



## Full restoration of marine conditions after the late Messinian Mediterranean Lago-Mare phase in Licodia Eubea and Villafranca Tirrena areas (east Sicily)

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**Abstract:** After the Upper Messinian Mediterranean Lago-Mare phase, at the end of the Messinian salinity crisis, the Mediterranean basin was characterized by a return to normal marine conditions starting with the Lower Pliocene (Zanclean). In this period, remarkably thick layers of calcareous pelitic sediments, very rich in planktonic foraminifers and nannofossils, were widely deposited in the Mediterranean basin. The calcareous pelitic deposits of Sicily (Trubi Formation), as well as in other Mediterranean regions, were deposited conformably on the pre-Pliocene substrate, which is mainly represented by Messinian evaporites or by the post-evaporitic Lago-Mare facies. We have analysed samples taken from the lower portion of the Trubi Formation (Zanclean), just above the Messinian facies, collected from Licodia Eubea and Villafranca Tirrena areas (eastern Sicily). Micropaleontological assemblages consist of benthic and planktonic foraminifers and a typical deep-water ostracod fauna. The microfossil association and the stratigraphy of the Messinian-Pliocene transitional layers, supported by calcareous nannoplankton data, demonstrate not only rapid sea-level rise in this sector of the Mediterranean region, but also that this event, occurred without producing erosional features, unlike at other sites (e.g., Strait of Gibraltar).

**Key-words:**

- Mediterranean Sea;
- Sicily;
- Zanclean Stage;
- bathyal ostracods;
- bathyal foraminifers;
- Trubi Formation;
- palaeoenvironmental evolution

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**Résumé : Rétablissement total des conditions marines après la phase "Lago Mare" du Messinien supérieur de la Mer Méditerranée dans les régions de Licodia Eubea et Villafranca Tirrena (Sicile orientale).**- Après la phase dite "Lago Mare" en Mer Méditerranée, à la fin de la crise de la salinité du Messinien supérieur, le bassin méditerranéen s'est caractérisé par un retour à des conditions marines normales à partir du Pliocène inférieur (Zancléen). Au cours de cette période, des accumulations remarquablement épaisses de sédiments pélitiques calcaires très riches en foraminifères planctoniques et nannofossiles se sont déposées dans le bassin méditerranéen. En Sicile, ces sédiments pélitiques calcaires sont connus à l'affleurement sous l'appellation de Formation de Trubi. Comme dans d'autres régions méditerranéennes, ils ont été déposés en concordance sur le substrat pré-Pliocène, qui est essentiellement représenté par les évaporites messiniennes ou par des sédiments post-évaporites à faciès "Lago Mare". Pour cette étude, nous avons analysé des échantillons récoltés dans les secteurs de Licodia Eubea et Villafranca Tirrena (Sicile orientale) à la base de la Formation de Trubi (Zancléen), immédiatement au-dessus du faciès messinien. Les résidus de lavages sont caractérisés par des associations micropaléontologiques de foraminifères, benthiques et planctoniques, et d'ostracodes typiques d'eaux profondes. Les caractéristiques de ces associations de microfossiles et l'observation stratigraphique des couches de la transition Messinien-Pliocène témoignent d'une élévation rapide du niveau de la mer dans ce secteur de la région paléoméditerranéenne ; en outre, elles sembleraient démontrer qu'ici, contrairement à ce qui a été observé sur d'autres secteurs (e.g., détroit de Gibraltar), cet événement serait survenu sans y produire de traces tangibles d'érosion.

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- foraminifères bathyaux ;
- Formation de Trubi ;
- évolution du paléoenvironnement

## 1. Introduction

During the Messinian Salinity Crisis (Hsü *et al.*, 1973), which lasted for about 640 kyr (KRIJGSMAN *et al.*, 1999; ROVERI *et al.*, 2014), various layers of evaporites, ranging in thickness from a few metres to hundred of metres, were deposited on the bottom of euxinic basins in a large part of the palaeo-Mediterranean area (ROUCHY & CARUSO, 2006).

During the Messinian post-evaporitic phase, several parts of the Mediterranean Basin emerged and were affected by strong subaerial erosion, chemical dissolution of evaporitic rocks and, in the broad shallow basin, deposition of terrigenous sediments containing brackish or freshwater faunas mostly of Paratethysian affinity (ORSZAG-SPERBER *et al.*, 2000; ROUCHY *et al.*, 2007; GLIOZZI *et al.*, 2007; GUERRA-MERCHÁN *et al.*, 2010; SCIUTO *et al.*, 2018; TEMANI *et al.*, 2018). This sedimentary facies, called "Lago-Mare" *sensu* RUGGIERI (1967), crops out discontinuously but widely throughout the Mediterranean Basin (*e.g.*, CITA *et al.*, 1978; ORSZAG-SPERBER *et al.*, 2000; ROUCHY & CARUSO, 2006).

In the Zanclean Age (early Pliocene), in several areas of the Mediterranean Basin, thick layers of sediment consisting of white pelitic limestone rich in planktonic foraminifers (Trubi Formation) (CITA, 1975; CITA *et al.*, 1990) and other correlated sedimentary facies (GUERRA-MERCHÁN *et al.*, 2010; LANCIS *et al.*, 2015) were deposited conformably on either Messinian evaporitic or post-evaporitic facies (BARRA *et al.*, 1998; GROSSI *et al.*, 2015; GENNARI *et al.*, 2008). These sediments show that, during the Zanclean, the Mediterranean basin returned to fully marine conditions because it was filled by a huge mass of water from the Atlantic Ocean (Zanclean flood) (CITA, 1975; CITA *et al.*, 1990; CITA & RYAN, 1973; BENSON, 1973; ROUCHY *et al.*, 2001; GARCIA-CASTELLANOS *et al.*, 2009; KRIJGSMAN *et al.*, 2018).

The present paper focuses on the marine ostracods, calcareous nannofossils and foraminifers collected from Zanclean stratigraphic levels cropping out above the evaporitic or post-evaporitic facies in two localities of eastern Sicily, Licodia Eubea and Villafranca Tirrena.

We aim simultaneously to a) analyse taxonomically and stratigraphically the most useful ostracod and foraminifers species found in the collected samples, and b) to reconstruct the palaeoenvironment in two sectors of the Mediterranean Basin for a period when, after the Messinian desiccation, normal-marine conditions were restored.

The Zanclean stratigraphic interval in the Mediterranean basin has been intensively analysed, both in outcrop and in cores, especially from biostratigraphic and palaeoecological perspective, at Capo Rossello (CITA & GARTNER, 1973; CITA, 1975; LANGEREIS & HILGEN, 1991) and Eraclea Minoa (COVERING *et al.*, 2000) along the southern Sicilian coast; at Buonfornello along the Tyrrhenian Sicilian coast (COVERING *et al.*, 2000); in some localities of southern Italy, *e.g.*, Capo Spartivento, Singa and Roccella (CHANNEL *et al.*, 1988; COVERING *et al.*, 2000) and broadly across the Mediterranean Basin (CITA & RYAN, 1973; CITA, 1975; HASEGAWA *et al.*, 1990; SPROVIERI & HASEGAWA, 1990; BARRA *et al.*, 1998; SPEZZAFERRI *et al.*, 1998; COVERING *et al.*, 2000; GENNARI *et al.*, 2008; TRENKWALDER *et al.*, 2008; DI STEFANO & STURIALE, 2010; CIPOLLARI *et al.*, 2013).

While considerable attention has been given to upper Messinian Lago-Mare ostracods (SCIUTO *et al.*, 2018, and references therein) much remains to be reported on Zanclean ostracods. Our study adds significantly to those of TRENKWALDER *et al.* (2008) on the Tertiary Piedmont Basin, CIPOLLARI *et al.*, 2013, on the Adana Basin (southern Turkey), and BENSON and RUGGIERI on single species or on particular groups of species (*e.g.*, RUGGIERI, 1953, 1992; BENSON, 1973; BARRA *et al.*, 1998).

## 2. Geological setting

The early Pliocene deposits sampled for this study belong to two different palaeogeographic contexts: the Villafranca Tirrena Basin (to the North) and the northwestern border of the Hyblean Plateau (to the South) (Fig. 1). In both cases the analysed sections have been attributed to the basal Zanclean, ostracod biozones CNPL1 Zone *sensu* BACKMAN *et al.* (2012) or MNN 12 biozone *sensu* MARTINI (1971) (SCIUTO *et al.*, 2018).

The Villafranca Tirrena Basin, situated in NE Sicily on the Tyrrhenian coast (Figs. 1-2), is structurally part of the Apennine-Maghrebien Chain ("Aspromonte Unit" *auct.*). It is characterised by a metamorphic basement covered unconformably by Miocene and Plio-Pleistocene deposits with extremely variable thickness (from a few to tens of meters), frequent facies changes, stratigraphic gaps and unconformities (LENTINI *et al.*, 1987). The sedimentary sequence starts with early-middle Miocene polygenic conglomerates passing laterally and upward to grey clayey marls with fine sand. Overlying these facies is the Messinian sequence, consisting of evaporitic carbonates (Calcare di Base *auct.*), calcareous breccias and



◀ **Figure 1:** Location of the Villafranca Tirrena and Abbeveratoio sections.

gypsum. During the post-evaporitic phase, medium and coarse sands and breccias, called "Arenazzolo" were deposited (e.g., MOTTURA, 1871; OGNIBEN, 1957; SCIUTO *et al.*, 2018). This deposit, where only the ostracod genera *Tyrrhenocythere* and *Cyprideis* were found, represents the Lago-Mare facies deposited in hyposaline or lacustrine-fluvial environments at the end of the Messinian (SCIUTO *et al.*, 2018). The sequence continues with the early Pliocene (Zanclean) Trubi Formation, evolving upwards to Pleistocene marls and sands.

The second area (Figs. 1-2) is a part of the Hyblean foreland, a predominantly calcareous plateau that occupies the SE sector of Sicily. The outcropping stratigraphic sequence, consisting mainly of carbonate sediments, with intercalated subaerial and submarine volcanic products, represents semi-continuous deposition from the Early Cretaceous to the Pleistocene (LENTINI *et al.*, 1987).

Also in the Hyblean sector, a series of deposits signifying the Salinity Crisis was formed during the Messinian Age. These include confined and discontinuous siliceous laminated sediments (Tripoli Formation), evaporitic limestones (Calcare di Base) and gypsum, which were deposited in semi-closed syndimentary tectonic basins, at a depth of 150-200 metres (PEDLEY & GRASSO, 1992).

Conformable post-evaporitic upper Messinian deposits followed. They consist of carbonate and gypseous breccias, marls, sands and silts locally containing oligohaline to freshwater faunas (Lago-Mare Facies). The beds are known as the "*Congeria strata*" where they are made up of marls containing oligohaline mollusc faunas and ostracods (DI GERONIMO *et al.*, 1989; PEDLEY & GRASSO, 1992; SCIUTO *et al.*, 2018) or as "Arenazzolo" where consisting of reddish arkoses containing brackish to freshwater ostracods (BONADUCE & SGARRELLA, 1999; ROVERI *et al.*, 2008; SCIUTO *et al.*, 2018). These deposits belong to the upper part of the *Loxococoncha muelleri* Zone *sensu*

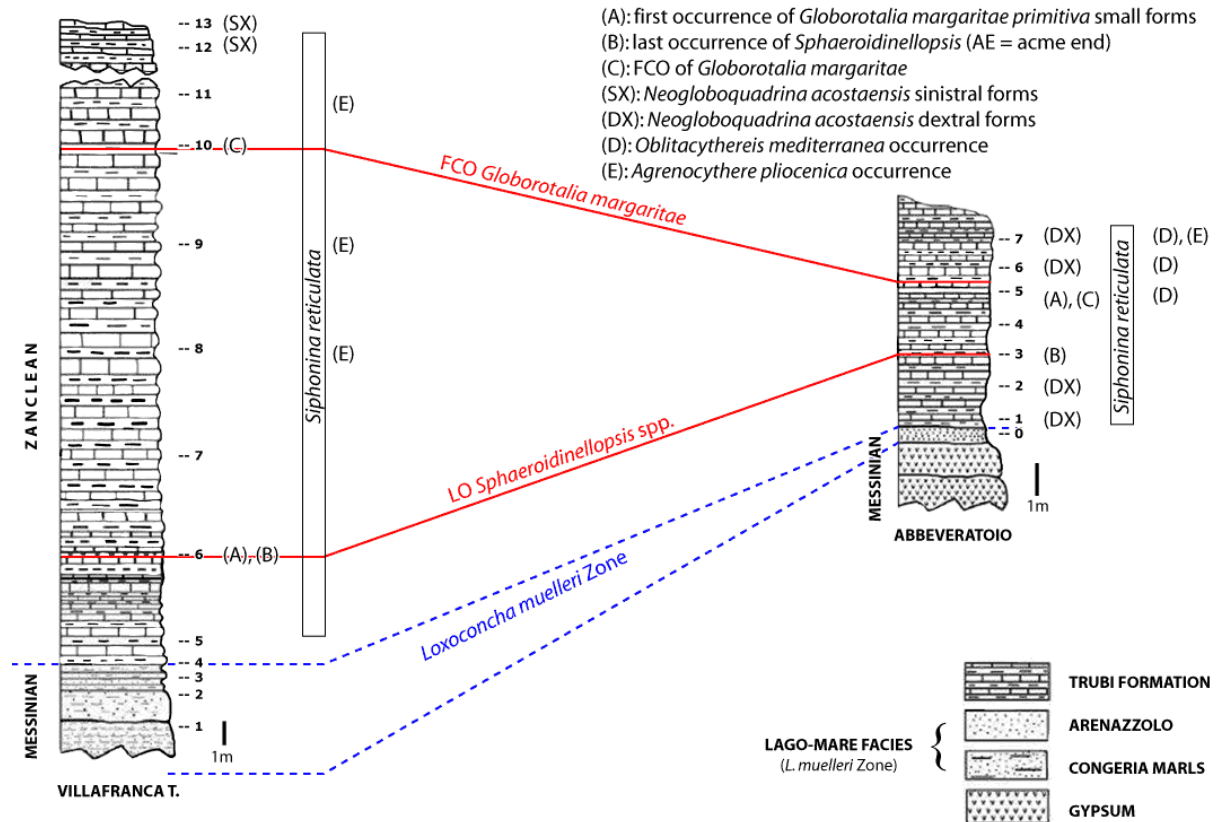
GROSSI *et al.*, 2011 (lower post-evaporitic phase of the Messinian stage) due to the co-occurrence of *Cyprideis agrigentina* DECIMA, 1964, *Loxococoncha muelleri* (MÉHES, 1908), *Loxococoncha eichwaldi* LIVENTAL, 1929, and *Tyrrhenocythere pontica* (LIVENTAL) in AGALAROVA *et al.*, 1961 (SCIUTO *et al.*, 2018).

The upper Messinian is overlain conformably by remarkably thick layers of lower Pliocene (Zanclean) white chalks, very rich in planktonic foraminifers and calcareous nannofossils (Trubi Formation), which represent the restoration of fully marine conditions. In the Licodia Eubea area, Pleistocene calcarenites and marls can be found at the top.

### 3. Material and methods

In the Villafranca Tirrena Basin, the chosen section, named Villafranca Tirrena (VT) (Figs. 1-2), crop out on the southern slope of Guardiola hill along the Galvaruso-Fondaco road (38°14' 02.42"N; 15°26'14.11"E; height 43 meters a.s.l.). In this locality, the lower Pliocene Trubi Formation (Fig. 2), consisting of white marl alternating with limestone, conformably overlies the upper Messinian post-evaporitic Lago-Mare facies represented by terrigenous medium- and coarse-grained sands and breccias (Arenazzolo) with ostracods belonging to the genus *Cyprideis* (SCIUTO *et al.*, 2018). Eight samples were taken from the base of the Trubi Formation (Fig. 2).

In the Hyblean foreland, the Abbeveratoio (LI) section (Figs. 1-2) is located a few dozen metres south of the village of Licodia Eubea (37°09' 20.11"N; 14°42'33.81"E; height 554 meters a.s.l.). The section starts with three metres of well stratified Messinian gypsum conformably overlain by a 50-cm-thick layer of post-evaporitic Lago-Mare facies represented by reddish sands and silty sands (Arenazzolo) with ostracods belonging to the genera *Cyprideis* and *Tyrrhenocythere* (SCIUTO *et al.*, 2018). The lower Pliocene Trubi Formation is conformable and consists of



**Figure 2:** Villafranca and Abbeveratoio stratigraphic logs. Correlations and main biostratigraphic events.

predominantly white marls and marly limestones (Trubi Formation), 7 m thick and containing rare specimens of *Neopycnodonte navicularis* (BROCCI, 1814) and common trace fossils attributable to *Zoophycos* spp. Seven samples were taken from this formation (Fig. 2).

Ostracod and benthic and planktonic foraminiferal assemblages were extracted for micropalaeontological analysis. From each sample, 250 g of sediment was washed using diluted hydrogen peroxide for disaggregation. The residues were sieved through standard sieves (63/125/250/500 µm). All ostracods in the <250 µm fraction of each sample were picked and subjected to careful taxonomic examination. From the >125 µm fraction 0.2 g/sample was picked and then a quarter of the sample was analysed if necessary for foraminifers. The ostracod specimens were examined and measured under a stereomicroscope and photographed in the 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 Palaeontological Museum of Catania University. Micrographs of foraminiferal specimens were taken by a scanning electron microscope (GEOL /EO Instrument JCM-6000), at the Center for Climate Change and Biodiversity in Lakes and Wetlands of Arpa Umbria, Perugia (Italy), with the collaboration of Dr Rosalba Padula, and the specimens are deposited in the Department of Physics and Geology, University of Perugia (Italy).

## 4. Results

### 4.1. OSTRACODS

A total of 19 species belonging to 18 genera has been found in Abbeveratoio section whereas 17 species belonging to 12 genera are recognised in the Villafranca Tirrena section (Table I; Plate 1). The species common to both sections, though with marked differences in abundance and distribution are: *Agrenocythere pliocenica* (SEGUENZA, 1880), *Costa tricostata pliocenica* RUGGIERI, 1992, *Bythocypris antoniettae* SCIUTO, 2012, *Bythocypris obtusata* (SARS, 1866), *Cytherella* sp. 1 and *Henryhowella* ex group *H. profunda* BONADUCE *et al.*, 1999 (*sensu* SCIUTO, 2014a), *Henryhowella* ex group *H. hirta* (COSTA, 1853) (*sensu* SCIUTO, 2014a) and *Bairdia conformis* (TERQUEM, 1878).

The species that are particularly abundant and widespread in the lower part of the Abbeveratoio section (Fig. 2; Table I) are: *Henryhowella* ex group *H. profunda* BONADUCE *et al.*, 1999 (*sensu* SCIUTO, 2014a), *Cytherella* sp. 1., *Cytherella russoi* SISSINGH, 1972, *C. tricostata pliocenica* RUGGIERI, 1992, *Henryhowella* ex group *H. hirta* (COSTA, 1853) (*sensu* SCIUTO, 2014a) and *Agrenocythere pliocenica* (SEGUENZA, 1880). Less abundant and widespread are *Oblitacythereis mediterranea* BENSON, 1977, *Bythocypris obtusata* (SARS, 1866) and *Acanthocythereis colinii* SCIUTO, 2014b. Poorly represented and of limited distribution are *Bairdia conformis* (TERQUEM, 1878), *Bairdoppilata* sp., *Buntonia dertonensis* RUGGIERI, 1954, *Buntonia sublatissima* (NEVIANI, 1906), *Bythocypris an-*



*toniettae* SCIUTO, 2012, *Ruggieria tetraptera palpebralis* RUGGIERI, 1960, *Pseudopsammocythere* sp., and *Krithe* cf. *inqua* ABATE *et al.*, 1993.

The ostracods of Villafranca Tirrena section are relatively rare and occur with few specimens in individual samples. Nevertheless, it is only here that species of *Parakrithe* as well as *Buntonia subulata subulata* RUGGIERI, 1954, *Bythocypris bosquetiana* (BRADY, 1866), *Cytheropteron eleonora* SCIUTO, 2012, *Cytheropteron pinarense* (BOLD, 1946) and *Cytherella* sp. occur.

Species of *Krithe* are a particular feature of this section, in some cases in high abundance, with the most abundant being *Krite compressa* (SEGUENZA, 1880).

#### 4.2. FORAMINIFERS

The assemblages of the two sections are similar with 49 species identified at Abbeveratoio and 44 species at Villafranca Tirrena (Table I; Plate 2). Benthonic foraminifers dominate the assemblages with a peak of 31 species at Abbeveratoio section and 29 species at Villafranca Tirrena. The planktonic foraminifers are represented by 15 and 18 species respectively in Villafranca Tirrena and Abbeveratoio sections.

In the Villafranca Tirrena section the *Globigerina bulloides* group (*G. bulloides*, *G. praebulloides* and *G. falconensis*) dominates the assemblages from the base to the top (sample VT 12), with high to very high frequencies. Species belonging to this group are cold-water eutrophic and thriving the Intermediate Water (IW). A slight decrease of *G. bulloides* abundance (to common) occurs in samples VT 7, VT 8 and VT 10 whereas *G. falconensis*, which is rare in the four basal samples, then becomes abundant.

The abundances of the warm-water oligotrophic species, *Globigerinoides ruber* and *G. sacculifer*, show trends opposite to that of the *G. bulloides* group.

The surficial cold-water eutrophic form, *Turborotalita quinqueloba*, is frequent or common in samples VT 5 and VT 6 and becomes abundant from VT 9 to the top of the section. The neogloboquadrinids, represented by *Neogloboquadrina acostaensis* (sinistral coiled forms), are variously rare or frequent in the basal samples and then become common to abundant from VT 10 to the top. *Orbulina universa* is always very abundant and dominates all sample assemblages. *Sphaeroidinellopsis* occurs only in the basal samples (VT 5 and VT 6), where it is rare, and then disappears.

*Globorotalia margaritae*, referred to *G. margaritae primitiva* CITA, 1973, is found throughout the section, where it varies from rare in the basal sample, VT 6, to common or abundant in VT 10. The large taxa, *G. margaritae* and *G. margaritae evoluta* (Plate 2), are common in VT 10 and increase to abundant at the top. At Abbeveratoio, the small species, *G. margaritae primitiva*, occurs only in sample LI 5, where it is rare, at the first appearance of *G. margaritae* large specimens. *G.*

*margaritae* become common in LI 6 and after abundant in LI 7.

It is important to note that in section VT *Globorotalia menardii* and *G. menardii neoflexuosa*, including some aberrant specimens are common to abundant in samples from VT 10 to the top. *G. puncticulata* is abundant in the uppermost samples of VT whereas at Abbeveratoio it is rare and occurs only at the top (sample LI 7).

At Abbeveratoio *Globigerina bulloides*, *G. falconensis* and *G. praebulloides* are variable in frequency, and fluctuate from very abundant (*G. bulloides*) in the basal samples, LI 1 and LI 2, to rare and/or common in samples LI 3-LI 7. The genus *Globigerinoides* (here represented by *G. obliquus*, *G. ruber* and *G. sacculifer*) is variably frequent with *G. obliquus* abundant to common in LI 1 and LI 2, rare in LI 3 and LI 4, and abundant from LI 5 to the top. *G. ruber* and *G. sacculifer* are mainly common with a slight decrease in samples LI 4 and LI 7.

Genus *Orbulina* dominates all samples, and is abundant to very abundant. The neogloboquadrinids are represented by rare *Neogloboquadrina incompta* and frequent to common *N. acostaensis* (dextrally coiled forms) in samples LI 1 and LI 2, and become rare from LI 5 to the top. *Sphaeroidinellopsis* species are commonly in the basal samples, become rare in LI 3, and are absent from overlying samples.

At Abbeveratoio, the epifaunal species *Planulina ariminensis* and the epifaunal and detritivore species *Lenticulina orbicularis* are consistently abundant to very abundant whereas *Cibicidoides pseudoungerianus* is common in the basal samples LI 1 and LI 2, becomes rare in LI 3 and LI 4, and sharply increases to being abundant in LI 5, where it is accompanied by abundant *C. ungerianus* and *Cibicides cicatricosus*. In the samples LI 6 and LI 7, all three species of *Cibicidoides* are rare.

In the case of infaunal species, the shallow-infaunal *Siphonina reticulata* ranges from common to abundant in all samples while *Bulimina aculeata*, *B. marginata*, *Uvigerina peregrina* and *U. pygmaea* are common to abundant in samples LI 5 to LI 7.

At Villafranca Tirrena species that occur in all samples are the epifaunal *Lenticulina orbicularis* and *Planulina ariminensis* and the shallow infaunal *Siphonina reticulata*.

The epifaunal species *Cibicidoides pseudoungerianus* is common only in the basal sample and then decreases markedly before becoming frequent in samples VT 10, VT 12 and VT 13. *Planularia cassis*, which prefers cold bottom waters, is common to frequent in the basal samples, becomes abundant in VT 9, and then decreases to common at the top of section.

The species *Marginulinopsis costata*, which prefers soft substrates enriched in organic matter (BALDANZA *et al.*, 2018), is common only in sample VT 11 whereas *Uvigerina pygmaea* and *U. peregrina* are common in samples VT 10 and VT 11.



**Table I:** Ostracods and foraminifers species found in Villafranca (VT) and Abbeveratoio (LI) sections. (X: 1 specimens. R: from 2 to 9 specimens. F: from 10 to 29 specimens. C: from 30 to 49 specimens. A: over 50 specimens. AA: over 100 specimens).

<b>Ostracods</b>	<b>VT 5</b>	<b>VT 6</b>	<b>VT 7</b>	<b>VT 8</b>	<b>VT 9</b>	<b>VT 10</b>	<b>VT 11</b>	<b>VT 12</b>	<b>VT 13</b>	<b>LI 1</b>	<b>LI 2</b>	<b>LI 3</b>	<b>LI 4</b>	<b>LI 5</b>	<b>LI 6</b>	<b>LI 7</b>
<i>Acanthocythereis colini</i> SCIUTO, 2014												X				X
<i>Agrenocythere pliocenica</i> (SEGUENZA, 1880)			X	X		X										R
<i>Argilloecia</i> spp.																X
<i>Bairdia conformis</i> (TERQUEM, 1878)								X								X
<i>Bairdoppilata</i> sp.																X
<i>Buntonia dertonensis</i> RUGGIERI, 1954										X	X					
<i>Buntonia sublatissima</i> (NEVIANI, 1906)													X			
<i>Buntonia subulata subulata</i> RUGGIERI, 1954									X							
<i>Bythocypris antoniettae</i> SCIUTO, 2012			X													X
<i>Bythocypris bosquetiana</i> (BRADY, 1866)								X								
<i>Bythocypris obtusata</i> (SARS, 1866)	X							X			X		X			X
<i>Bythocypris</i> sp. 1										X						
<i>Costa tricostata pliocenica</i> RUGGIERI, 1992	X								X	X	X	X		X		
<i>Cytherella</i> sp. 1								X	X	X	X	X	X	X	X	R
<i>Cytherella</i> sp. 2								X	X							
<i>Cytheropteron eleonora</i> SCIUTO, 2012									X							
<i>Cytheropteron pinarense</i> (BOLD, 1946)		X														
<i>Cytherella rusoi</i> SISSINGH, 1972										X	X	X	X	X	X	
<i>Cytherella</i> sp. 3										X						
<i>Echinocythereis</i> sp.											X					
<i>Henryhowella ex H. profunda</i> BONADUCE et al., 1999 group	X								X	X	X	X	X	X	X	R
<i>Henryhowella ex H. hirta</i> (COSTA, 1853) group									X			X		X		X
<i>Krithe iniqua</i> BARRA et al., 1993		X		X	X			X								
<i>Krithe</i> cf. <i>K. iniqua</i> BARRA et al., 1993																X
<i>Krithe compressa</i> (SEGUENZA, 1880)	X	X						R	X	X	X					
<i>Krithe perpulchra</i> ABATE et al., 1993		X			X											
<i>Krithe</i> spp.										X		X				X
<i>Oblitacythereis mediterranea</i> BENSON, 1977														X	X	X
<i>Parakrithe</i> sp. 1					X											
<i>Parakriyhe</i> sp. 2									X							
<i>Pseudopsammocythere</i> sp.											X	X				
<i>Ruggieria tetraptera palpebralis</i> RUGGIERI, 1960																X
<b>Planktonic foraminifera</b>	<b>VT 5</b>	<b>VT 6</b>	<b>VT 7</b>	<b>VT 8</b>	<b>VT 9</b>	<b>VT 10</b>	<b>VT 11</b>	<b>VT 12</b>	<b>VT 13</b>	<b>LI 1</b>	<b>LI 2</b>	<b>LI 3</b>	<b>LI 4</b>	<b>LI 5</b>	<b>LI 6</b>	<b>LI 7</b>
<i>Globigerina bulloides</i> (ORBIGNY, 1826)	AA	AA	F	C	AA	A	A	C	AA	AA	AA	R	R	C	C	R
<i>Globigerina falconensis</i> BLOW, 1959		R	R	R	A	C	C	C	C		C	R	R			
<i>Globigerina praebulloides</i> BLOW, 1959	A	AA	AA	A	AA	C	A	C	C	R	C	C	C	A	C	R
<i>Globigerina siphonifera</i> ORBIGNY, 1839	F	F	F	C	R	R	R	R	R							
<i>Globigerinella obesa</i> BOLLI, 1957	A	AA	C	C	A	C	C	R	R							
<i>Globigerinoides obliquus</i> (BOLLI, 1957)										A	C	R	R	C	C	A
<i>Globigerinoides ruber</i> (ORBIGNY, 1839)	F	C	F	A	AA	AA	A	A	A	C	C	C	R	C	C	C
<i>Globigerinoides sacculifer</i> (BRADY, 1877)	F	C	F	A	A	AA	A	A	C/A	C	C	C	R	C	C	F
<i>Globorotalia crassaformis</i> (GALLOWAY & WISSELER, 1927)											R	R		C	F	A
<i>Globorotalia margaritae primitiva</i> CITA, 1973		X	X	R	R	A									R	
<i>Globorotalia margaritae</i> BOLLI & BERMUDEZ, 1965						C	A		R					R	C	A
<i>Globorotalia menardii</i> (ORBIGNY, 1826)		R				C	A	R	C							R
<i>Globorotalia menardii neoflexuosa</i> SRINIVASAN, 1974						C	C		C							R
<i>Globorotalia puncticulata</i> (ORBIGNY in DESHAYES, 1832)								A	C							R
<i>Neogloboquadrina acostaensis</i> (BLOW, 1959)	R	F		F	R	C	R	A(s)	C(s)	F (d)	C (d)			R (d)	R(d)	R(d)
<i>Orbulina universa</i> ORBIGNY, 1839	AA	AA	AA	AA	AA	AA	AA	AA	AA	A	AA	AA	AA	AA	A	AA
<i>Orbulina suturalis</i> BRÖNNIMANN, 1951										C	A	A	F	R	C	C
<i>Sphaeroidinellopsis</i> spp.		X	X							C	F	R				
<i>Turborotalita quinqueloba</i> (NATLAND, 1938)	C	A	F	C	A	A	C	C	R							



Benthic foraminifera	VT 5	VT 6	VT 7	VT 8	VT 9	VT 10	VT 11	VT 12	VT 13	LI 1	LI 2	LI 3	LI 4	LI 5	LI 6	LI 7
<i>Bulimina aculeata</i> ORBIGNY, 1826	X				R	R			R				F	C	A	C
<i>Bulimina marginata</i> ORBIGNY, 1826													C	A	AA	AA
<i>Cibicides cicatricosus</i> (SCHWAGER, 1866)						R						R	F	A	F	R
<i>Cibicoides pseudoungerianus</i> (CUSHMAN, 1922)	C		X	R		F	R	F	F	C	C	R		A	R	R
<i>Cibicoides ungerianus</i> (ORBIGNY, 1846)		F	R	R		R		F	R	R	F	R		A	R	R
<i>Florilus boueanum</i> (ORBIGNY, 1846)	X		R	R	R		X			R						
<i>Cibicoides wuellersdorpii</i> (SCHWAGER, 1866)				R						R	R	C	R		R	X
<i>Gyroidina altiformis</i> R.E. STEWART & K.C. STEWART, 1930	R	F	R	F	R	R	R	R	R	R	F	C	C	A	C	C
<i>Heterolepa floridana</i> CUSHMAN, 1918	X	X	X	R	X	R	R			R		R		R		R
<i>Hoeglundina elegans</i> (ORBIGNY, 1826)		F	R	X		X	R					C	C	A	C	R
<i>Laevidentalina filiformis</i> (ORBIGNY, 1826)	R	F	R	R	F	R	C	C	C/F			X	X	F	F	R
<i>Lagena striata</i> (ORBIGNY, 1839)	R		R		R			X	R		R	R	X	R	F	R
<i>Lenticulina orbicularis</i> (ORBIGNY, 1826)	R	F	R	C	AA	C	C	C	A	AA	A	A	C	A	C	A
<i>Lenticulina calcar</i> (LINNAEUS, 1758)	R			R		R				F	C	C	R	R	F	
<i>Lobatula lobatula</i> (WALKER & JACOB, 1798)	F							R	R							
<i>Marginulinopsis costata</i> (BATSCH, 1791)				X	R	C	R	R		F		X	A	C	C	
<i>Marginulina hirsuta</i> ORBIGNY, 1826	X					F	R	X		F	X	X	X	R	X	
<i>Melonis padanum</i> PERCONIG, 1952	X			R		R		R		R	X	F	A	C	C	
<i>Mucronina compressa</i> (COSTA, 1855)	X	R	F	R	F	A	C	R	R		R	C	C	C	A	C
<i>Mucronina monachanta</i> (REUSS, 1850)		R	R	R	F	C		R	R		C	C	A	A	R	
<i>Planularia cassis</i> (FICHTEL & MOLL, 1798)	C	R	F	X	A	C	C	C	F	F	C	C	C	F	F	R
<i>Planulina ariminensis</i> ORBIGNY, 1826	R	F	F	C	AA	A	A	C	F	AA	AA	AA	A	A	C	A
<i>Siphonina reticulata</i> (CZJZEK, 1848)	R	F	R	C	A	F	C	R	R	C	A	C	C	A	C	F
<i>Uvigerina peregrina</i> CUSHMAN, 1923						C		R					R	C	A	A
<i>Uvigerina pygmaea</i> ORBIGNY, 1826			R	R	F	R	C	X	X	F	F	C	C	A	A	A
<i>Vaginulinopsis/Vaginulina</i>										X	F	C	C	C	C	A
<i>Vulvulina pennatula</i> (BATSCH, 1791)				F	C	C	F	F								

### 4.3. NANNOFOSSILS

The calcareous nannofossil assemblages of the Trubi Formation were reported by SCIUTO *et al.* (2018). The presence of *Ceratholithus acutus* GARTNER & BUKRY, 1974, and that of *Reticulofenestra zancleana* DI STEFANO & STURIALE, 2010, allow the Trubi Formation, to be assigned to one of the basal Zanclean calcareous nannofossil biozones, CNPL1 Zone *sensu* BACKMAN *et al.* (2012) or MNN 12 Biozone *sensu* MARTINI (1971). The nannofossil assemblages of Abbeveratoio and Villafranca Tirrena section are similar, and are rich with the specimens being well preserved. The presence of *Ceratholithus acutus* and *Reticulofenestra zancleana* in basal samples (LI 1-3) of Abbeveratoio indicate basal biozone MNN12 (early Pliocene, Zanclean). In particular, the presence of *R. zancleana* defines partial-range subzone MNN 12b with the first occurrence (FO) into the Cycle 1 (5,332 Ma) and the last common occurrence (LCO) at Cycle 7 (5,199 Ma), as reported by DI STEFANO & STURIALE (2010). In addition, few specimens of *Amaurolithus primus* are found in the same samples. Samples LI 4 and LI 5 show a decrease in the abundance of reticulofenestrids and an increase in *Coccolithus pelagicus*. The species *Helicosphaera carterii* becomes frequent from sample LI 5 to the top of the section. In Villafranca Tirrena the calcareous nannofossil assemblages are rich throughout the section, though *Ceratholithus acutus* and *Reticulofenestra zancleana*

are rare, and *Scyphosphaera apsteinii* and *Scyphosphaera piriformis* are rare but well preserved. *Helicosphaera carterii* is common.

### 5. Discussion

Among the ostracod species found in the sections under study, *Agrenocythere pliocenica* (SEGUENZA, 1880) is particularly significant because, according to BENSON (1972a, 1972b, 1973, 1984), it indicates psychrospheric oceanic conditions, *i.e.*, water masses generally deeper than 1000 m with temperature around 4°-8°C (BENSON, 1973). The *A. pliocenica* FO in the Mediterranean Basin corresponds to the first common occurrence (FCO) of *Globorotalia margaritae* (COLALONGO *et al.*, 1990), and is reported from all Pliocene deep-water sediments in central and southern Italy (*e.g.*, SCIUTO, 2003, 2014a) and from the bathyal Pliocene sequences in ODP cores from the Tyrrhenian Sea (BENSON, 1972a, 1972b; COLALONGO & PASINI, 1980; COLALONGO *et al.*, 1990). *Agrenocythere pliocenica* became extinct in the Mediterranean during the Calabrian because of the raising of the Gibraltar threshold that prevented the entry of Atlantic cold water into the Mediterranean, thus forcing the disappearance of the psychrosphere (BENSON, 1973).

The distribution of *Bythocypris obtusata* and *B. antoniettae* SCIUTO, 2012, seems to have been influenced by temperature. *B. obtusata* has been reported from the modern Norwegian and British



coasts in water depths between 145 and 165 m by SARS (1928) and in the Recent Mediterranean Sea at depths between 150 and 2905 m by PURI *et al.* (1969). *B. antoniettae* was found by BREMAN (1975) in an interval of core 353 from bathyal sediments of the Adriatic Sea, corresponding, according to STRAATEN (1966), to a very cold period of the early Pleistocene. As fossils, the species are reported from upper Pliocene-Pleistocene deep-water environments (SCIUTO, 2003, 2012, 2014a, 2015). Their occurrence at Abbeveratoio indicates that the two species were present in the Mediterranean basin during the Zanclean Stage.

*Costa (Cuneocosta) tricostata pliocenica* is commonly referred to Pliocene and Pleistocene bathyal environments (RUGGIERI, 1992; SCIUTO, 2005, 2014a).

*Cytherella* spp. and *Bairdia conformis* are relatively abundant and, while showing very broad bathymetric distributions in both the Atlantic and the Mediterranean (BONADUCE *et al.*, 1983; WHATLEY & COLES, 1987; GUERNET & LETHIERS, 1989; MONTENEGRO *et al.*, 1998), are represented in most bathyal associations (BENSON, 1973; SCIUTO, 2003, 2014a, 2014b).

*Acanthocythereis colinii* SCIUTO, 2014b, is reported from Pliocene bathyal sediments from Capo Milazzo (SCIUTO, 2014a, 2014b). Its occurrence at Abbeveratoio demonstrates its presence in the Mediterranean basin, in the Zanclean Stage.

Poorly represented species such as *Ruggieria tetraptera palpebralis* RUGGIERI, 1960, *Buntonia dertonensis* RUGGIERI, 1954, and *B. sublatissima* (NEVIANI, 1906) are reported from deep-water sediments (e.g., SCIUTO, 2003), with *B. sublatissima* also known in the Recent in shallower environments.

The group of *Krithe* species, considered heurypates but normally present in ostracod associations of bathyal environments (e.g., COLES *et al.*, 1996; SCIUTO, 2003, 2014a, 2014b, 2015), is strongly represented at Villafranca, where *Krithe compressa* reaches significant values of abundance (Table I). This latter species is synonymous with *Krithe* sp. 5 of WHATLEY and ZHAO (1993) which has been found living below 900 m in the South China Sea (BONADUCE & BARRA, 2002).

Finally, *Oblitacythereis mediterranea* BENSON, 1977, is known in the Pliocene of Mediterranean region, from the Atlantic coast of Morocco to Cyprus and in cores from the eastern Mediterranean (DSDP Site 376), as well as in outcrop, especially in northern Sicily (BENSON, 1977). The genus *Oblitacythereis* ranges from the Paleogene to the Recent and typically lives in the lower thermosphere just above the psychrosphere (BENSON, 1977). This genus and its association with a typical deep-water assemblage, define a sedimentation depth of about 500-700 m situated above the boundary between the psychrosphere and the overlying thermosphere in the Miocene Ras il-Pelgrin section (BONADUCE & BARRA, 2002).

On the basis of synecological and autoecological data, all species recorded here, can be considered compatible with each other and referable in full to a very deep water environment since the basal samples in all the section.

The foraminiferal data informs an understanding of both the structure of the water column and the conditions of the sea floor in two different palaeogeographical contexts, the Villafranca Tirrena Basin in the north and the northwestern border of the Hyblean Plateau in the south.

The distribution and frequencies of planktonic species (Table I), including those belonging to the warm-water oligotrophic genera *Globigerinoides* and *Orbulina*, demonstrates a well organised marine water column. Indeed, *Globigerinoides obliquus*, *G. sacculifer* and *G. ruber*, common at Abbeveratoio and very abundant at Villafranca Tirrena, evidences that warm, shallow oligotrophic waters are always present and stable into the water column. The genus *Orbulina*, ever-present and very abundant in both sections, indicates the occurrence of persistent warm and highly productive intermediate waters. The proliferation of neogloboquadrinids, which are phytoplankton grazers that live close to or just below the thermocline, testifies to the presence of a deep chlorophyll zone.

In both sections, the occurrences, sometimes very abundant, of the cold-water eutrophic *Globigerina bulloides* group, together with *Turborotalita quinqueloba*, suggests that the water column was thermally stratified. This thermal signal is more evident at Villafranca Tirrena where *T. quinqueloba* is abundant; in contrast, this species is absent from Abbeveratoio.

*Sphaeroidinellopsis* spp., which characterise the basal Zanclean (e.g., COUVERING *et al.*, 2000; VIOLANTI *et al.*, 2011) with its acme zones, occur very rarely in the basal samples of both sections, and then disappear.

The most important events identified in the two sections studied are (Fig. 2):

1. the AE (acme end) of *Sphaeroidinellopsis* in sample 6 from the VT section and sample 3 from Abbeveratoio. At Villafranca Tirrena, the first occurrence of small forms of *Globorotalia margaritae* (identified as *G. margaritae primitiva*) coincides with the AE.
2. the first peak of dextral *Neogloboquadrina acostaensis* in sample 1 and the second peak in sample 5 from Abbeveratoio;
3. the FCO of *Globorotalia margaritae* in sample 10 at Villafranca Tirrena and in sample 5 at Abbeveratoio section, and
4. two peaks of sinistral *Neogloboquadrina acostaensis* in samples 12 and 13 at Villafranca Tirrena.





Benthic assemblages provide valuable information about depth and oxygen content and availability of nutrients at the sea floor. The infaunal and shallow-infaunal forms are represented by a rather high number of taxa that, sometimes, are characterised by low relative abundances. The dominant species in all the assemblages are *Siphonina reticulata*, *Bulimina aculeata*, *B. marginata*, *Uvigerina peregrina* and *U. pigmaea*.

The abundance of *Siphonina reticulata*, inferred to be indicative of Early Pliocene Mediterranean Intermediate Water (EPMIW) (SGARRELLA *et al.*, 1997), suggests that this synchronous re-colonisation event reported from throughout the Mediterranean (SPEZZAFERRI *et al.*, 1998; IACCARINO *et al.*, 1999; PIERRE *et al.*, 2006; ROUCHY *et al.*, 2007; VIOLANTI *et al.*, 2011) is recognisable in our sections also and can be correlated with lithological cycle 6 (DI STEFANO *et al.*, 1996).

The epifaunal assemblages in the two sections (including *Cibicides*, *Cibicidoides*, *Fontbotia*, *Gyroidinella*, *Heterolepa*, *Lenticulina*, *Planularia*, *Planulina*, and *Pyrgo*) are comparable. The abundance of each species is generally very low, with only *Cibicidoides pseudoungerianus*, *Lenticulina orbicularis*, *L. calcar*, *Planulina ariminensis*, *Gyroidina altiformis* showing rather high values.

The prevalence in the assemblages of infaunal and epifaunal species that preferred cold bottom waters, such as *Lenticulina orbicularis*, *Planulina ariminensis* and *Siphonina reticulata*, demonstrates that the sea floor was consistently cold. The constant presence of the epifaunal *Planulina ariminensis*, characteristic of well-oxygenated conditions (KOUVENHOVEN & ZWAN, 2006), and the co-occurrence of the passive suspension feeder *Cibicidoides pseudoungerianus* (JØRISSEN, 1988; MURRAY, 1991, 2006), widespread on well-oxygenated bottoms with high organic-carbon fluxes, indicate that the seafloor did not experience a decrease in oxygen level and that nutrients were always abundant. The availability of nutrients is supported also by the constant presence, in both sections, of the epifaunal and detritivore *Lenticulina orbicularis*. The presence of common to abundant infaunal species *Bulimina aculeata*, *B. marginata*, *Uvigerina peregrina* and *U. pigmaea* in the uppermost three samples at Abbeveratoio implies an increase in organic matter on the seafloor and at the water-sediment interface. The above-mentioned species, however, are generally rare at Villafranca Tirrena and become more abundant only in samples VT 9 (where they are frequent) and VT 11 (common). The increase in organic matter in this peculiar interval is evidenced also by the common occurrence in sample VT 11 of the infaunal species *Marginulinopsis costata* that proliferates on soft bottoms enriched in organic matter (BALDANZA *et al.*, 2018). This species is common to abundant in the uppermost three samples at Abbeveratoio.

Abundant organic matter in bottom sediment, which is essential for infaunal species, is limited

to discrete intervals of the two sections: at Villafranca Tirrena, from the samples VT9 to VT11, and at Abbeveratoio from samples LI 3 to LI 7.

As indicated by SGARRELLA *et al.* (2012), the species *Planulina ariminensis*, *Cibicidoides* spp. and *Hoeglundina elegans* preferred oligotrophic and oxic seafloor conditions while the spinose *Bulimina* and costate *Uvigerina* favoured eutrophic or meso-eutrophic and hypoxic or oxic bottom conditions.

The bathymetric depth is indicated, in both sections, by the abundant and constant presence of outer neritic to bathyal species (*Bulimina aculeata* and *B. marginata*, *Cibicidoides pseudoungerianus*, *Uvigerina peregrina* and *U. pigmaea*, *Hoeglundina elegans*, *Planulina ariminensis*, *Gyroidina altiformis*, *Lenticulina orbicularis*, *L. calcar*, *Melonis padanum*, and *Siphonina reticulata*).

According to SGARRELLA *et al.* (2012), the species *Lenticulina orbicularis*, *Planulina ariminensis* and *Siphonina reticulata* indicate cold, oxygenated and/or oligotrophic bathyal environments at a depth of 200-600 metres whereas *Planulina ariminensis* was recognised by DRINIA *et al.* (2010) as occurring at an upper bathyal depth.

DRINIA *et al.* (2010) inferred open-marine conditions for the Messinian/early Pliocene transition in the eastern Mediterranean (Zakynthos Island, Greece) from the diversity of benthic and planktonic foraminifers. Again, according to PUJOS, 1976, and JØRISSEN, 1988, the abundance of *Lenticulina* spp., *Cibicidoides pseudoungerianus*, *Planulina ariminensis*, *Pullenia* and *Gyroidina* and the absence of shelf-taxa suggest an upper bathyal depth.

## 6. Conclusion

The new data provided by ostracods and benthic foraminifers allow us to reconstruct the palaeoenvironmental conditions that existed during the deposition of the lowermost Trubi Formation, above the M/P boundary.

A well-organised water column, with stable warm shallow oligotrophic waters followed by highly productive intermediate warm waters with a deep chlorophyll zone in which phytoplankton grazers (neogloboquadrinids) proliferated, developed during lower Trubi sedimentation.

The presence in both sections of cold-water eutrophic species shows thermal stratification of the water column. The bottom was constantly cold, probably with little mixing of water masses and isolation of the seabed. Food availability, in the form of nutrients and organic fluxes which stimulated the proliferation of benthic infaunal/shallow infaunal and epifaunal species, was generally high.

The coexistence of *Agrenocythere pliocenica* and *Oblitacythereis mediterranea* in the upper middle part of the Abbeveratoio section evidences the existence, at the bottom of the palaeobasin, of oceanic conditions corresponding to the transition between the psychrosphere and the thermo-



sphere at a depth of around 500-700 m (BONADUCE & BARRA, 2002). At Villafranca Tirrena, the presence of *Agrenocythere pliocenica*, a psychrospheric species that lived under oceanic conditions deeper than 1000 m and at 4°-8°C (BENSON, 1973, 1978), confirms the greater depth and decidedly colder conditions at the bottom of the Villafranca basin compared to the Licodia Eubea basin.

No reworking of fossils has been detected in any samples. Taxa referable to environments shallower than the bathyal zone are absent so that all species identified and, hence, all fossil assemblages can be considered *in situ*.

In the sections studied and in equivalent stratigraphic successions elsewhere in the region, the Trubi Formation conformably overlies either the upper Messinian Lago-Mare facies or the Messinian evaporitic facies with a sharp boundary. In outcrop there is no evidence of erosion at the boundary. This observation accords with conclusions drawn from most stratigraphic sections containing the Messinian/Zanclean boundary (e.g., CITA & RYAN, 1973; CITA *et al.*, 1978).

The character of the boundary, together with the absence of faunal contamination since the basal samples, as already reported by BENSON (1973), suggests an undisturbed environment since the beginning of sedimentation.

The conformable relationship at the Messinian-Pliocene transition in Sicily is distinctly different from the relationship occurring in other sectors of the Mediterranean basin, particularly in the Western Mediterranean near the Straits of Gibraltar (Alboran Sea, Malaga basin) where the Messinian/Zanclean boundary is marked by a strongly erosional surface at the top of the Miocene (GARCIA-CASTELLANOS *et al.*, 2009; GUERRA-MERCHÁN *et al.*, 2010; CARUSO *et al.*, 2020). The Miocene deposits on both sides of the straits, are deeply incised, with the erosional channels filled by Pliocene and post-Pliocene sediments. Incision was effected by a catastrophic flood event, generated by an enormous volume of Atlantic water that, following the sudden lowering of the Gibraltar threshold by subsidence or erosion, refilled the Mediterranean basin (GARCIA-CASTELLANOS *et al.*, 2009; GUERRA-MERCHÁN *et al.*, 2010).

In the Sicilian sections of the Trubi Formation studied, there is no mixing of marine and non-marine faunas in the lower stratigraphic levels. No deposits related to Lago/Mare environments have been found above the Messinian/Zanclean boundary, in contrast to a report (GENNARI *et al.*, 2008) from the northern Apennine region where a slow rise of oceanic water is interpreted with the development of environments intermediate between those of Lago-Mare and the oceanic ones above the Messinian/Zanclean Boundary. We deem it probable that these intermediate facies, given their rarity in the Messinian-Zanclean transition, may be due to local sedimentary displacement phenomena and redeposition rather

than normal sedimentation. According several authors (e.g., CITA & RYAN, 1973; CITA *et al.*, 1978; ROUCHY *et al.*, 2001), it is logical to hypothesise, on the basis of the acquired data that, also in the studied sector, there has been a very rapid ingression of the Atlantic water following Messinian deposition. This process has resulted in a clear faunal and sedimentological differentiation between the upper Messinian and Zanclean facies.

The absence of erosional surfaces that characterises the Miocene/Pliocene boundary in the western Mediterranean basin is probably due to the distance of the studied sections from the Atlantic-Mediterranean seaway. The energy of the Zanclean flow that caused the erosion of both sides of the Straits of Gibraltar (GARCIA-CASTELLANOS *et al.*, 2009) dissipated as the water mass flowed eastward due to its lateral and vertical expansion. The subsequent impingement upon the Sicilian threshold would have led to a further loss of energy as the of the western basin filled.

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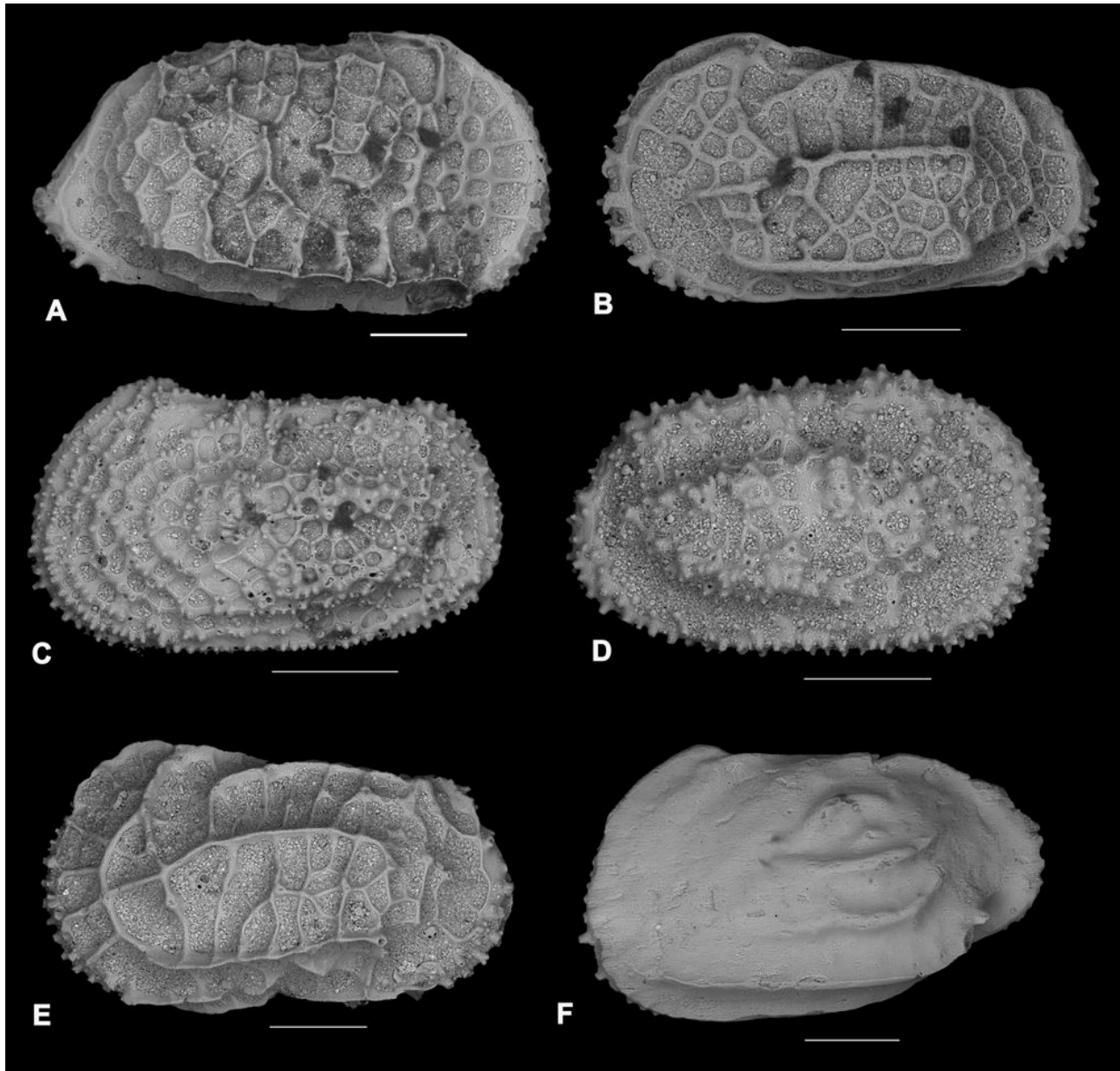
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## Plates



**Plate 1: Ostracods** (scale bar: 200 $\mu$ m).

A) *Agrenocythere pliocenica* (SEGUENZA, 1880); right valve, external lateral view.

B) *Costa (Cuneocosta) tricostata pliocenica* RUGGIERI, 1992; left valve, external lateral view.

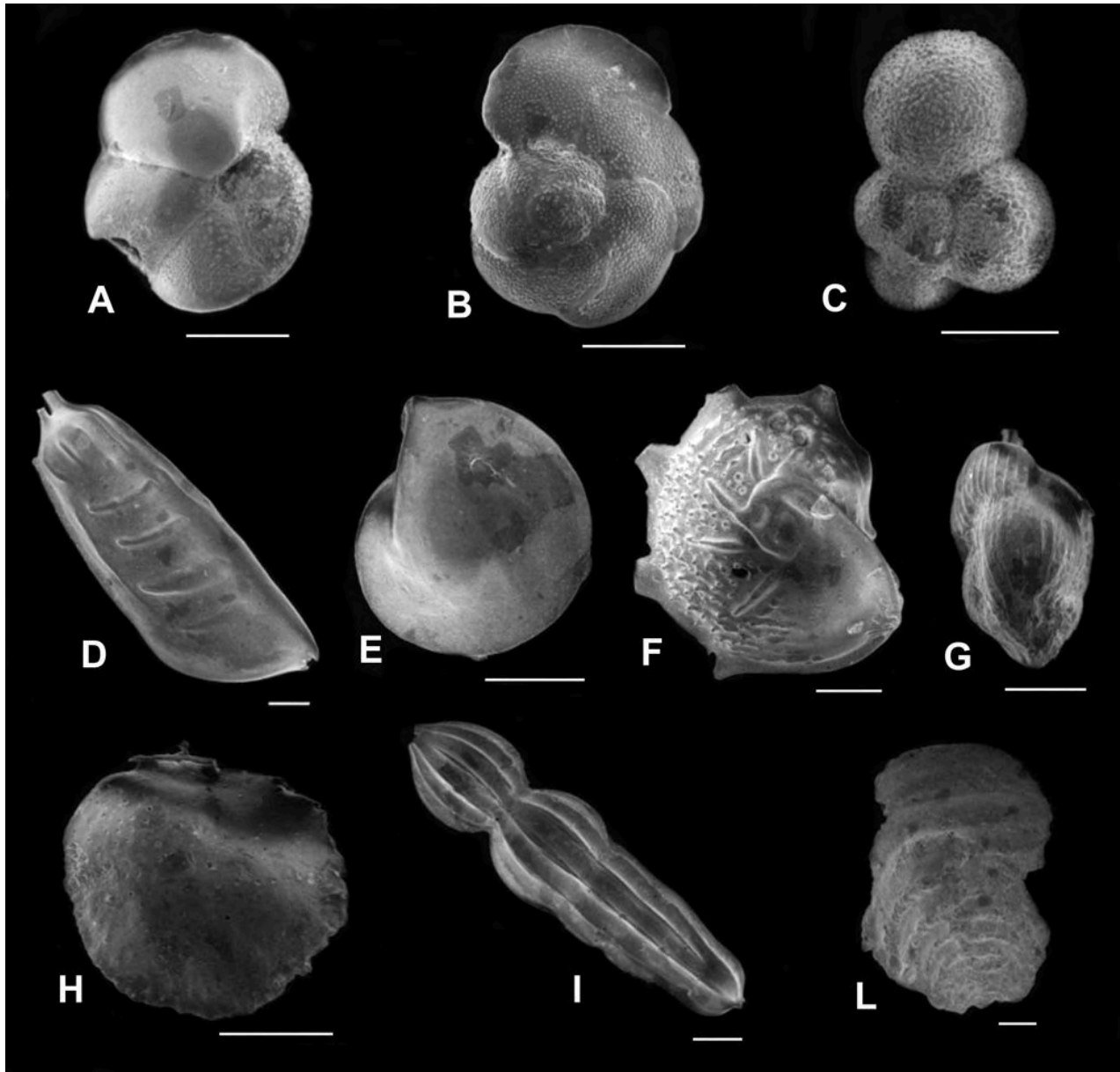
C) *Henryhowella* ex *H. hirta* (COSTA, 1853) group, SCIUTO, 2014; left valve, external lateral view.

D) *Henryhowella* ex *H. profunda* BONADUCE *et al.*, 1999 group, SCIUTO, 2014; right valve, external lateral view.

E) *Oblitacythereis mediterranea* BENSON, 1977; left valve, external lateral view.

F) *Ruggieria tetraptera palpebralis* RUGGIERI, 1960; left valve, external lateral view.





**Plate 2: Foraminifera** (scale bar: 200µm).

A) *Globorotalia margaritae* BOLLI & BERMUDEZ, 1965; apertural view.

B) *Globorotalia margaritae evoluta* CITA, 1973; spiral view.

C) *Globigerina bulloides* (ORBIGNY, 1826); spiral view.

D) *Vaginulina legumen* (LINNAEUS, 1758).

E) *Lenticulina orbicularis* (ORBIGNY, 1826).

F) *Lenticulina calcar* (LINNAEUS, 1758) with features like to the *Lenticulina echinata* (ORBIGNY, 1846).

G) *Uvigerina pygmaea* (ORBIGNY, 1826).

H) *Siphonina reticulata* (CZJZEK, 1848).

I) *Marginulina costata* (BATSCH, 1791).

L) *Vulvulina pennatula* (BATSCH, 1791).