems to be vicariant with *Cyprideis anlavauxensis* (Grossi and Gennari, 2008). This species is reported from the Messinian of Eraclea Minoa (Decima, 1964), the upper Miocene (Pannonian Stage) of the northern Vienna Basin (Kováč et al., 1998), the upper Miocene of eastern Anatolia (Nazik et al., 2008), Pliocene of Almeria (Addicott et al., 1978), the upper Miocene (Sarmatian) of Thrace (Turkey), the lower Sarmatian of Romania (Radu and Stoica, 2005), the upper Miocene deposits of Anatolia (Şafak et al., 1999), and the early Pannonian of Hungary (Kollmann 1960). The majority of *Cyprideis* species live in brackish (meso-brachyhaline), euryhaline, mainly mesohaline (5–18‰) environments but also oligohaline and hyperhaline (Gross, 2004, inter alias).

Cyprideis ex *C. torosa* (Jones, 1850) group
Figure 6.10-12

- 1964 *Cyprideis torosa* (Jones); Decima, pl. 11, figs. 3-8c, pl. 12, figs. 1-8d, pl. 15, figs. 11-15.
- 2002 *Cyprideis torosa* (Jones, 1850); Wouters, pl. 3, figs. 1a-4d.
- 2005 *Cyprideis torosa* (Jones, 1850); Matzke-Karasz and Witt, pl. 3, figs. 8-11.
- 2007 *Cyprideis torosa* (Jones, 1850); Medley, Tibert, Patterson, Allen, Greer, and Colin, pl. 1, fig. e.
- 2012 *Cyprideis torosa* (Jones, 1850); Lucena-Moya, Abraín, Pardo, Hermida and Domínguez, p. 6.
- 2011 *Cyprideis torosa*; Frenzel, Schulze, Pint, Boomer, and Feike, p. 59.

2013 *Cyprideis torosa* (Jones, 1850); Valls, Rued, and Mesquita-Joanes, fig 3, G-I.
 2015 *Cyprideis torosa* (Jones, 1850); Altınsaçlı, Altınsaçlı, and Paçal, p. 379.
 2015 *Cyprideis torosa* (Jones, 1850); Schornikov, pl. 1, figs. 15-18.
 2016 *Cyprideis torosa* (Jones, 1850); Bejaoui, Sciuto, Karoui-Yaakoub, Reitano, and AliNebiha, fig. 7, G-I.
 2016 *Cyprideis torosa* (Jones); van Baak, Stoica, Grothe, Aliyeva, and Krijgsman, figs. 4, 18.

According to Ligios and Gliozzi (2012), the high similarity of *C. agrigentina*, *C. ruggierii*, *C. torosa*, and in part *C. crotonensis* and *C. calabra*, probably linked to tight phylogenetic relationships, suggests to us to include them in a comprehensive informal “*C. torosa* group”. Also Wouters (2016) confirms that *Cyprideis torosa* Jones, 1850 is a single, highly variable, polymorphic and widely distributed species, with locally different populations.

This group includes euryhaline and eurythermal species that can live from freshwater to hypersaline water (sebkha) (Athersuch et al., 1989; Boomer et al., 1996). It has been reported from western and southern Europe, i.e., Mediterranean coasts, including Mediterranean Isles, and the Atlantic coasts of West and Northwest Europe. The species is also known from North Africa (Bejaoui et al., 2016), Eurasia, Central and Southwest Asia, (the Black Sea, Caspian Sea, Lake Aral and Lake Issyk Kul), and China (Wouters, 2002). It was also found in hypersaline environment at Santa Pola, a coastal salt marsh of the Western Mediterranean (Mezquita et al., 2011), in brackish estuaries and lagoons of mainland Portugal (Cabral et al., 2016) and in coastal mesohaline lagoons in Turkey (Altınsaçlı et al., 2015). Fossil specimens are reported from the Miocene to Recent (Meisch, 2000). *Cyprideis torosa* is indicated as Paratethyan species (Matzke-Karasz and Witt, 2005).

Family LOXOCONCHIDAE Sars, 1925
 Genus LOXOCONCHA Sars, 1866

Type species. *Cythere rhomboidea* Fisher, 1855 by subsequent designation of Brady and Norman (1889).

Loxoconcha eichwaldi Livaltal, 1929
 Figure 6.13-14

1929 *Loxoconcha eichwaldi*; Livaltal, p. 34, pl. 1, figs. 42, 43.
 1978 *Loxoconcha eichwaldi* Livaltal, 1929; Olteanu, p. 1020, pl. 7, fig. 2.
 1979 *Loxoconcha eichwaldi* Livaltal, 1929; Carbonnel, p. 114, pl. 1, fig. 4.

1999 *Loxoconcha eichwaldi* Livaltal, 1929; Gliozzi, p. 204, pl. 1, fig. d.
 2001 *Loxoconcha eichwaldi* Livaltal, 1929; Tunoğlu, pl. 1, figs. 14, 15.
 2007 *Loxoconcha eichwaldi* Livaltal; Gliozzi, Ceci, Grossi, and Ligios, p. 331.
 2008 *Loxoconcha eichwaldi* Livaltal; Gliozzi and Grossi, p. 290.
 2008 *Loxoconcha eichwaldi*; Bossio, Ciampalini, Colonese, Da Prato, Rafanelli, and Zanchetta, tav. 1, fig. 13.
 2008 *Loxoconcha eichwaldii* Livaltal, 1929; Grossi and Gennari, fig. 4c.
 2008 *Loxoconcha eichwaldi*; Trenkwalder, Violanti, D’Atri, Lozar, De la Pierre, and Irace, p. 94.
 2016 *Loxoconcha eichwaldi* Livaltal, 1929; Stoica, Krijgsman, Fortuin, and Gliozzi, pl. 6, figs. 10-17.
 2016 *Loxoconcha eichwaldi* Livaltal; van Baak, Stoica, Grothe, Aliyeva, and Krijgsman, figs. 4, 13-14.

Loxoconcha eichwaldi is widespread in the Pliocene, in the Pontian (Gliozzi, 1999; inter alias) and in the Pannonian (Krstić, 1972) of the Paratethyan region. In the Tethyan region it is reported from the upper Messinian of Corsica, Italy, and France (Carbonnel, 1979). The figured specimen comes from the upper Messinian *Congerina* strata of Cave San Giorgio. This species, which was found at Eraclea Minoa by Grossi et al. (2015), is reported for the first time from the southeastern Sicily.

Loxoconcha muelleri (Méhes, 1908)
 Figure 6.15-16

1908 *Cythereis mülleri* Méhes; p. 562, pl. 8, figs. 15-18, pl. 9, figs. 1-4.
 1929 *Loxoconcha mülleri* (Méhes, 1908); Zalani, p. 168, pl. 36, figs a-d, pl. 37, figs. a-b.
 1979 *Loxoconcha mülleri* (Méhes, 1908); Carbonnel, p. 116, pl. 1, figs. 6, 7, 12.
 1998 *Loxoconcha muelleri* (Méhes, 1908); Kováč, Barath, Kovačova-Slamkova, Pipík, Hlavaty, and Hudačkova, pl. 4, fig. 1.
 2007 *Loxoconcha muelleri* (Méhes, 1908); Faranda, Gliozzi, and Ligios, fig. 3(8).
 2007 *Loxoconcha muelleri* (Méhes, 1908); Gliozzi, Ceci, Grossi, and Ligios, p. 331.
 2007 *Loxoconcha muelleri* (Méhes, 1908); Rouchy, Caruso, Pierre, Blanc-Valleron, and Bassetti, pl. 5, fig. 8.
 2008 *Loxoconcha muelleri*; Bossio, Ciampalini, Colonese, Da Prato, Rafanelli, and Zanchetta, pl. 1, fig. 12.

- 2008 *Loxoconcha mülleri* (Méhes, 1908); Grossi and Gennari, fig. 4b.
- 2008 *Loxoconcha muelleri*; Trenkwalder, Violanti, D'Atri, Lozar, De la Pierre, and Irace, p. 94.
- 2011 *Loxoconcha mülleri* (Méhes, 1908); Grossi, Gliozzi, and Cosentino, p. 68.
- 2016 *Loxoconcha muelleri* (Méhes, 1908); Stoica, Krijgsman, Fortuin, and Gliozzi, pl. 6, figs. 1-9.

Loxoconcha muelleri and *L. eichwaldi* are Paratethyan species, which were widespread in the Mediterranean area during the Lago-Mare event (Faranda et al., 2007). Particularly *L. muelleri* is reported from the post evaporitic Adana Basin (Turkey) (Faranda et al., 2013) from the upper Messinian of Montepetra (Italy) (Grossi and Gennari, 2008), France and Corsica (Carbonnel, 1979) and Algeria (Rouchy et al., 2007).

According to Grossi et al. (2011), in the Mediterranean area the *L. muelleri* zone comprises an interval zone of between the FO of *L. muelleri* and the FO of the Paratethyan ostracod *Loxocorniculina djaffarovi* (Suzin, 1956). Within this interval the ostracod association is scarce and oligotypic and formed mainly of *L. muelleri* and *C. agrigentina*. Only in the upper part of the *L. muelleri* Zone the association becomes richer and also includes *L. eichwaldi* and *T. pontica*.

This species, which was found at Eraclea Minoa by Grossi et al. (2015), is reported for the first time from southeastern Sicily.

Loxoconcha n. sp.
Figure 6.17

Large size *Loxoconcha* (length = 535 µm, height = 290 µm), subtrapezoidal in lateral view. Valve ornamented with a dense reticulation consisting of polygonal muri and irregular fossae. Anterior and posterior marginal areas are covered by regular little fossae aligned to the margins. Although showing some resemblance with *Loxoconcha limata* Schweyer or with *Loxoconchissa reticulata* Faranda et al., 2007, the species is currently assigned to the genus *Loxoconcha*. Since this species is represented by only one specimen, we have left the species denomination in open nomenclature. The figured specimen comes from the Cave San Giorgio sampling station. Repository numbers of the figured specimens are PMC. OFS 30–47.

DISCUSSION

The ostracod fauna found in the different sections analyzed in the present work has oligotypic

character and is certainly comparable, both at genus and species level, with the Lago-Mare ostracods associations reported by many authors for other localities of the Paleomediterranean Basin (Gliozzi et al., 2007, inter alias). According to these authors, the paleogeographical distribution of the upper Messinian Lago-Mare ostracod species studied, i.e., *Loxoconcha muelleri*, *L. eichwaldi*, *Tyrrhenocythere pontica*, *T. ruggierii*, *Cyprideis pannonica*, *C. anlavauxensis* and *C. torosa* allow to be considered them as Paratethyan affinity species, or rather, species that during the post evaporitic phase spread from the eastern region (Paratethys) to the western region (Paleomediterranean). This phenomenon was favored essentially by the presence of special hydrological conditions in the Paleomediterranean area (large and shallow water basins in connection with each other and with the large waterways of the Paratethyan region) (Gliozzi et al., 2007; Olteanu and Jipa, 2006).

During the post evaporitic interval of the upper Messinian in East Sicily (Di Geronimo et al., 1989; Pedley and Grasso, 1992), as well as in other basins of the Mediterranean area (Rouchy et al., 2001; Rouchy and Caruso, 2006, inter alias), these basins, were formed above the evaporitic and pre-evaporitic substratum, because of the intense tectonic activity, that bent or broke it, giving rise to synclinals or grabens. In this thin tectonics basins, terrigenous sediments, which contained a brackish to fresh water ostracod fauna (Lago-Mare facies), were deposited. The shallow character of these basins is also witnessed by the finding of charophyte gyrogonites, among which, the best preserved are referable *Chara hispida* Linnaeus, 1753 (Soulié-Marsche and García, 2015) (Figure 7; repository number PMC. Gt.FS 48). *Chara hispida* lives in oligotrophic, freshwater shallow lake environments, peatland, mud-calcareous gyttja; it can occasionally be found in brackish waters. Therefore, it may be characterized as tollerant to salinity at a depth from about 0.5 m to about 3.5 m (Barinova et al., 2014 and references therein). The two different facies identified in the Licodia Eubea area, namely the arkosic sands “Arenazzolo” in the Abbeveratoio section and the marls of “*Congerina strata*” in the Cave San Giorgio section, correspond to two contiguous environments where salinity plays a decisive role in the selection of the species found. The “Arenazzolo sands”, where only the genera *Tyrrhenocythere* and *Cyprideis* were found, represented a sedimentary facies deposited in a hyposaline or lacustrine-fluvial envi-

ronment. The marls of *Congerina* strata, where, in addition to the previous genera, was found also the genus *Loxoconcha*, corresponded to a sedimentary facies deposited in a shallow water marine-transitional environment (internal lagoon) characterized by salty, brackish oligohaline water, with the addition of fluvial lacustrine water. This conclusion can be confirmed by the presence of Hydrobiidae, Thiaridae and Limnocardiidae to which the oligohaline genera *Neritina*, *Melanopsis* and *Dreissena* can be added (Di Geronimo et al., 1989). Above the sedimentary Lago-Mare facies, or directly on the gypsum strata, several tens of meters of the lower Pliocene white chalks (Trubi Formation),

which represent the rapid return to the normal marine sedimentation, crop out in apparent concordance.

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