



Messinian Lago-Mare ostracods from Tunisia

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Abstract: Micropalaeontological analyses were performed on two stratigraphical sections sampled in upper Messinian deposits outcropping in eastern Tunisia, allowing us to identify some sedimentary levels with high concentrations of fresh or brackish water ostracods, which can be referred to the Lago-Mare fauna. Some of these species can be considered Paratethysian, or rather as species that spread in the Mediterranean area starting from the Paratethys areas, while others show Paratethysian affinity. The Lago-Mare fauna is little known in the south Mediterranean regions and the present article provides new data on its geographic distribution.

Of the two sections sampled, the first one, the Wadi El Kebir section, is located in the south eastern part of the Cape Bon Peninsula and shows horizons dominated by *Cyprideis agrigentina* and *Cyprideis* ex *C. torosa* group; the second one, the Salakta section, is located in the Sahel region and shows a level with a very rich Lago-Mare ostracod fauna consisting essentially of *Amnicythere propinqua*, *Mediocytherideis punctata*, and *Ilyocypris gibba*.

Key-words:

- Ostracods;
- upper Messinian;
- Lago-Mare facies;
- Tunisia;
- palaeoenvironmental evolution

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Résumé : *Ostracodes du Lago-Mare messinien en Tunisie.*- Des analyses micropaléontologiques ont été réalisées sur deux coupes stratigraphiques échantillonnées dans des dépôts du Messinien supérieur affleurant en Tunisie orientale. Elles nous ont permis d'identifier certains niveaux sédimentaires présentant de fortes concentrations en ostracodes d'eaux douce ou saumâtre, qui peuvent être rapportés à la faune de faciès Lago-Mare. Certaines de ces espèces peuvent être considérées comme paratéthysiennes ou plutôt comme des espèces ayant migré en Mer Méditerranéenne depuis les régions paratéthysiennes, alors que d'autres présentent une affinité paratéthysienne. La faune de faciès Lago-Mare est peu connue dans les régions sud-méditerranéennes et cet article fournit de nouvelles données sur sa répartition géographique.

Des deux sections étudiées, la première, la coupe de Wadi El Kebir, située dans la partie sud-est de la péninsule du Cap Bon, comporte des niveaux dominés par *Cyprideis agrigentina* et *Cyprideis* ex gr. *C. torosa*, tandis que la seconde, la coupe de Salakta, située dans la région du Sahel, comporte un niveau doté d'une très riche faune d'ostracodes de faciès Lago-Mare, essentiellement constituée des espèces *Amnicythere propinqua*, *Mediocytherideis punctata* et *Ilyocypris gibba*.

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**Mots-clefs :**

- Ostracodes ;
- Messinien supérieur ;
- faciès Lago-Mare ;
- Tunisie ;
- évolution paléoenvironnementale

1. Introduction

At the end of the Miocene, the Mediterranean basin underwent one of the most disturbing environmental crisis that occurred in geological time. During this event, called Messinian Salinity Crisis (MSC) (HSÜ *et al.*, 1973; CLAUZON *et al.*, 1996; GLIOZZI *et al.*, 2007; GARCIA-CASTELLANOS *et al.*, 2009; GROSSI *et al.*, 2011; KRIJGSMAN *et al.*, 2018; G. MASCLE & J. MASCLE, 2019; BEN MOSHE *et al.*, 2020, *inter alia*), started 5.97 Ma ago (MANZI *et al.*, 2013), large thicknesses of evaporites were deposited on the bottom of Mediterranean Sea (RUGGIERI, 1967; BENSON, 1978; CITA *et al.*, 1978; G. MASCLE & J. MASCLE, 2019, *inter alia*). The causes that led to the deposition of evaporitic salts can be correlated to the more or less total closure of the connection between the Atlantic and Mediterranean seas.

According to an old hypothesis, the Mediterranean Sea dried up completely, due to the closure of the Strait of Gibraltar, leading to the deposition of evaporitic salts in deep hypersaline basins (HSÜ *et al.*, 1973; BENSON 1973a, 1973b; CITA *et al.*, 1978, *inter alia*). More recently, researchers have argued that the Strait of Gibraltar did not close entirely and that the Mediterranean Sea did not completely dry up; on the contrary, they suggest the presence of shallow saline water sedimentation on the floor of deep depressions, with a recurrent feeding mechanism of these depressions, including alternation of dewatering and filling events, or a system of basins located at different altitudes but connected by waterfalls (ROVERI *et al.*, 2014; KRIJGSMAN *et al.*, 2018; G. MASCLE & J. MASCLE, 2019).

The temporary Mediterranean disconnection from the Atlantic Ocean would be the result of a tectonic uplift of the Gibraltar threshold that controls the inflow of water required to compensate for its hydrological deficit (CITA *et al.*, 1978; GARCIA-CASTELLANOS *et al.*, 2009, *inter alia*).

According to BEN MOSHE *et al.*, 2020, during the third stage of the MSC (Lago-Mare event, 5.55-5.33Ma) the Mediterranean Sea level fluctuated repeatedly. Several parts of the Mediterranean Basin emerged and were affected by intense continentalization, with strong subaerial erosion phenomena, chemical dissolution of the previous Messinian evaporites, and, in the widespread lower basin area, deposition of terrigenous sedimentary facies characterized by brackish to a freshwater fauna (ORSZAG-SPERBER *et al.*, 2000; ROUCHY *et al.*, 2007; GLIOZZI *et al.*, 2007). This sedimentary facies, called "Lago-Mare" (*sensu*

RUGGIERI, 1967), occurs discontinuously but widely in the Mediterranean Basin from the Eastern to the Western Basin (ORSZAG-SPERBER *et al.*, 2000; ROUCHY & CARUSO, 2006; GLIOZZI *et al.*, 2007; GROSSI *et al.*, 2011; FARANDA *et al.*, 2013, *inter alia*).

According to the studies undertaken in Sicily and in many geographical areas of the Central Mediterranean Basin, the sediments deposited during the Lago-Mare event are represented by two different facies: the first consists of marls containing oligohaline faunas ("*Congerina* marls") (DI GERONIMO *et al.*, 1989; SCIUTO *et al.*, 2018), the second consists of reddish arkosic sands ("*Areazzolo*") containing brackish to freshwater ostracods (BONADUCE & SGARELLA, 1999; ROVERI *et al.*, 2008; SCIUTO *et al.*, 2018). Part of this fauna points to original mesohaline to hyperhaline shallow-water paleoenvironments with low oxygen content (GROSSI *et al.*, 2015) seemingly produced by overflows from the Pannonian-Pontian Paratethysian waters (GLIOZZI *et al.*, 2007; STOICA *et al.*, 2016).

Only a few detailed studies have been carried out on the Messinian ostracods of Tunisia, (Gulf of Gabes, South Tunisia; BONADUCE *et al.*, 1992) and even fewer on the "Lago-Mare" fauna. General studies have been performed on the Messinian facies (EL EUCH-EL KOUNDI *et al.*, 2009; ABDI *et al.*, 2014; FRIGUI *et al.*, 2016). Therefore, the main purpose of the present contribution focuses on the ostracod fauna collected from two stratigraphic sequences out-cropping in some localities in Eastern Tunisia, is to verify the presence of both Lago-Mare faunas and Paratethysian species therein.

The acquisition of this data will allow us to understand and to interpret the paleoecologic and paleoclimatic evolution of this area during the post evaporitic phase of the late Messinian.

2. Geological setting

The Messinian facies are relatively rare in Tunisia. The evaporitic ones are only known offshore, the terrigenous ones are only known in the Cap Bon Peninsula in northern Tunisia (BUROLLET, 1951; COLLEUIL, 1976; BEN SALEM, 1992; FRIGUI *et al.*, 2016; TEMANI *et al.*, 2018, 2019) and in the Sahel region (BESÈME & KAMOUN, 1988; KAMOUN *et al.*, 2001; MOISSETTE *et al.*, 2010; ABDI *et al.*, 2014; FRIGUI *et al.*, 2016; TEMANI *et al.*, 2018, 2019). They are usually squeezed between the upper Tortonian coastal to continental deposits (Saouaf and Somaa Formations) and the Lower Pliocene marine marls.

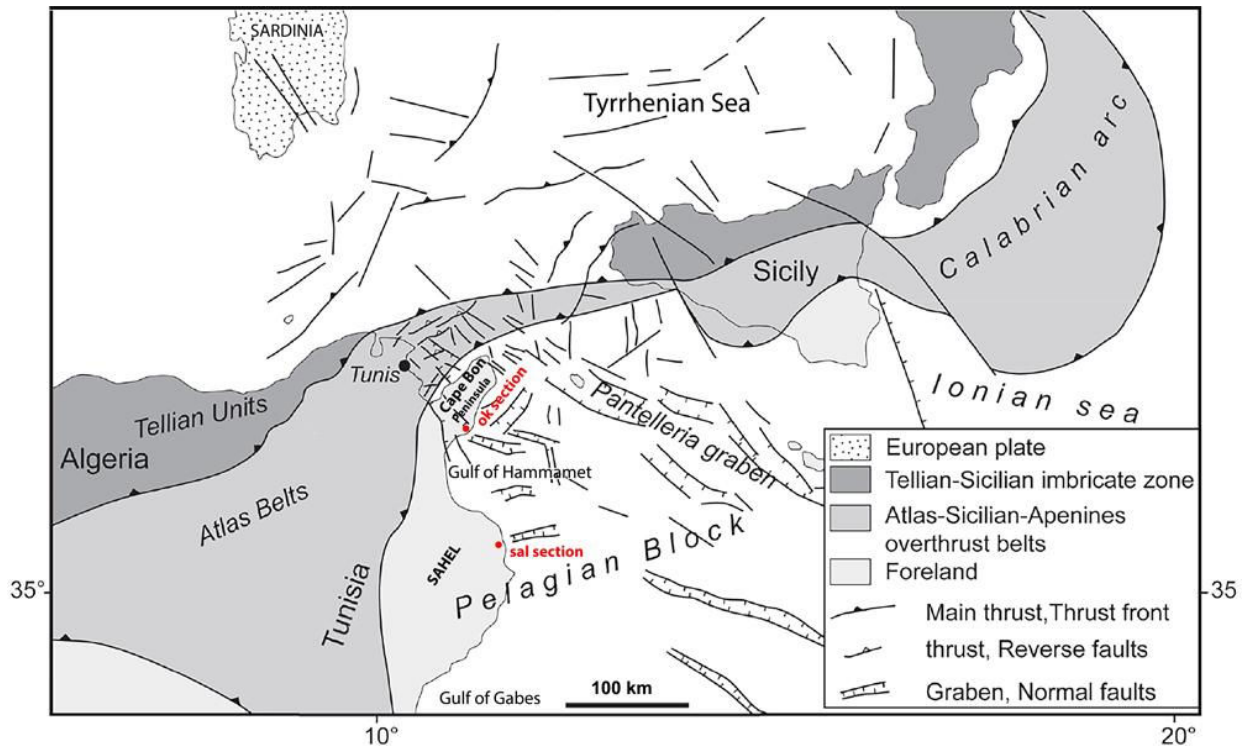


Figure 1: Structural scheme of the Central Mediterranean area with the location of the OK Section and SAL Section (modified after many authors).

The Cape Bon Peninsula (Fig. 1) is almost entirely constituted by the Jebel Abderrahmane anticline. The oldest series exposed is the Middle Eocene Souar Formation (BUROLLET, 1956; ABDI *et al.*, 2014). The overlying Neogene deposits consist of marine and terrestrial siliciclastic facies and carbonates (BUROLLET, 1956; COLLEUIL, 1976; DEMARCQ *et al.*, 1976; BEN SALEM, 1992; BÉDIR *et al.*, 1996; MANNAÏ-TAYECH, 2006).

The Sahel area in Eastern Tunisia (Fig. 1) extends from the "North-South Axis" eastward to the Mediterranean Sea. It is a flat foreland to the east of the Alpine Domain of Tunisia (Fig. 1). The outcropping sedimentary series range from the Upper Miocene to the Quaternary (BUROLLET, 1956; DEMARCQ *et al.*, 1967; KAMOUN, 1981; BESÈME & KAMOUN, 1988; BÉDIR, 1995; GAALOU, 1995; BEN YOUSSEF *et al.*, 2002; FRIGUI, 2003; ABDI *et al.*, 2014).

In these areas, the Messinian deposits (Fig. 2) are represented by two lithostratigraphic units: the Beni Khiair Fm. and the Oued El Bir Fm. (COLLEUIL, 1976; FOURNIE, 1978; BISMUTH, 1984; BÉDIR *et al.*, 1996; MOISSETTE *et al.*, 2010; FRIGUI *et al.*, 2016). The Beni Khiair Fm., with its lateral offshore equivalent, the Melqart Fm. (BONADUCE *et al.*, 1988), consists of oolitic and bioclastic limestones alternating with sandy and marly layers. The Oued El Bir Fm., or Oued bel Khedim Fm. in offshore wells, consists of sands, sandstones, and sometimes chalky clays. The Beni Khiair Fm. was described by COLLEUIL (1976) who proposed a Tortonian age for its lower part (Somaa and Beni Khiair formations and a Messinian age for its uppermost part (Oued El Bir Fm.). BEN SALEM (1998)

and HOOYBERGHS and BEN SALEM (1999) distinguished continental siliciclastic deposits (Somaa Fm.) followed by marine deposits represented by sandstones and clays (Beni Khiair Fm.) referred to the lower Messinian (N17 biozone of BLOW). The oolitic limestones follow. The sedimentary sequence ends with lagoonal and lacustrine siliciclastic deposits (Oued El Bir Fm.) attributed to the upper Messinian (Fig. 2) (MOISSETTE *et al.*, 2010; ABDI *et al.*, 2014; FRIGUI *et al.*, 2016).

3. Material and methods

Two stratigraphic sequences were sampled for ostracod faunas: the Wadi El Kebir section and the Salakta section.

The Wadi El Kebir (OK) section (Fig. 3) crops out in the eastern side of the Wadi El Kebir dam, in the Nabeul region, south eastern part of the Cape Bon Peninsula. It consists of about 8.5 m thick siliciclastic deposits. It can be divided into two lithostratigraphic units. The first one, 2.5m thick, is mostly sandy and capped at the top by sandstone sediments (70 cm) that are very rich in gastropods. This horizon shows bioturbation at the base, with bryozoa, algae, and echinoderms debris at the top. The second unit begins with centimetric sandy-clayey layers followed by laminated clays interbedded in sandstones. The top part (80 cm thick) is mostly sandy and sometimes shows clay levels with sandstones. These deposits correspond to the upper Messinian "Oued El Bir Fm." (Fig. 2) (SAÏD BENZARTI *et al.*, 2010; MOISSETTE *et al.*, 2010; FRIGUI *et al.*, 2016; present paper). Fifty-one samples were taken from the Wadi El Kebir section.

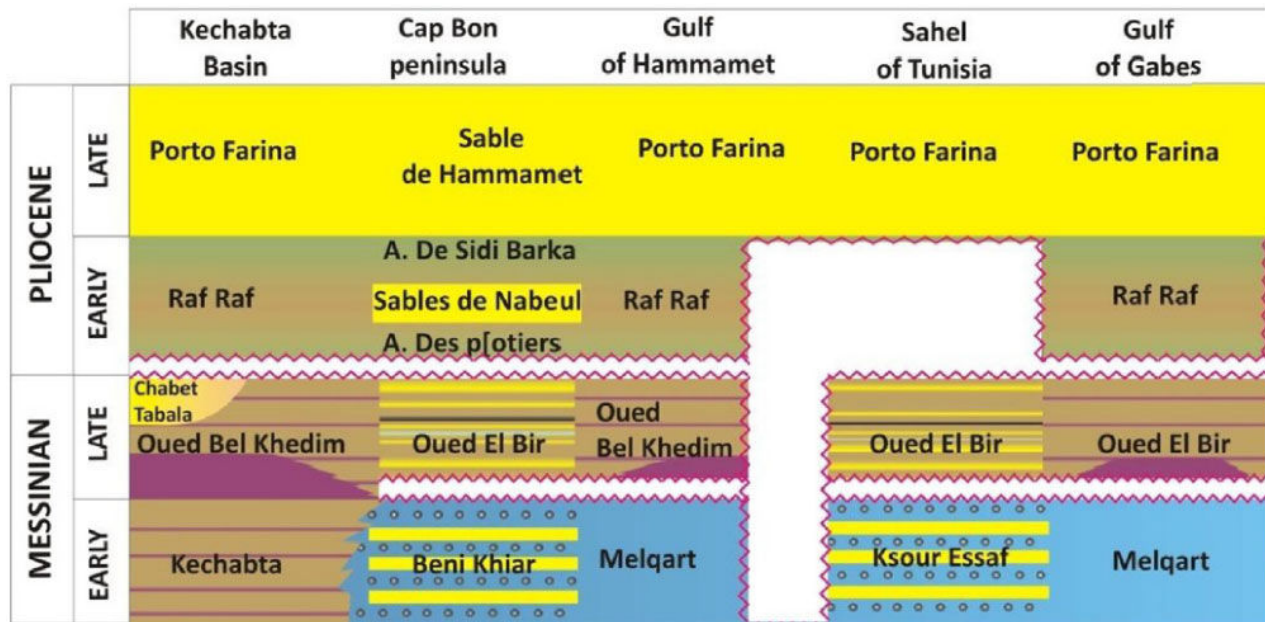


Figure 2: Stratigraphic schema of the investigated region (modified after FRIGUI *et al.*, 2016).

The Salakta section (SAL) (Fig. 5) is nearly 10 m thick and is located about 3 km north of the village of Salakta. The lower levels consist of 2 m thick silty marls followed by 3.5 m of bioclastic sand interbedded with centrimetric marl levels. This sand shows fragments of bivalves and bioturbations in some levels. Moving upwards, one finds 1.5 m of yellow sandstone displaying abundant gasteropod molds, followed by 2m of yellow fine sands containing bioclasts and Pectinids and grading up to calcareous sandstones. The whole is covered by 1m of green marl containing broken and complete oyster shells and 50 cm of fine sand. Thirty-one samples were taken from the Salakta section. The deposits correspond to the upper Messinian "Oued El Bir Fm."

For each sample, 250g of sediments were washed using diluted hydrogen peroxide for their disaggregation and sieved through standard sieves (63/125/250/500 µm). Residuals ≥250 µm were picked out completely and used for detailed taxonomic investigations. From the 125 µm sieve-residual 0.2 g/sample were picked and then quartered when necessary.

SEM micrographs were obtained through a LMU Tescan Vega II Scanning Electron Microscope at the Electronic Microscopy Laboratory of the University of Catania.

The specimens are deposited in the paleontological and sedimentological laboratory of the Geological Survey of the National Office of Mines of Tunisia.

Wadi El Kebir (OK) section (Figs. 3-4): 31 ostracod taxa were identified in the OK section. The ostracod fauna is rare and not referable to a purely marine environment and is only represented, sometimes abundantly, by species of the genus *Cyprideis* JONES, 1857.

Salakta (SAL) section (Figs. 5-6): 53 ostracod taxa were identified in the SAL section. The ostracod fauna is not referable to a purely marine environment and is concentrated in a precise stratigraphic interval between samples 9 and 17 (Fig. 4). Ostracod association in this level consist of such species widespread and abundant as *Candona* and *Cyprideis* associated with *Phlyctenophora farkasi* (ZALANYI, 1913) and *I. gibba*, followed by *Amnicythere propinqua* (LIVENTAL, 1929), *Mediocytherideis punctata* (LIGIOS *et al.*, 2008) and species belonging to the genera *Cytherois*, *Cypria*, and *Ilyocypris*. Foraminifers are rare. In this group of samples were found charophyte gyrogonites, the best preserved of which are referable to *Chara hispida* LINNAEUS, 1753, and *C. vulgaris* LINNAEUS, 1753.

The distribution of *Miocyprideis polita* BONADUCE *et al.*, 1992, is particularly meaningful; it is distributed, sometimes abundantly, in the lower and upper portion of the section, but it is practically absent between samples 9 and 21.

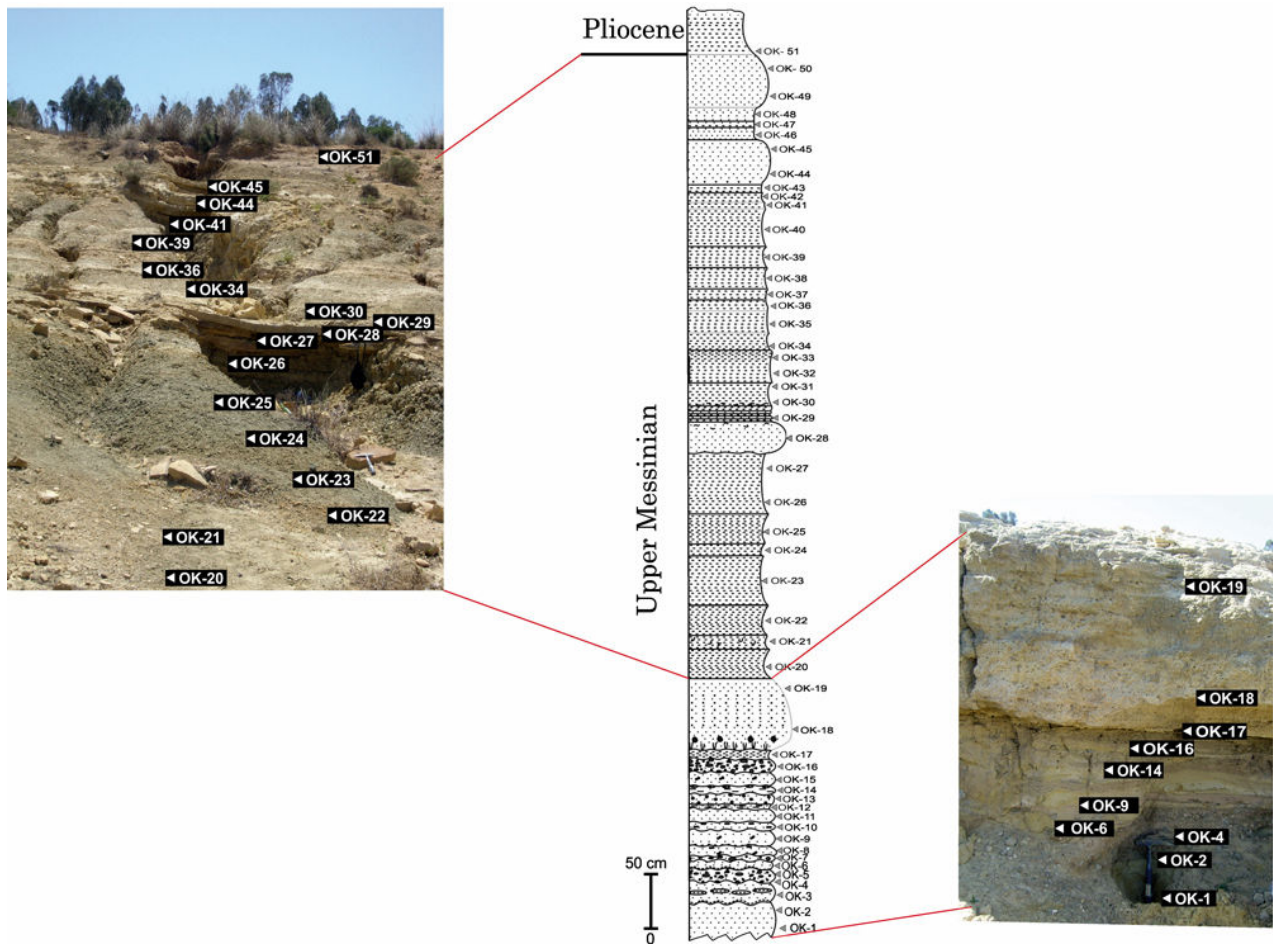


Figure 3: The sedimentary succession cropping out at OK section and the corresponding stratigraphical log with sampling location.

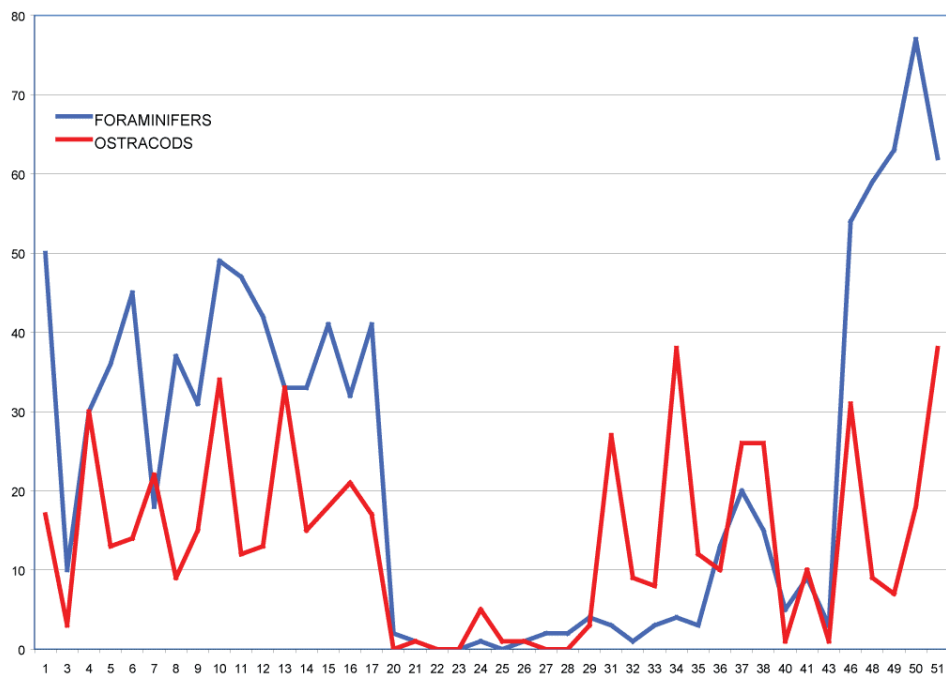


Figure 4: Distribution of ostracods and foraminifers along the OK section (abscissa axis=samples; ordinate axis=number of specimens).

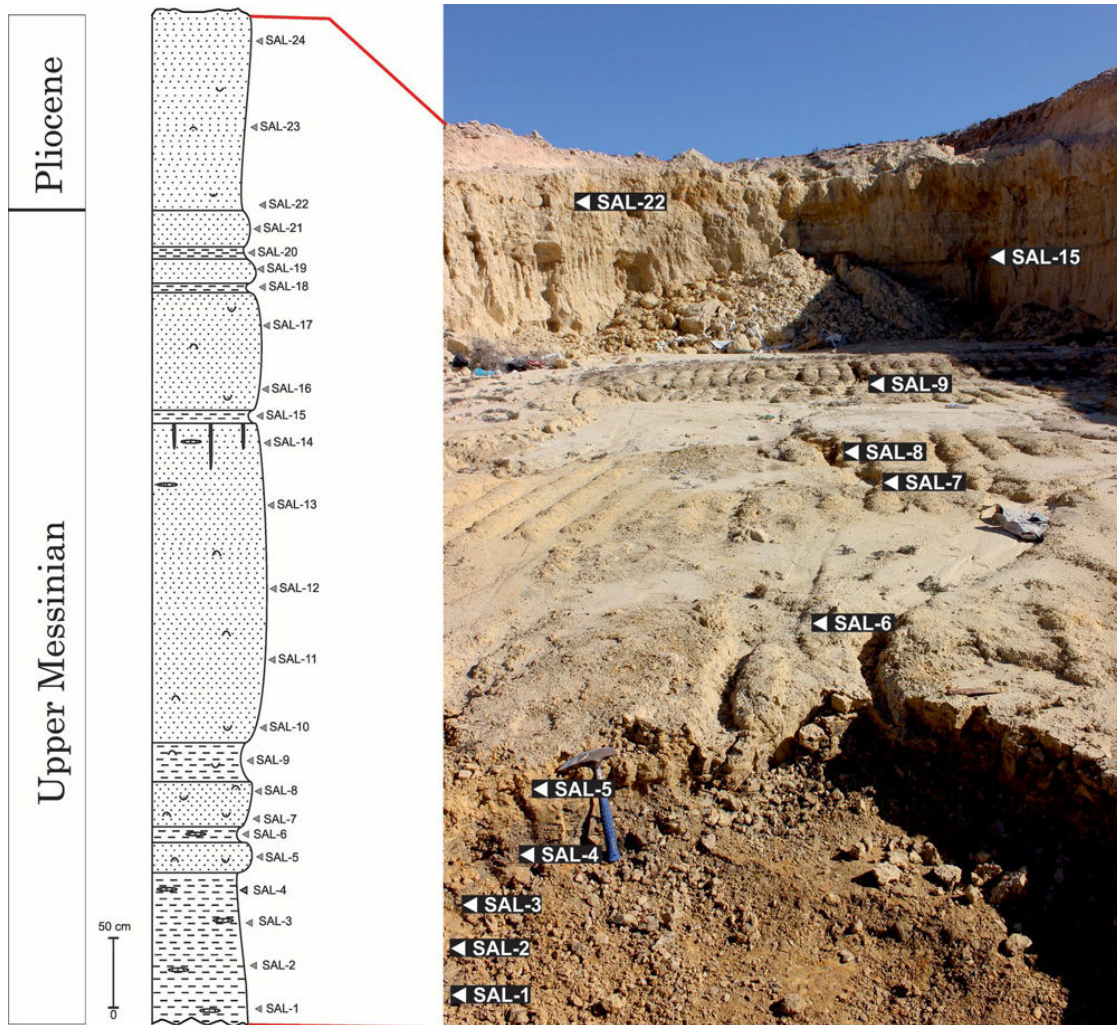


Figure 5: The sedimentary succession cropping out at SAL Section and the corresponding stratigraphical log with sampling location.

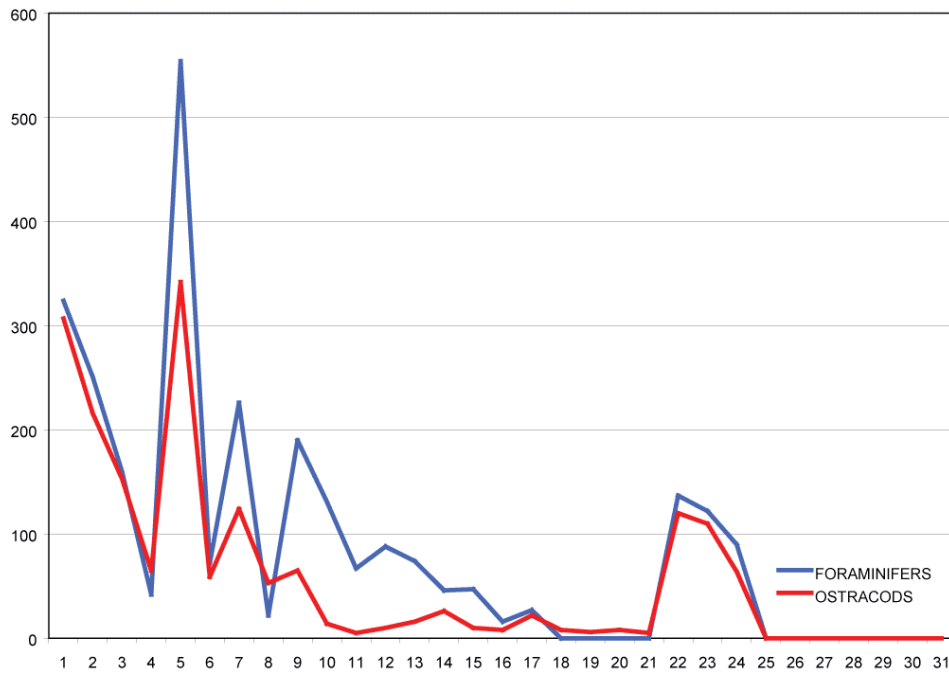


Figure 6: Distribution of foraminifers and ostracods along the SAL Section (abscissa axis=samples; ordinate axis= number of specimens).



4. Systematic palaeontology

Ostracod species are particularly important for the late Messinian paleogeography and paleo-environment. They are well represented in some stratigraphic levels of the two sections and are listed systematically (according to MEISCH *et al.*, 2019).

They were found for the first time in this studied sector of the Mediterranean area.

Class OSTRACODA LATREILLE, 1806

Subclass PODOCOPA SARS, 1866

Order PODOCOPIDA SARS, 1866

Family CANDONIDAE KAUFMANN, 1900

Genus *Phlyctenophora* BRADY, 1880

Type species: *Phlyctenophora zealandica* BRADY, 1880.

***Phlyctenophora farkasi* (ZALANYI, 1913)**

(Pl. 1, fig. 1)

2006 *Phlyctenophora farkasi* (ZALANYI), OLTEANU, p. 20.

2007 *Phlyctenophora farkasi*, PEZELY & SREMAC, p. 83.

2008 *Phlyctenophora farkasi* (ZALANYI, 1913), FARANDA *et al.*, p. 301, Pl. 5, fig. 4

2013 *Phlyctenophora farkasi* (ZALANYI, 1913), FARANDA *et al.*, p. 846, Figs. 6 (u), 7 (e, f, h).

P. farkasi is reported always from shallow marine water and transitional environments, such as marshes, lagoons, and estuaries, often associated with *Neomonoceratina laskarevi* (KRSTIC & PIETRZENIUK, 1972). The species has been found in the Upper Miocene of central Crete (FARANDA *et al.*, 2008), the Badenian (Langhian-lower Serravallian) of the North Croatian Basin (BAKRAČ *et al.*, 2010), Transylvania (OLTEANU, 2006), and Medvednica Mt. (Croatia) (PEZELJ & SREMAC, 2007). In the Messinian the species is reported from the Adana Basin in southern Turkey (FARANDA *et al.*, 2013). The species does not appear to be reported in Italy. The genus is reported from the Upper-Middle Miocene of Buonfornello (ARUTA, 1982).

P. farkasi is stratigraphically referred to the higher part of the upper Badenian in the Carpathian area (OLTEANU, 2006) and in the Pokupsko area (Banovina, Croatia) where it is recognized the NO10 Zone *Carinocythereis carinata* – *Phlyctenophora farkasi* of the upper Badenian (HAJEK-TADESSE & PRTOJAN, 2011). According to OLTEANU (2006), the species would be part of an association that would represent the faunal transition between the Paratethysian region fauna and those of the Mediterranean area.

Family ILYOCYPRIDIDAE

KAUFMANN, 1900

Subfamily Ilyocypridinae

KAUFMANN, 1900

Genus *Ilyocypris* BRADY & NORMAN, 1889

Type species: *Cypris gibba* RAMDOHR, 1808.

***Ilyocypris gibba* (RAMDOHR, 1808)**

(Pl. 1, fig. 2)

1808 *Cypris gibba* RAMDOHR, p. 91, Pl. 3, figs. 13-14, 17;

1965 *Ilyocypris gibba* (RAMDOHR); DEVOTO, p. 345, Fig. 50.

1979 *Ilyocypris gibba* (RAMDOHR); CARBONNEL & PEYPOUQUET, p. 195, Pl. 1, fig. 2.

1998 *Ilyocypris gibba* (RAMDOHR); GLIOZZI & MAZZINI, p. 80, Pl. 2, fig. A.

1999 *Ilyocypris gibba* (RAMDOHR); MAZZINI *et al.*, p. 297, Pl. 2, fig. 5.

2000 *Ilyocypris gibba* (RAMDOHR); MEISCH, p. 245, Fig. 104.

2005 *Ilyocypris gibba* (RAMDOHR); RODRIGUEZ-LÁZARO & MARTIN-RUBIO, p. 40, Pl. 1, figs. 1-3, 7.

2006 *Ilyocypris gibba* (RAMDOHR); ROSSETTI *et al.*, p. 124, Fig. 2 (I-K).

2006 *Ilyocypris gibba* (RAMDOHR); PIERI *et al.*, p. 5.

2008 *Ilyocypris gibba* (RAMDOHR); AKDEMIR, p. 109, Fig. 3.

2008 *Ilyocypris gibba* (RAMDOHR); BEKER *et al.*, p. 12, Pl. 1, figs. 10-11.

2014 *Ilyocypris gibba* (RAMDOHR); UÇAK *et al.*, p. 4.

2015 *Ilyocypris gibba* (RAMDOHR); SCIUTO *et al.*, p. 50, Pl. 1, U.

Remarks: *I. gibba* (RAMDOHR) is a Holarctic species, known from a very wide area in Europe and Asia, as well as from East Africa and North America (HENDERSON, 1990). In Sicily it has been recorded in Recent deposits by PIERI *et al.* (2006) and in Pleistocene sediments by SCIUTO *et al.* (2015). The stratigraphical distribution of *I. gibba* is wide, ranging from the Tortonian to the Recent (BEKER *et al.*, 2008). The species is widespread in all freshwater environments, in a wide temperature range.

Family CYTHERIDEIDAE SARS, 1925

Genus *Cyprideis* JONES, 1857

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

***Cyprideis agrigentina* DECIMA, 1964**

(Pl. 1, fig. 3)

1964 *Cyprideis pannonica agrigentina*; DECIMA, p. 108-111, Pl. 29, figs. 4-8; Pl. 30, figs. 1-10; Pl. 31, fig. 1.2; Pl. 37, figs. 16-21.

1964 *Cyprideis pannonica pseudoagrigentina*; DECIMA, p. 111-113, Pl. 31, figs. 3-7; Pl. 32, figs. 1-2; Pl. 38, figs. 1-2.



1978 *Cyprideis pannonica* (MÉHES); BENSON, p. 780, Pl. 2, figs. 4-8.

1999 *Cyprideis "agrigenina"* DECIMA; BONADUCE & SGARRELLA, p. 84-86, Pl. 1, fig. 1.

2007 *Cyprideis agrigenina* DECIMA; ROUCHY *et al.*, p. 392-393, 400, 407, 410-411, Pl. 4, figs. 1-2.

2008 *Cyprideis agrigenina* DECIMA; GROSS *et al.*, p. 133, 135, 137-140.

2008 *Cyprideis agrigenina* DECIMA; TRENKWALDER *et al.*, p. 94.

2018 *Cyprideis agrigenina* DECIMA; SCIUTO *et al.*, p. 11, Fig. 6.9

Remarks: According to GLIOZZI (1999) the specific attribution of *Cyprideis* is rather complex. Indeed, the morphological characters of the carapace can be too diverse to justify the adoption of the term *C. ex gr. pannonica* by GROSS *et al.* (2008) to indicate rather small and nearly smooth specimens of the genus found in upper Sarmatian and lower Pannonian sediments of the central Paratethys. This character is so distinct that LIGIOS and GLIOZZI (2012) continue to propose to create the "*C. torosa* group", including species such as *C. agrigenina* DECIMA, 1964, *C. ruggierii* DECIMA, 1964, *C. torosa* (JONES, 1850), and in part *C. crotonensis* DECIMA, 1964, and *C. calabra* DECIMA, 1964 (LIGIOS & GLIOZZI, 2012).

In this paper, we have decided to continue to use the specific name "*agrigenina*". We have identified the species through the observation of the internal characters of the carapace and particularly muscle scars, hinge, and duplicature. All the others specimens of "*Cyprideis*" have been grouped into the "*C. torosa* group" according to LIGIOS and GLIOZZI (2012).

C. agrigenina is widespread in all the brackish Mediterranean domain during the "Lago-Mare" phase of the Messinian Salinity Crisis from the end of the evaporitic phase (about 5.5 Ma) to the Messinian/Zanclean boundary (5.33 Ma) (COSENTINO *et al.*, 2007; GROSS *et al.*, 2008; GUERRA-MERCHÁN *et al.*, 2010; CIPOLLARI *et al.*, 2013). It seems to occur more frequently in the mesohaline high mesohaline facies, where it creates oligotypic assemblages together with *Ammonia tepida* (BONADUCE & SGARRELLA, 1999; GROSSI & GENNARI, 2008; GUERRA-MERCHÁN *et al.*, 2010), while in the oligo-mesohaline environment it seems to be vicariant with *Cyprideis anlavauxensis* (GROSSI & GENNARI, 2008).

C. agrigenina is reported from the Messinian of Eraclea Minoa (DECIMA, 1964), the Pannonian Stage of the northern Vienna Basin (KOVÁČ *et al.*, 1998), the Upper Miocene of eastern Anatolia (NAZIK *et al.*, 2008), the Pliocene of Almeria (ADDICOTT *et al.*, 1978), the Sarmatian of Turkey, the lower Sarmatian of Romania (RADU & STOICA, 2005), the Upper Miocene deposits of Anatolia (ŞAFAK *et al.*, 1999) and the lower Pannonian of Hungary (KOLLMANN, 1960). The majority of *Cyprideis* species live in brackish (meso-brachyhaline), euryhaline, mainly mesohaline (5-18‰) environ-

ments but also oligohaline and hyperhaline (GROSS, 2004, *inter alia*). GLIOZZI *et al.* (2007) consider *C. agrigenina* as a Lago-Mare species with Paratethysian affinity. Unlike *C. torosa*, *C. agrigenina* cannot be considered as a paleosalinometer for the MSC (GROSSI *et al.*, 2015).

***Cyprideis ex C. torosa* (JONES, 1850) group LIGIOS & GLIOZZI (2012)**

(Pl. 1, fig. 4)

1964 *Cyprideis torosa* (JONES); DECIMA, Pl. 11, figs. 3-8c; Pl. 12, figs. 1-8d; Pl. 15, figs. 11-15.

2002 *Cyprideis torosa* (JONES, 1850); WOUTERS, Pl. 3, figs. 1a-4d.

2005 *Cyprideis torosa* (JONES, 1850); MATZKE-KARASZ & WITT, Pl. 3, figs. 8-11.

2007 *Cyprideis torosa* (JONES, 1850); MEDLEY *et al.*, Pl. 1, fig. e.

2012 *Cyprideis torosa* (JONES, 1850); LUCENA-MOYA *et al.*, p. 6.

2011 *Cyprideis torosa*; FRENZEL *et al.*, p. 59.

2013 *Cyprideis torosa* (JONES, 1850); VALLS *et al.*, Fig 3, G-I.

2014 *Cyprideis torosa* (JONES, 1850); CHEKHOVSKAYA *et al.*, p. 213, Pl. 2, fig. 7.

2015 *Cyprideis torosa* (JONES, 1850); ALTINSAÇLI *et al.*, p. 379.

2015 *Cyprideis torosa* (JONES, 1850); SCHORNIKOV, Pl. 1, figs. 15-18.

2016 *Cyprideis torosa* (JONES, 1850); BEJAOUI *et al.*, Fig. 7, G-I.

2016 *Cyprideis torosa* (JONES); BAAK *et al.*, Figs. 4, 18.

2018 *Cyprideis ex C. torosa* (JONES, 1850) group; SCIUTO *et al.*, p. 11, Fig. 6.10-12

Remarks: Following LIGIOS and GLIOZZI (2012), who point to the remarkable similarity of *C. agrigenina*, *C. ruggierii*, *C. torosa*, and in part *C. crotonensis* and *C. calabra*, we included these species in a comprehensive informal "*C. torosa* group". WOUTERS (2016) also confirms that *Cyprideis torosa* JONES, 1850, is a single, highly variable, polymorphic, and widely distributed species, with locally different populations. This group includes euryhaline and eurythermal species that can live from freshwater to hypersaline water (sebkha) (ATHERSUCH *et al.*, 1989; BOOMER *et al.*, 1996; BEJAOUI *et al.*, 2016). It has been reported from western and southern Europe, i.e. the Mediterranean coasts, including the Mediterranean Isles, and from the Atlantic coasts of west and northwest Europe. The species is also known from North Africa (BEJAOUI *et al.*, 2016), Eurasia, central and southwest Asia, (Black Sea, Caspian Sea, Lake Aral, and Lake Issyk Kul), and China (WOUTERS, 2002). It was also found in hypersaline environment at Santa Pola, a coastal salt marsh of the western Mediterranean (MEZQUITA *et al.*, 2011), in brackish estuaries and lagoons of mainland Portugal (CABRAL *et al.*, 2016), and in coastal mesohaline lagoons in Turkey (ALTINSAÇLI *et al.*, 2015). Fossil specimens are reported from the Miocene to Recent (MEISCH, 2000).



Family LEPTOCYTHERIDAE HANAI, 1957
Subfamily Leptocytherinae HANAI, 1957
Genus *Leptocythere* SARS, 1925

Type species: *Cythere pellucida* BAIRD, 1850.

***Amnicythere propinqua* (LIVENTAL, 1929)**
 (Pl. 1, fig. 5)

1929 *Cythere propinqua* LIVENTAL, p. 20, Pl. 1, figs. 21-22.

1996 *Leptocythere cymbula* LIVENTAL, 1929; BOOMER *et al.*, p. 81, Fig. 4 A-H.

1999 *Leptocythere propinqua* LIVENTAL; GLIOZZI, p. 199, Pl. 1, fig. c.

2004 *Amnicythere cymbula* OLTEANU, p. 4.

2007 *Amnicythere propinqua* (LIVENTAL, 1929); GLIOZZI *et al.*, p. 331.

2008 *Amnicythere propinqua* (LIVENTAL, 1929); GLIOZZI & GROSSI, p. 290.

2008 *Amnicythere propinqua* (LIVENTAL, 1929); GROSSI & GENNARI, p. 77.

2014 *Amnicythere cymbula* (LIVENTAL, 1929), CHEKHOVSKAYA *et al.*, p. 213, Pl. 1, fig. 8.

2016 *Amnicythere propinqua* LIVENTAL; STOICA *et al.*, p. 859, Pl. 4, figs. 1-11.

2018 *Amnicythere propinqua* LIVENTAL; WILLIAMS *et al.*, p. 56, Fig. 12 (1).

Remarks: *A. propinqua* is typical of shallow and oligo mesohaline waters. It is reported from the Upper Miocene strata (Pontian) of the Taman Peninsula (Azov Sea) (STOICA *et al.*, 2016), from the Upper Pliocene and post Pliocene of the Caspian and Black Sea regions (BOOMER *et al.*, 1996), from the Upper Pleistocene and Holocene of the northern Caspian Sea, where it is commonly reported at depth of 2.5-10 m with salinity of 7-13.5‰ (CHEKHOVSKAYA *et al.*, 2014), and from the Holocene of the Black Sea, where it is considered to be part of the Ponto-Caspian (brackish) assemblages (WILLIAMS *et al.*, 2018).

In the Mediterranean region *A. propinqua* is reported from Lago-Mare events in the northern and central Apennines (GLIOZZI *et al.*, 2007; GLIOZZI & GROSSI, 2008; GROSSI & GENNARI, 2008), in the upper Messinian of Aléria Basin (Corsica) (CARBONNEL, 1978), and in the upper Messinian of the Moncucco quarry (Torino Hill) (TRENKWALDER *et al.*, 2008).

The genus *Amnicythere* is widespread in the Miocene in the Paratethysian with *Loxoconchissa*, *Loxocorniculina*, *Pontoniella*, and *Zalanyiella*. These taxa migrated to the Mediterranean domain during the Messinian Lago-Mare event (GROSSI & GENNARI, 2008), and *A. propinqua* is therefore indicated as Paratethysian (GLIOZZI *et al.*, 2005; GLIOZZI & GROSSI, 2008).

Subfamily Mediocytherideisinae
MANDELSTAM, 1960

Genus *Mediocytherideis*
MANDELSTAM, 1956

Type species: *Cytherideis apatoica* SCHWEYER, 1949, by original designation.

Mediocytherideis (Sylvestra) punctata
LIGIOS *et al.*, 2008

(Pl. 1, fig. 6)

2008 *Mediocytherideis (Sylvestra) punctata* LIGIOS *et al.*, p. 156, Pl. 4, figs. 1-10; Pl. 5, figs. 1,2.

2012 *Mediocytherideis (Sylvestra) punctata* LIGIOS *et al.*; LIGIOS *et al.*, p. 357

The reports of all the species belonging to the genus *Mediocytherideis* refer to brackish environments (LIGIOS *et al.*, 2008). The genus is reported from the Upper Miocene sediments of Lake Pannon, from where it spread, alongside other taxa, to Recent Caspian Sea (CZICZER *et al.*, 2009), and from the Upper Miocene of the Strymon Basin (northern Greece) (GROSSI *et al.*, 2015). *Mediocytherideis* is considered as a Paratethysian genus, while the species *M. punctata* is a Mediterranean species with Paratethysian affinity (GLIOZZI *et al.*, 2007; LIGIOS *et al.*, 2008).

5. Discussion and conclusion

The characters of the microfauna found along the two sections analysed in the present paper highlight that, during the late Messinian post-evaporitic phase, thin basins of tectonic origin formed above the evaporitic and pre-evaporitic substratum also in the North African region (ROUCHY *et al.*, 2001; ROUCHY & CARUSO, 2006; SCIUTO *et al.*, 2018, *inter alia*). These basins, which could at first be assimilated to open lagoons, were, at certain times of their evolution, isolated from the sea and colonized by brackish and even fresh-water species when river inputs prevailed (Lago-Mare fauna); in the absence of fluvial inputs, conditions of hypersalinity, like sebka, would have been established.

The shallow-water character of these basins is also indicated by the finding of charophyte gyrogonites, the best preserved of which are referable to *Chara hispida* LINNAEUS, 1753 (Pl. 1, fig. 15). *C. hispida* lives in oligotrophic, freshwater, shallow-lake environments, peatland, mud-calcareous gytzia (*i.e.*, floating islands); it can occasionally be found also in brackish waters. Therefore, it may be characterized as tolerant to salinity at depth from about 0.5 m to about 3.5 m (BARINOVA *et al.*, 2014, and references therein).



According to GLIOZZI *et al.* (2007) and LIGIOS *et al.* (2008), *Amnocythere propinqua*, *Cyprideis agrigentina*, and *Mediocytherideis punctata* can be considered as species with Paratethysian affinity.

The finding of species belonging to the genus *Miocyprideis* in the lower part of the SAL section, would indicate warm climatic conditions for this stratigraphic level. Indeed, Recent species of the genus *Miocyprideis* live only in warm tropical shallow waters of the Indo-Pacific region (MADDOCKS, 1995, *inter alia*) and in the Atlantic coasts (CARBONNEL, 1986). In the Recent Mediterranean the genus is not reported and its disappearance could be linked to Plio-Pleistocene cooling.

Finally, the discovery, both in Sicily and Tunisia, of *C. torosa*, suggests that the Sicilian Channel high played a modest role in preventing the migration of the non marine fauna from NE to SW in the paleomediterranean area during the Lago-Mare event (SCIUTO *et al.*, 2018; present paper).

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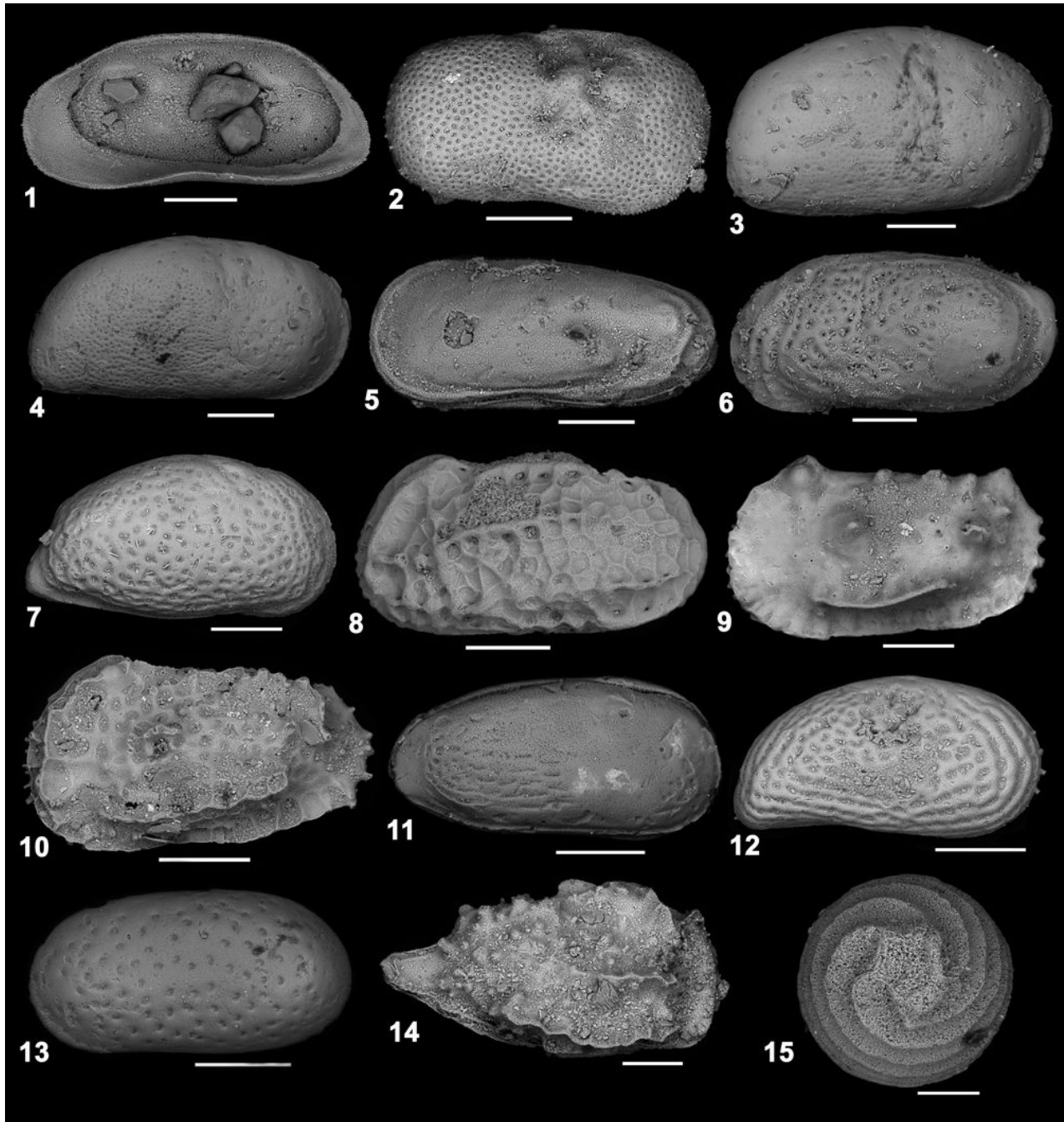


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Plate

**Plate 1:**

- fig. 1 - *Phlyctenophora farkasi* (ZALANYI, 1913). Right valve internal view (Scale bar 200 μ m);
fig. 2 - *Ilyocypris gibba* (RAMDOHR, 1808). Right valve, external view (Scale bar 200 μ m);
fig. 3 - *Cyprideis agrigentina* DECIMA, 1964. Right valve, external view (Scale bar 200 μ m);
fig. 4 - *Cyprideis* ex *C. torosa* (JONES, 1850) group LIGIOS & GLIOZZI (2012). Right valve, external view (Scale bar 200 μ m);
fig. 5 - *Amnicythere propinqua* (LIVENTAL, 1929). Left valve, external view (Scale bar 200 μ m);
fig. 6 - *Mediocytherideis punctata* LIGIOS *et al.*, 2008. Left Valve, external view (Scale bar 200 μ m);
fig. 7 - *Peteraurila musculus* ARUTA & RUGGIERI, 1980. Right valve, external view (Scale bar 200 μ m);
fig. 8 - *Chrysocythere* cf. *paradisus* DORUK, 1973. Left valve, external view (Scale bar 200 μ m);
fig. 9 - *Occlusacythereis* cf. *cultrata* RUGGIERI & RUSSO, 1980. Left valve, external view (Scale bar 200 μ m);
fig. 10 - *Okadaleberis* sp. 1. Left valve, external view (Scale bar 200 μ m);
fig. 11 - *Keijella loricata* BONADUCE *et al.*, 1992. Right valve, external view (Scale bar 200 μ m);
fig. 12 - *Cytheridea arca* BONADUCE *et al.*, 1992. Right valve, external view (Scale bar 200 μ m);
fig. 13 - *Miocyprideis polita* BONADUCE *et al.*, 1992. Left valve, external view (Scale bar 200 μ m);
fig. 14 - *Neomonoceratina* cf. *N. laskarevi* (KRSTIC & PIETRZENIUK, 1972). Right valve, external view (Scale bar 200 μ m);
fig. 15 - *Chara hispida* LINNAEUS, 1753 (Scale bar 100 μ m).