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 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). Micropalaeontological 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

Citation: SCIUTO F. & BALDANZA A. (2020).- Full restoration of marine conditions after the late Messinian Mediterranean Lago-Mare phase in Licodia Eubea and Villafranca Tirrena areas (east Sicily).- Carnets Geol., Madrid, vol. 20, no. 6, p. 107-123.

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, Italie).- Après la phase "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-evaporites à facies "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 semblaient 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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Published online in final form (pdf) on March 17, 2020
[Editor: Bruno GRANIER; language editors: Stephen CAREY and Bruno FERRÉ]
Mots-clés :
- Mer Méditerranée ;
- Sicile ;
- Zanclean ;
- ostracodes bathyaux ;
- 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 (Krügman et al., 1999; Roveri et al., 2014), various layers of evaporites, ranging in thickness from a few metres to hundreds of metres, were deposited on the bottom of euaxinic 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; Gloazzi et al., 2007; Guerra-Merchan 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-Merchan et al., 2010; Lances 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; García-Castellanos et al., 2009; Krügman et al., 2018).

The present paper focuses on the marine ostracods, calcareous nanofossils 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 biocartographic and palaeoecological perspective, at Capo Rossello (Cita & Gartner, 1973; Cita, 1975; Langereis & Hilgen, 1991) and Eraclea Minoa (Couvering et al., 2000) along the southern Sicilian coast; at Buonfornello along the Tyrrenian Sicilian coast (Couvering et al., 2000); in some localities of southern Italy, e.g., Capo Spartivento, Sinag and Roccella (Channel et al., 1988; Couvering 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; Spezzaferrl et al., 1998; Couvering 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 Tyrrenian coast (Figs. 1-2), is structurally part of the Apennine-Maghrebian 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
gypsum. During the post-evaporitic phase, medium and coarse sands and breccias, called "Arenazzolo" were deposited (e.g., Mottrum, 1871; Ogniben, 1957; Sciuto et al., 2018). This deposit, where only the ostracod genera Tyrhenocythere and Cyprideis were found, represents the Lago-Mare facies deposited in hypersaline 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 synsedimentary 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 Loxoconcha muelleri Zone sensu Grossi et al., 2011 (lower post-evaporitic phase of the Messinian stage) due to the co-occurrence of Cyprideis agrigenitena Decima, 1964, Loxoconcha muelleri (Méhes, 1908), Loxoconcha eichwaldi Livental, 1929, and Tyrhenocythere 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 Tyrhenocythere (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* (Brocchi, 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 plicenica* (Seguenza, 1880), *Costa tricostata plicenica* Ruggieri, 1992, *Bythocypris antoniettae* Sciuoto, 2012, *Bythocypris obtusa* (Sars, 1866), *Cytherella* sp. 1 and *Henryhowella ex group* H. profunda Bonaduce et al., 1999 (*sensu* Sciuoto, 2014a), *Henryhowella ex group* H. hirta (Costa, 1853) (*sensu* Sciuoto, 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 (*sensu* Sciuoto, 2014a), *Cytherella sp. 1., Cytherella russi Sissingh, 1972, C. tricostata plicenica Ruggieri, 1992, *Henryhowella ex group* H. hirta (Costa, 1853) (*sensu* Sciuoto, 2014a) and *Bairdia conformis* (Terquem, 1878). Poorly represented and of limited distribution are *Bairdia conformis* (Terquem, 1878), *Bairdoppilata* sp., *Buntonia dertonensis* Ruggieri, 1954, *Buntonia sublatissima* (Neviani, 1906), *Bythocypris an-
**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). Bentonic 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 at Abbeveratoio it is rare and sharply increases to being abundant in LI 5, where it is accompanied by abundant Uvigerina peregrina 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. marginita, 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 specimen. 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).

| Ostracods                     | 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 |
|------------------------------|------|------|------|------|------|-------|-------|-------|-------|------|------|------|------|------|------|------|
| Acanthocythereis colini      |      |      | X    |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Agrenocythere pliocenica     | X    | X    | X    |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Argoillocia spp.             |      |      |      |      |      |       |       |       |       | X    |      |      |      |      |      |      |
| Bairdia conformis            |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Bairdopilata sp.             |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Buntonia dertonensis         |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Buntonia sublatissima        |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Buntonia subulata            |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Bythocypris antoniettae      |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Bythocypris bosquetiana      |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Bythocypris obtusata         |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Costa tricostata             |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Cytherella sp. 1             |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Cytherella sp. 2             |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Cytheropteron eleonorae      |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Cytheropteron pinarense      |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Cytherella russii           |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Echinocythereis sp.          |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Henryhowella ex H. profunda |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Krithe iniqua Barra et al.   |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Krithe cf. K. iniqua Barra et al. |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Krithe compressa             |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Krithe percultra             |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Krithe spp.                  |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Oblitacythereis mediterranea |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Ostracods and foraminifers   |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |

| Planktonic 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 |
|-------------------------------|------|------|------|------|------|-------|-------|-------|-------|------|------|------|------|------|------|------|
| Globigerina bulloides         | AA   | AA   | F    | C    | AA   | A     | A     | C     | AA    | AA   | AA   | R    | C    | R    | C    | R    |
| Globigerina falconensis       | R    | R    | R    | A    | C    | C     | C     | C     | C     | R    | C    | R    | C    | R    | R    | R    |
| Globigerina praelouloides     | R    | R    | R    | A    | C    | C     | C     | C     | C     | C    | C    | C    | C    | C    | C    | C    |
| Globigerina siphonifera       | F    | F    | F    | C    | R    | R    | R    | R    | R    | R    | R    | R    | R    | R    | R    | R    |
| Globigerinella obesa           | A    | A    | C    | C    | A    | C    | C    | C    | C    | C    | C    | C    | C    | C    | C    | C    |
| Globigerinoidea obliquus       | A    | A    | C    | R    | R    | R    | C    | A    | C    | A    | C    | A    | C    | A    | C    | A    |
| Globigerinoides ruber          | F    | F    | F    | A    | AA   | AA   | A    | A    | C    | C    | C    | C    | C    | C    | C    | C    |
| Globigerinoides saccularis     | F    | F    | F    | A    | A    | AA   | A    | A    | C/A  | C    | C    | C    | C    | C    | C    | C    |
| Globorotalia crassiformis     |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Globorotalia margaritae       |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Globorotalia margaritae       |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Globorotalia menardii         |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Globorotalia menardii neoflexuosa |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Globorotalia puncticulata     |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Neogloboquadrina acostaeansis |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Orbulina universa             |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Orbulina suturealis           |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |
| Sphaeroidinellopsis sp.       |      |      |      |      |      |       |       |       |       |      |      |      |      |      |      |      |

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4.3. Nannofossils

The calcareous nannofossil assemblages of the Trubi Formation were reported by SCIUTO et al. (2018). The presence of Ceratolithus acutus GARTNER & BUKY, 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 Tirrenia section are similar, and are rich with the specimens being well preserved. The presence of Ceratolithus 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 Amauroolithus primus are found in the same samples. Samples LI 4 and LI 5 show a decrease in the abundance of reticulofenestrads and an increase in Coccolithus pelagicus. The species Helicosphaera carterii becomes frequent from sample LI 5 to the top of the section. In Villafranca Tirrenia the calcareous nannofossil assemblages are rich throughout the section, though Ceratolithus acutus and Reticulofenestra zancleana are rare, and Scyphosphaera apsteini 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 psychrophoric 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 Tyrrenian 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 psychosphere (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. antoniitae was found by Bremman (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).

Cythereella 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 Cape 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, Bunitonia 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 Krith species, considered heurybates 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 Krithes compressa reaches significant values of abundance (Table 1). This latter species is synonymous with Krithes 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 psychrophere (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 psychrophere and the overlying thermosphere in the Miocene Ras il-Pellegrin 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 1), 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., Colvering 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 (Kouwenhoven & Zwan, 2006), and the occurrence of the passive suspension feeder *Cibicidoides pseudoungerianus* (Jorissen, 1988; Murray, 1991, 2006), widespread on well-oxygenated bottoms with high organic-carbon fluxes, indicate that the sea floor 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 Villafraanca 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 (Balianza 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 Villafraanca 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 Puodos, 1976, and Jorissen, 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 plicenica and Oblitacythereis mediterranea in the upper middle part of the Abbeveratoio section evidences the existence, at the bottom of the palaeoasis, 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 plicacena, a psammospheric 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 area 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-Merchan 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-Merchan 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 faacies, 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.

**Acknowledgments**

The authors are grateful to the reviewers and the editors for detailed comments on the manuscript. A special thank to Stephen Carey for the precious suggestions and comments on the English language. Thanks are due also to Mr. Alfonso Viola (Electronic Microscopy Laboratory, University of Catania) for assistance with SEM photomicrographs. Catania Palaeoecological Research Group contribution no. 449. Research carried out with funds intended for Sciuto, provided by the University of Catania "Piano per la Ricerca 2016-2018" to A. Rosso, n. 22722132118.

**Bibliographic references**

Abate S., Barra D., Aiello G. & Bonaduce G. (1993).– The genus Kritho Brady, Crosskey and Robertson, 1874 (Crustacea: Ostracoda) in the Pliocene-Early Pleistocene of the M. San Nicola section (Gela, Sicily).– Bolletino della Società Paleontologica Italiana, Modena, vol. 32, no. 3, p. 349-366.

Agalarova D.A., Kadyrova Z.K. & Kulieva S.A. (1961).– Ostracoda from Pliocene and post Pliocene deposits of Azerbaijan, Baku.– Azerbaijan State Publisher, Baku, 420 p. [in Russian].

Backman J., Raffi I., Rio D., Formaciari E. & Pälke H. (2012).– Biozontion and biochronology of Miocene through Pleistocene calcareous nanofossils from low and middle latitudes.– Newsletters on Stratigraphy, Stuttgart, vol. 45, no. 3, p. 221-244.

Balanzá A., Bizzarr R., Famiani F., Garassino A., Pasini G., Cherin M. & Rosatini F. (2018).– The early Pleistocene whale-fall community of Bargiano (Umbria, Central Italy): Palaeoecological insights from bentthic foraminifera and brachyuran crabs.– Palaeontologia Electronica 21. 1.11A 1-27. URL: https://doi.org/10.26879/779
BARRA D., BONADUCE G. & Sgarrella F. (1998).- Paleoenvironmental bottom water conditions in the early Zanclean of the Cape Rossello area (Agrigento, Sicily).- *Bollettino della Società Paleontologica Italiana*, vol. 37 no. 1, p. 61-88.

BENSON R.H. (1972a).- Ostracodes as indicators of threshold depth in the Mediterranean during the Pliocene. *In*: Stanley D.J. (ed.), *The Mediterranean Sea: a natural sedimentation laboratory*. - Dowden, Hutchinson & Ross, Stroudsburg, p. 63-73.

BENSON R.H. (1972b).- The *Bradleya* problem, with descriptions of two new psychrospheric ostracode genera, *Agronocythere* and *Poseidonamicus* (Ostracoda: Crustacea).- *Smithsonian Contributions to Paleobiology*, Washington D.C., vol. 12, p. 1-138.

BENSON R.H. (1973).- 36.2 Psychrospheric and continental Ostracoda from ancient sediments in the floor of the Mediterranean.- *In*: Ryan W.B.F., Hsu K.J., Cita M.B., Dumitrca P., Lort J.M., Maync W., Nesteroff W.D., Pautot G., Stradner H. & Weze F.C.- *Initial Reports of the Deep Sea Drilling Project*, Washington D.C., vol. XIII, part 1, p. 1002-1008.

BENSON R.H. (1975).- The origin of the psychrosphere as recorded in changes of deep-sea ostracode assemblages.- *Lethaia*, Oslo, vol. 8, p. 69-83.

BENSON R.H. (1977).- Evolution of Oblitacythereis from *Paleocosta* (Ostracoda: Trachyleberididae) during the Cenozoic in the Mediterranean and Atlantic.- *Smithsonian Contributions to Paleobiology*, Washington D.C., vol. 33, p. 1-47.

BENSON R.H. (1978).- 35. The paleoecology of the ostracodes of DSDP Leg 42A. *In*: Hsu K.J., Montadt L., Bernoulli D., Bizon G., Cita M., Erickson A., Fabricius F., Garrison R.E., Kidd R.B., Melieres F., Muller C. & Wright R.C.- *Initial Reports of the Deep Sea Drilling Project*, Washington D.C., vol. XLII, part 1, p. 777-786.

BENSON R.H. (1984).- Estimating greater paleodepts with ostracodes, especially in past thermospheric oceans.- *Paleogeography, Paleoclimatology, Paleoecology*, vol. 48, p. 107-141.

BOLD W.A. van den (1946).- Contribution to the study of Ostracoda with special reference to the Tertiary and Cretaceous microfauna of the Caribbean region.- Ph.D. Rijksuniversiteit te Utrecht, J.H. de Bussy, Amsterdam, 167 p.

BONADUCE G. & BARRA D. (2002).- The ostracods in the paleoenvironmental interpretation of the late Langhian - early Serravallian section of Ras-il-Pellegrin (Malta).- *Rivista Italiana di Paleontologia e Stratigrafia*, Milano, vol. 108, p. 211-222.

BONADUCE G., BARRA, D. & AIELLO G. (1999).- The genus *Henryhowella puri*, 1957 (Crustacea, Ostracoda) in the Atlantic and Mediterranean from Miocene to Recent.- *Bollettino della Società Paleontologica Italiana*, Modena, vol. 38, p. 59-72.

BONADUCE G., Ciliberto B., Masoli M., Minichelli G. & Pugliese N. (1983).- The deep-water benthic ostracodes of the Mediterranean. *In*: Madocks R.F. (ed.), Application of Ostracoda.- University of Houston, p. 459-471.

BONADUCE G. & Sgarrella F. (1999).- Paleoecological interpretation of the latest Messinian sediments from southern Sicily (Italy).- *Memorie della Società Geologica Italiana*, Roma, vol. 54, p. 83-91.

BRADY G.S. (1866).- On new or imperfectly known species of marine Ostracoda.- *Transactions of the Zoological Society of London*, London, vol. 5, p. 956-993.

BREMEN E. (1975).- Ostracodes in a bottom core from the deep southeastern basin of the Adriatic Sea. I, II.- Koninklijke Nederlandse Akademie van Wetenschappen, Proceedings (Ser. B), Amsterdam, vol. 78, p. 198-218.

BROCCHI G. V. (1814).- Conchologia fossile subappenninica, con osservazioni sugli Appennini e sul suolo adiacente.- Dalla Stamperia Reale, Milano, pp. 214.

CARUSO A., BLANC-VALLERON M.-M., DA PRATO S., PIERRE C. & ROUCHY J.-M. (2020).- The late Messinian "Lago-Mare" event and the Zanclean Reflooding in the Mediterranean Sea: New insights from the Cuevas del Almanzora section (Vera Basin, South-Eastern Spain).- *Earth-Science Reviews*, vol. 200, article 102993, 20 p.

CHANNEll J.E.T., RIO D. & THUNELL R.C. (1988).- Miocene/Pliocene boundary magnetostratigraphy at Cape Spartivento, Calabria, Italy.- *Geology*, vol. 16, no. 12, p. 1096-1099.

CIPOLLARI P., COSENTINO D., RAEFF G., TAYLOR F., SCHILDGEN T.F., FARANDA C., GROSSI F., GLIOZZI E., SMEDILE A., GENNARI R., DARBARAS G., DUDAS F., Ö. GÜRÜZ K., NAZIK A. & ECHTLER H. (2013).- Easternmost Mediterranean evidence of the Zanclean flooding event and subsequent surface uplift : Adana Basin, southern Turkey. *In*: Robertson A. H.F., PARLAK O. & ÜNLÜGEN U.C. (eds.), Geological Development of Anatolia and the Easternmost Mediterranean Region.- *Geological Society, London, Special Publications*, vol. 372, p. 473-493.

CITA M. (1973).- 47. Pliocene biostratigraphy and chronostratigraphy. *In*: Ryan W.B.F., Hsu K.J., Cita M.B., Dumitrca P., Lort J.M., Maync W., Nesteroff W.D., Pautot G., Stradner H. & Weze F.C.- *Initial Reports of the Deep Sea Drilling Project*, Washington D.C., vol. XIII, part 1, p. 1343-1379.
Cita M. (1975).- Foraminiferal biozonation of Pliocene deep-sea sediments from the Mediterranean. A revision. - Rivista Italiana di Paleontologia e Stratigrafia, Milano, vol. 81, p. 527-566.

Cita M.B. & Gartner S. (1973).- The Stratotype Zanclean: foraminiferal and nanofossil biostratigraphy. - Rivista Italiana di Paleontologia e Stratigrafia, Milano, vol. 79, p. 503-558.

Cita M.B. & Ryan W.B.F. (1973).- 47.5 Time-scale and general synthesis. In: Ryan W.B.F., Hsu K.J., Cita M.B., Dumitrca P., Lort J.M., Maync W., Nestoroff W.D., Pautot G., Stradner H. & Weze F.C.- Initial Reports of the Deep Sea Drilling Project, Washington D.C., vol. XIII, part 1, p. 1405-1415.

Cita M.B., Santambrogio S., Melillo B. & Rogat F. (1990).- 14. Messinian paleoenvironments: New evidence from the Tyrrenhian Sea (ODP Leg 107). In: Kastens K.A., Mascle J., Aurox C., Bonatti E., Broglio C., Channell J., Curzi P., Emeis K.-C., Glaçon G., Hasegawa S., Heike W., McCoy F., McKenzie J., Mascle G., Mendelson J., Muller C., Rehault J.-P., Robertson A., Sartori R., Sprovieri R. & Torri M.- Proceedings of the Ocean Drilling Program, Scientific Results, Washington D.C., vol. 107, p. 1405-1415.

Cita M.B., Wright R.C., Ryan W.B.F. & Longinelli A. (1978).- 53. Messinian paleoenvironments. In : Hsu K.J., Montadert L., Bernoulli D., Bizzoni G., Cita M., Erickson A., Fabricius F., Garrison R.E., Kidd R.B., Mélières F., Müller C. & Wright R.C.- Initial Reports of the Deep Sea Drilling Project, Washington D.C., vol. XLII, part 1, p. 1003-1035.

Colalongo M.L. & Pasini G. (1980).- 30. La ostracofauna plio-pleistocenica della sezione della Vrica in Calabria (con considerazioni sul limite Neogene-Quaternario).- Bollettino della Società Paleontologica Italiana, Modena, vol. 19, no. 1, p. 44-126.

Colalongo M.L., Pasini G., Poluzzi A. & Sprovieri R. (1990).- Relationship between the benthic foraminifers and the ostracodes in the Pliocene-Pleistocene Tyrrenhian deep-sea record (ODP Leg 107, site 654). In: Kastens K.A., Mascle J., Aurox C., Bonatti E., Broglio C., Channell J., Curzi P., Emeis K.-C., Glaçon G., Hasegawa S., Heike W., McCoy F., McKenzie J., Mascle G., Mendelson J., Muller C., Rehault J.-P., Robertson A., Sartori R., Sprovieri R. & Torri M.- Proceedings of the Ocean Drilling Program, Scientific Results, Washington D.C., vol. 107, p. 479-493.

Coles G.P., Ainsworth N.R., Whatley R.C. & Jones R.W. (1996).- Foraminifera and Ostracoda from Quaternary carbonate mounds associated with gas seepage in the Porcupine Basin, offshore western Ireland.- Revista Española de Micropaleontología, Madrid, vol. 28, no. 2, p. 113-151.

Costa O.G. (1853).- Paleontologia del Regno di Napoli. Parte III.- Giorgio Franz, Monaco, 196 p. (XVI Pls.).

Couvering J. A., Van, Castadordi D., Cita M.B., Frederik J. H. & Rio D. (2000).- The base of the Zanclean Stage and of the Pliocene Series.- Episodes, Beijing, vol. 23, no. 3, p. 179-187.

Decima A. (1964).- Ostracodi del gen. Cyprideis Jones del Neogene e del Quaternario italiani.- Palaeontographia Italica, vol. 57, p. 81-133.

Di Geromino L., Esi D. & Grasso M. (1989).- Gli strati a"congerie" del Messiniano superiore del margine nord occidentale ibleo. Caratteristiche faunistiche e possibili implicazioni paleogeografiche e paleoclimatiche.- Atti Accademia Peloritana dei Pericolanti, Messina, vol. 68, no. 1, p. 129-150.

Di Stefano E., Sprovieri R. & Scartantino S. (1996).- Chronology of biostratigraphic events at the base of the Pliocene.- Paleopelagios, Roma, vol. 6, p. 401-414.

Di Stefano A. & Suriale G. (2010).- Refinements of calcareous biostratigraphy at the Miocene/Pliocene Boundary in the Mediterranean region.- Geobios, Villeurbanne, vol. 43, p. 5-20.

Drinia H., Antonarakou A., Tsourou T., Tzortzaki E., Filippidi A. & Nikolagu K. (2010).- The Messinian/early Pliocene transition in eastern Mediterranean: New palaeoenvironmental data from the Kalamaki section (Zakynhos Island, Greece).- Geophysical Research Abstracts, Vol. 12, EGU2010-13926-1, EGU General Assembly 2010.

Garcia-Castellanos D., Estrada F., Jiménez-Munt I., Gorini C., Fernández M., Vergés J. & De Vincente R. (2009).- Catastrophic flood of the Mediterranean after the Messinian salinity crisis.- Nature, vol. 462, p. 778-782.

Gartner S. & Bukry D. (1974).- Ceratolithus acutus Gartner and Bukry n. sp. and Ceratolithus amplificus Bukry and Percival - nomenclatural clarification.- Tulean Studies in Geology and Palaeontology, vol. 11, p. 115-118.

Genner R., Iaccarino M.S., Di Stefano A., Stefanele G., Cipollari P., Manzi V., Roveri M. & Cosentino D. (2008).- The Messinian-Zanclean boundary in the Northern Apennine.- Stratigraphy, vol. 5, no. 3-4, p. 307-322.

Gliozzi E., Ceci M.E., Grossi F. & Legios S. (2007).- Paratethyan ostracod immigrants in Italy during late Miocene.- Geobios, Villeurbanne, vol. 40, p. 325-337.

Grossi F., Gliozzi E. & Cosentino D. (2011).- Paratethyan ostracod immigrants mark the biostratigraphy of the Messinian Salinity Crisis.- Joannea Geologie und Paläontologie, Graz, vol. 11, p. 66-68.
Grossi F., Gliozzi E., Anadón P., Castorina F. & Voltaggio M. (2015).- Is *Cyprideis* agrigentina a good paleosalinometer for the Messinian Salinity Crisis? Morphometrical and geochemical analyses from the Eraclea Minoa section (Sicily).- Paläogeography, Paläoclimatology, Paläoecology, vol. 419, p. 75-89.

Guénet C. & Lethiers F. (1989).- Ostracodes et recherche des milieux anciens : possibilités et limites.- Bulletin de la société Géologique de France, Paris, vol. 8, no. 5, p. 577-588.

Guerra-Merchán A., Serrano F., García M., Gofas S., Esu D., Gliozzi E. & Grossi F. (2010).- Messinian Lago-Mare deposits near the Strait of Gibraltar (Malaga Basin, S Spain).- Paläogeography, Paläoclimatology, Paläoecology, vol. 285, p. 264-276.

Hasegawa S., Sprovieri R. & Poluzzi A. (1990).- 29. Quantitative analysis of benthic foraminiferal assemblages from Plio-Pleistocene sequences in the Tyrrenhenian Sea, ODP Leg 107. In: Kastens K. A., Masce J., Aurox C., Bonatti E., Brogiela C., Channell J., Curzi P., Emeis K.-C., Glaçon G., Hasegawa S., Hieke W., McCoy F., McKenzie J., Masce G., Mendelson J., Muller C., Rehault J.-P., Robertson A., Sartori R., Sprovieri R. & Torri M.- Proceedings of the Ocean Drilling Program, Scientific Results, Washington D.C., vol. 107, p. 461-478.

Hsu K.J., Ryan W.F.B. & Cita M.B. (1973).- Late Miocene desiccation of the Mediterranean.- Nature, UK, vol. 242, p. 240-244.

Iaccarino S., Castradore D., Cita M.B., Di Stefano E., Gaboardi S., McKenzie J.A., Spezzaferri S. & Sprovieri R. (1999).- The Miocene/Pliocene boundary and the significance of the earliest Pliocene flooding in the Mediterranean.- Memorie della Società Geologica Italiana, vol. 54, p.109-131.

Jorissen F.J. (1988).- Benthic foraminifera from the Adriatic Sea: principles of phenotypic variation.- Utrecht Micropaleontological Bulletins, Utrecht, vol. 37, p.1-74.

Kouwenhoven T.J. & Zwan J.G. van der (2006).- A reconstruction of late Miocene Mediterranean circulation patterns using benthic foraminifera.- Palæogeography, Palæoclimatology, Palæoecology, vol. 230, no. 1-4, p. 373-385.

Krigsmann W., Hilgen F.J., Raffi I., Sierro F.J. & Wilson D.S. (1999).- Chronology, causes and progression of the Messinian Salinity Crisis.- Nature, vol. 400, p. 652-655.

Krigsmann W., Capella W., Simon D., Hilgen F.J., Kouwenhoven T.J., Meijer, P.T. & Flecker R. (2018).- The Gibraltar Corridor: Watergate of the Messinian Salinity Crisis.- Marine Geology, vol. 403, 238-246.

Lancis C., Tent-Maucurs J.E., Flores J.A. & Soria J.M. (2015).- The Pliocene Mediterranean infilling. Cytology Messinien Méditérranée ancien.- Mediterranean Surface: New biostratigraphic data based on calcareous nanofossils (Bajo Segura Basin, SE Spain).- Geologia Acta, Barcelona, vol. 13, no. 3, p. 211-228.

Langereis C.G. & Hilgen F.J. (1991).- The Rossello composite: a Mediterranean and global reference section for the early to early late Pliocene.- Earth and Planetary Science Letters, vol. 104, p. 211-225.

Lentini F., Grasso M. & Carbone S. (1987).- Introduzione alla geologia della Sicilia e guida all’escursione.- Convegno della Società Geologica Italiana, Naxos-Pergusa 22-25 Aprile 1987, Catania, 60 p.

Liventz E.V. (1929).- Ostracoda from the Akchagyl and Apscheron strata along the Babazansky section. In: Agalarova D.A., Kadyrova Z.K. & Kulieva S.A. (eds., 1961), Ostracoda from Pliocene and post-Pliocene deposits of Azerbaijan.- Baku, 58 p. [in Russian].

Martini E. (1971).- Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci A. (ed.), Proceedings of the II Planktonic Conference.- Tecnoscienze, Roma, vol. 2, p. 739-785.

Meées G. (1908).- Beitrage zur Kenntnis der pliozonen Ostrakoden Ungarns. II. Die Darwinulidaen und Cytheridaen der unterpannonischen Stufe.- Foldtani Kozlony, vol. 38, Supplement, p. 601-635.

Montenegro M.E., Pugliese N. & Bonaduce G. (1998).- Shelf ostracods distribution in the Italian seas. In: Crasquin-Soleau S., Braccini E. & Lethiers F. (eds.), What about Ostracods?- Bulletin du Centre Recherche elf Explorations Production, Pau, Mémoire 20, p. 91-101.

Mottura A. (1871).- Sulla formazione terziaria della zona solifera della Sicilia.- Memorie descrittive della Carta Geologica d’Italia, Roma, vol. 1, p. 50-140.

Murray J. (2006).- Ecology and applications of benthic Foraminifera.- Cambridge University Press, p. 1- 426.

Neviani A. (1906).- Ostracodi delle sabbie postpliocene di Carrubbare (Calabria).- Bollettino della Società Geologica Italiana, Roma, vol. 25, p. 185-216.

Ogniben L. (1957).- Petrografia della serie solifera siciliana e considerazioni geologiche relative.- Memorie descripttive della Carta Geologica d’Italia, Roma, vol. 33, 276 p.

Orszag-Sperber F., Roucy J.M. & Blanc-Valleron M.-M. (2000).- La transition Messinien Pliocène en Méditerranée orientale (Chypre) : la période du Lago-Mare et sa signification.- Comptes Rendus de l’Académie des Sciences (Series IIA - Earth and Planetary Science), Paris, vol. 331, no. 7, p. 483-490.

Pedley M. & Grasso M. (1992).- Miocene syntectonic sedimentation along the western margins of the Hyblean-Malta platform: A guide to plate margin processes in the central Mediterranean.- Journal of Geodynamics, vol. 15, p. 19-37.
Pierre C., Caruso A., Blanc-Valleron M., Rouchy J.-M. & Orszag-Sperber F. (2006). Reconstruction of the paleoenvironmental changes around the Miocene-Pliocene boundary along a west-east transect across the Mediterranean.- Sedimentary Geology, vol. 188-189, p. 319-340.

Pujo M. (1976). Écologie des foraminifères benthiques et des Thécamoebiens de la Gironde et du plateau continental Sud-Gascogne: application à la connaissance du Quaternaire terminal de la région Ouest-Gironde.- Mémoires de l’Institut de Géologie du Bassin d’Aquitaine, Bordeaux, vol. 8, 274 p.

Puri H.S., Bonaduce G. & Gervasio A.M. (1969). Distribution of Ostracoda in the Mediterranean. In: Neale J.W. (ed.), The taxonomy, morphology and ecology of recent Ostracoda.- Oliver & Boyd, Edinburgh, p. 358-411.

Rouchy J.-M. & Caruso A. (2006). The Messinian salinity crisis in the Mediterranean Basin: a reassessment of the data and an integrated scenario.- Sedimentary Geology, vol. 188-189, p. 35-67.

Rouchy J.-M., Caruso A., Pierre C., Blanc-Valleron M.-M. & Bassetti M.A. (2007). The end of the Messinian salinity crisis: evidences from the Cheif Basin (Algeria).- Palæogeography, Palæoclimatology, Palæoecology, vol. 254, p. 386-417.

Rouchy J.-M., Orszag-Sperber F., Blanc-Valleron M.-M., Pierre C., Rivière M., Combouiré-Nebout N. & Panayides I. (2001). Paleoenvironmental changes at the Messinian-Pliocene boundary in the eastern Mediterranean: southern Cyprus basins.- Sedimentary Geology, vol. 145, p. 93-117.

Roveri M., Flecker R., Kriegsmann W., Loﬁ J., Lugli S., Manzi V., Siervo J.F., Bertini A., Camerlenghi A., De Lange G., Govers R., Hilgen F. J., Hübscher C., Meijer T. P. & Stoica M. (2014). The Messinian Salinity Crisis: Past and future of a great challenge for marine sciences.- Marine Geology, vol. 352, p. 25-58.

Roveri M., Manzi V., Gennari R., Iaccarino S. & Lugli S. (2008). Recent advances in the Messinian stratigraphy of Italy and their Mediterranean-scale implication.- Bollettino della Società Paleontologica Italiana, Modena, vol. 47, p. 71-85.

Ruggieri G. (1953). Età e fauna di un terrazzo marino sulla costa Ionica della Calabria.- Giornale di Geologia (serie 2), Bologna, vol. 23, p. 19-168.

Ruggieri G. (1954). Iconografia degli Ostracodi marini del Pliocene e del Pliocene italiani.- Atti della Società Italiana di Scienze Naturali, - Milano, vol. 93, no. 3, 4, p. 561-575.

Ruggieri G. (1960). Ostracofauna miocenica del ragusano.- Rivista mineraria siciliana, Palermo, vol. 63, p. 1-5.

Ruggieri G. (1967). The Miocene and later evolution of the Mediterranean Sea. In: Adams C.G. & Ager D.V. (eds.), Aspects of Tethyan biogeography.- Systematics Association, University of California, Publication 7, p. 283-290.

Ruggieri G. (1992). Considerazioni tassonomiche su ostracodi neogencgi e pleistocenici risultate dalla revisione di vecchi lavori dello scrittore.- Bollettino della Societá Paleontologica Italiana, Modena, vol. 31, no. 2, p. 175-188.

Sars G.O. (1866).- Observations on the ostracods from the Cape of Good Hope.- Scandinavian Journal of Geology, vol. 4, p. 213-219.

Sars G.O. (1922-1928).- An account of the Crustacea of Norway vol. IX: Ostracoda.- Bergen Museum, 277 p.

Sciuto F. (2003). Dati preliminari sull’ ostracofauna del Capo Milazzo (Sicilia NE).- Bollettino della Società Paleontologica Italiana, Modena, vol. 42, no. 1-2, p. 179-184.

Sciuto F. (2005). Ostracods of the upper Pliocene of Capo Milazzo (Sicilia NE) ed implicazioni paleoambientali.- Rendiconti della Società Paleontologica Italiana, Modena, vol. 2, p. 219-227.

Sciuto F. (2012). New ostracod species from Lower Pleistocene bathyal sediments of Cape Milazzo (NE, Sicily).- Bollettino della Società Paleontologica Italiana, Modena, vol. 51, no. 2, p. 117-125.

Sciuto F. (2014a). Ostracods of the upper Pliocene-Pleistocene Punta Mazza succession (NE Sicily) with special focus on the Family Trachyleberididae- Silvester-Bradley, 1948, and description of a new species.- Carnets Geol., Madrid, vol. 14, no. 1, p. 1-1319.

Sciuto F. (2014b). Acanthocythereis coliniti nov. nom for A. reticulata Sciuto, 2014.- Carnets Geol., Madrid, vol. 14, no. 3, p. 39.

Sciuto F. (2015). Palaeoenvironmental and palaeoecogeographical traits on deep-water ostracod assemblages from the lower Pleistocene sediments along the Ionian side of Mount Etna (Sicily, Italy).- Carnets Geol., Madrid, vol. 15, no. 14, p. 179-197.

Sciuto F., Baldanza A., Temani R. & Privitera G. (2018).- New reports of Paratethyan ostracods affinity from the Mediterranean Basin (Sicily, Italy).- Palaeontologia Electronica, 21.1.12A, 19 p. URL: https://doi.org/10.26879/800

Seguenza G. (1880).- Le formazioni terziarie nella provincia di Reggio Calabria.- Regia Accademia dei Lincei, Roma, vol. 3, 416 p.

Sgarrella F., Di Donato V. & Sproveri R. (2012). Benthic foraminiferal assemblage turnover during intensification of the Northern Hemisphere glaciation in the Piacenzian Punta Piccola section (southern Italy).- Palæogeography, Palæoclimatology, Palæoecology, vol. 333-334, p. 59-74.
Sgarrella F., Sprovieri R., Di Stefano E., Caruso A. (1997).- Palaeoceanographic conditions at the base of the Pliocene in the southern Mediterranean basin. Rivista Italiana di Paleontologia e Stratigrafia, vol. 103, p. 207-220.

Sissingh W. (1972).- Late Cenozoic Ostracoda in the South Aegean Island Arc. Utrecht Micropaleontology Bulletin, vol. 6, p. 1-187.

Spezzaferri S., Cita M.B. & McKenzie J.A. (1998).- 2. The Miocene/Pliocene boundary in the eastern Mediterranean: results from sites 967 and 969. In: Robertson A.H.F., Emeis K.-C., Richter C., Camerlenghi A. (eds.). Proceedings of the Ocean Drilling Program, Scientific Results, Washington D.C., vol. 160, p. 9-28.

Sprovieri R. & Hasegawa S. (1990).- 28. Pliopleistocene benthic foraminifer stratigraphic distribution in the deep-sea record of the Tyrrenian Sea (ODP Leg 107). In: Kastens K. A., Mascle J., Auroux C., Bonatti E., Brogia C., Channell J., Curzi P., Emeis K.-C., Glaçon G., Hasegawa S., Heke W., McCoy F., McKenzie J., Mascle G., Mendelson J., Muller C., Rehault J.-P., Robertson A., Sartori R., Sprovieri R. & Torii M. Proceedings of the Ocean Drilling Program, Scientific Results, Washington D.C., vol. 107, p. 429-459.

Straaten L.M.J.U. van (1966).- Micro-malacological investigation of cores from the southeastern Adriatic Sea. Koninklijke Neder-landse Akademie van Wetenschappen, Verhandelingen (series B), Amsterdam, vol. 69, p. 429-445.

Temani R., Ammar K.H. & Sciuto F. (2018).- New reports of Messinian Lago-Mare Episodes from Tunisia: ostracods and paleoenvironmental implications. In: Zhang Z., Khelifi N., Mezghani A. & Heggy E. (eds.), Patterns and mechanisms of climate, paleoclimate and paleoenvironmental changes from low-latitude regions. Proceedings of the 1st Springer Conference of the Arabian Journal of Geosciences (CAJG-1), Tunisia 2018, p. 69-71.

Terquem O. (1878).- Les foraminifères et les entomocènes- ostracodes du Pliocene supérieur de l’Île de Rhodes. Deuxième Section (ostracodes). Mémoires de la Société Géologique de France, vol. 3, p. 81-135.

Trenkwalder S., Violanti D., Atri A. d’, Lozar F., Dela Pierre F. & Irace A. (2008).- The Miocene/Pliocene boundary and the early Pliocene micropalaeontological record: new data from the Tertiary Piedmont Basin (Moncucco quarry, Turin Hill, northwestern Italy). Bollettino della Società Paleontologica Italiana, vol. 47 (2), p. 87-103.

Violanti D., Dela Pierre F., Trenkwalder S., Lozar F., Clari P., Irace A. & Atri A. d’ (2011).- Biostratigraphic and palaeoenvironmental analyses of the Messinian/Zanclean boundary and Zanclean succession in the Moncucco quarry (Piedmont, northwestern Italy). Bulletin de la Société Géologique de France, vol. 182, no. 2, p. 149-162.

Whitley R. & Coles G. (1987).- The late Miocene to Quaternary ostracoda of leg 94, Deep Sea Drilling Project. Revista Española de Micropaleontología, Madrid, vol. 19, no. 1, p. 33-97.

Whitley R. & Zhao Q.H. (1993).- The Krithe problem: A history of the distribution of Krithe and Pararakrithe (Crustacea, Ostracoda) in the South China Sea. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 103, p. 281-297.
### Plate 1: Ostracods (scale bar: 200µm).

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

B) *Costa (Cuneocosta) tricostata pliocenica* RUGGERI, 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* RUGGERI, 1960; left valve, external lateral view.
Plate 2: Foraminifers (scale bar: 200µm).
A) Globorotalia margaritae BOLLI & BERMUDEZ, 1965; apertural view.
B) Globorotalia margaritae evoluta CITTA, 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 (CZIEK, 1848).
I) Marginulina costata (BATSCH, 1791).
L) Vulvulina pennatula (BATSCH, 1791).