



Review article

Late Messinian ostracods from Eastern Tunisia

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ABSTRACT

Two stratigraphic sections referable to the late Messinian have been identified and studied in eastern Tunisia; the first, south of Cape Bon (Salakta-SAL section), the second in the Sahel region (Wadi el Kebir-OK section). The analysis of the ostracod fauna content (assemblages) has revealed that in some stratigraphic levels some taxa are certainly attributable to the Lago-Mare fauna, while other taxa, observed in subsequent or previous stratigraphic levels, are referable to true shallow-water marine environments. From these latter shallow water marine levels, several ostracods species were recognized; some of which, due to their morphological particularities, have been described as new species.

Consequently, in this article, 24 species belonging to the genera *Cytherella*, *Pajjenborchellina*, *Cimbourila*, *Pokornyella*, *Dorukella*, *Graptocythere*, *Capsocythere*, *Chrysocythere*, *Okadaleberis*, *Ruggieria*, *Cytheretta*, and *Neomonoceratina* are described and illustrated as new.

1. Introduction

The late Messinian deposits in Tunisia are little known. Whereas evaporitic deposits are only found offshore, outcrops of marine sediment (Beni Khiar and Oued El Bir Fm.) are rare and only known in eastern Tunisia: in the Cap Bon peninsula near Bizerte (Burolet, 1951; Colleuil, 1976; Ben Salem, 1998; Frigui et al., 2016; present paper) and in the Sahel region (Besème and Kamoun, 1988; Kamoun et al., 2001; Moissette et al., 2010; Frigui et al., 2016; present paper). They are usually squeezed between upper Tortonian coastal to continental deposits (Saouaf and Somaa formations) and lower Pliocene marine marls (Raf Raf Fm.). Also the Messinian calcareous microfauna is little known; the only detailed studies are those conducted by Bonaduce et al., 1992, which illustrates and describes the Upper Messinian ostracods recovered from the well Ashtart 1 in the Gulf of Gabes, and by Temani et al., 2018, 2019, which illustrates the ostracods referable to the Lago-Mare phase of the late Messinian. In the present work the analysis of the ostracod assemblages from two late Messinian sections outcropping in eastern Tunisia is presented. Previous studies allowed us to identify, in some stratigraphic levels of the same sections, ostracod assemblages referable to the Lago-Mare facies (Temani et al., 2019, 2018). In this paper, the marine ostracod assemblages, showing characteristics referable to shallow marine environments are analyzed.

The acquisition of these new data will allow us to improve and increase the knowledge of the late Messinian marine ostracod fauna of this area.

2. Materials and methods

2.1. Sampled sections

The marine ostracod assemblages studied in this article were recovered from two sections, outcropping in the eastern Tunisia (Figs. 1 and 2): the Wadi El Kebir section (OK) (36°30'07" N; 10°44'46"E) and the Salakta section (SAL) (35°24'18"N; 11°00'12" E). Both sections belong to the Oued El Bir Formation, referred to the late Messinian by several authors (Burolet, 1951; Colleuil, 1976; Ben Salem, 1998; Frigui et al., 2016).

In the SAL section, most of the detected ostracods species here described, were collected in the lowest 1,50 m of the outcrop within silty marls (Fig. 2). Above these basal levels are observed sediments containing Lago-Mare ostracod assemblages, i.e. from a semi-closed lagoonal environment with episodic freshwater influences (Temani et al., 2018, 2019). In the OK section (Fig. 2), four marine species were found along the eight meters of the outcrop in sands containing also dispersed Lago-Mare faunas (Temani et al., 2019).

2.2. Sampling protocol and species determination

A total 82 of samples were recovered from the SAL (31 samples) and OK (51 samples) sections.

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

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Fig. 1. Geographical location of the Salakta sampling station. (SAL) and Wadi el Kebir sampling station (OK) in Eastern Tunisia.

fraction of each sample, were picked and subjected to careful taxonomic examination. From the $>125\ \mu\text{m}$ fraction 0.2 g/sample was picked and then a quarter of the sample was analysed if necessary for foraminifers. Specimens were examined and measured under the LMU Tescan Vega II Scanning Electron Microscope (SEM) at the Electron Microscopy Laboratory of the Department of Biological, Geological and Environmental Science of the Catania University. Systematics of Ostracoda was based on Horne et al. (2001) and species identification profited from key papers on the Mediterranean area, among which Müller (1894); Puri et al. (1969) and Bonaduce et al. (1992)!

Specimens are deposited in the Paleontological and Sedimentological Laboratory of the Geological Survey of the National Office of Mines of Tunisia.

3. Results

3.1. Wadi El Kebir section (OK section)

In the OK section (Fig. 2) a total of 31 taxa of ostracods have been identified.

Based on their distribution along the stratigraphic sequence, the section was divided into three intervals: the lower part (samples 1–19) is characterized by few specimens of *Cyprideis torosa* (Jones, 1850),

Cyprideis agrigentina (Decima, 1964) and by specimens belonging to the genera *Cytheridea* and *Leptocythere*. Specimens belonging to the genera *Paracytheridea*, *Mutilus*, *Callistocythere*, *Aurila*, *Loxoconcha*, *Xestoleberis*, *Pontocypris*, *Cushmanidea*, *Polycoppe*, *Cluthia* and *Bairdia* are less widespread and less abundant.

In the middle part of the section (samples 20–29), the ostracod fauna occurring in the lower previous interval disappears, excepting for *C. torosa* and the genera *Aurila*, *Leptocythere* and *Cytheridea* that, however, show very low abundances, ranging from 1 to 3 species/sample. Rare benthic foraminifera as *Elphidium crispum* (Linnaeus, 1758) and *Ammonia beccarii* (Linnaeus, 1758) are also present.

In the uppermost final part of the section (samples 30–51), some ostracods show the highest abundances observed in this OK stratigraphic sequence, but species diversity is low. *C. torosa*, *Leptocythere* and *Cytheridea* are the most abundant taxa, followed by much less abundant species belonging to the genera *Pontocypris*, *Paracytheridea*, *Euxinocythere* and *Pontocythere*. Among foraminifera, *Elphidium crispum* and *Ammonia beccarii* are still found in the continuity of the previous interval.

3.2. Salakta section (SAL section)

A total of 53 taxa of ostracods have been identified in the SAL section (Fig. 2). This section has been subdivided into five intervals based on the ostracod distribution observed along the stratigraphic sequence.

In the first basal interval, a series of samples (1–8) is characterized by the presence of species belonging to the genus *Neomonoceratina* which are very abundant and widespread in all the samples; less widespread but sometimes with high abundance are the taxa *Acanthocythereis*, *Cytheridea*, *Oculusocythereis*, *Peteraurila*, *Kriithe*, *Cyamocythereidea*, *Cytherella*, *Aurila*, *Capsocythere*, *Xestoleberis*, *Chrysocythere*, *Loxoconcha*, *Leptocythere*, *Lixouria*, *Falunia*, *Tegmenia*, *Callistocythere*, *Urocythereis*, *Cytherella*, *Pontocypris*, *Cytherelloida*, *Keijella*, *Bairdia* and *Hiltermannicythere*. Foraminifera are abundant and well diversified. The most abundant and widespread are *E. crispum* and *A. beccarii*, as seen in the OK section also.

Upwards, from sample 9 to 17 (second interval), the section is characterized by an ostracod association consisting by widespread and abundant species of *Candona* and *Cyprideis* associated with *Phlyctenophora farkasi* (Zalanyi, 1913) and *I. gibba*; subordinated species are *Amnicythere propinqua* (Livental, 1929), *Mediocytherideis punctata* Ligios et al. 2008 and species belonging to the genera *Cytheroidea*, *Cypria*, *Loxoconcha*, *Caudites*, *Tenedocythere*, *Lepthocythere*, *Callistocythere*, and *Ilyocypris*. In some samples, these ostracods can be associated with rare *Neomonoceratina*, *Aurila*, *Peteraurila* and *Tegmenia siderea*. Foraminifera are rare and represented by very few specimens. In this group of samples were found charophyte gyrogonites, among which, the best preserved are referable to *Chara hispida* Linnaeus 1753 and *C. vulgaris* Linnaeus 1753.

No ostracods have been found in the overlying layers of the third interval (samples 18–21) and the microfauna is represented only by very few specimens of *E. crispum* and *A. beccarii* (not exceeding 4 specimens in total).

From sample 22 to 24 (fourth interval), ostracods are represented mainly by species belonging to the genera *Microcytherura*, *Cytherella*, *Cytheridea*, *Aurila* and *Neomonoceratina*, and less abundant species from the genera *Miocyprideis*, *Cytherella*, *Graptocythere*, and *Dokurella*. Among the foraminifera community, are encountered the planktonic species *Globigerinoides trilobus* and for the first time *Globorotalia crassaformis*. The occurrence (only 3 specimens) of *G. crassaformis* (FO 3.6 Ma) may refer these deposits to the Piacenzian (Lirer et al., 2019).

The last samples of the section (samples 25–31, fifth interval) are barren of calcareous microfossils.

From those sections, a total of 3316 valves of ostracods (2748 in the SAL Section and 568 in the OK Section) were encountered and allowed us to describe 84 species among which 24 were considered as new thanks to specific morphological criteria. The following section thus details the taxonomic investigations conducted for the present work.

3.3. Systematic Paleontology. (Sciuto F. & Temani R.)

A first series of taxa considered as news, belonging to the genera *Cytherella*, *Paijenborchellina*, *Cimbourila*, *Pokornyella*, *Dorukella*,

Graptocythere, *Capsacythere*, *Chrysocythere*, *Okadaleberis*, *Ruggieria*, *Cytheretta*, *Neomonoceratina*, are listed below, described and illustrated.

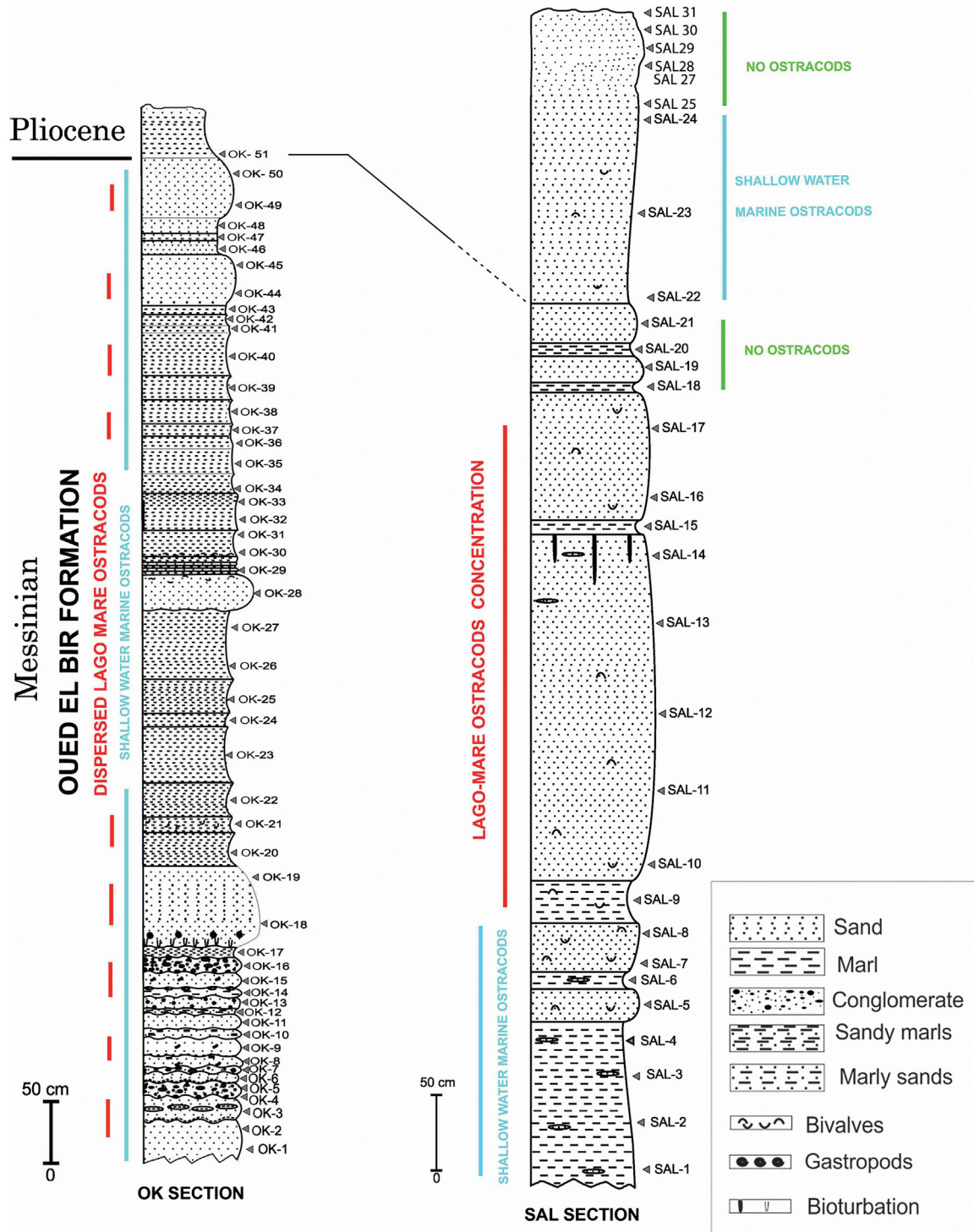


Fig. 2. Stratigraphic logs of OK section and SAL section and distribution of ostracod assemblages.

Class OSTRACODA Latreille, 1806
 Subclass PODOCOPA Sars, 1866
 Order PLATYCOPIDA Sars, 1866
 Superfamily CYTHERELLOIDEA Sars, 1866
 Family CYTHERELLIDAE Sars, 1866
 Genus *Cytherella* Jones, 1849
 Type species: *Cythere ovata* (Roemer, 1841)

Cytherella ilariae n. sp.
 (Fig. 3.1)

Etymology: The species is dedicated to Ilaria Mazzini, micropalaeontologist (CNR, Roma)

Material: six valves

Holotype: One right valve, collection number PMC O 30 H 03/12/2019.
Paratypes: two right valves and one left valve. PMC O 86-88 P 03/12/2019

Type locality: The Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: *Cytherella ilariae* n. sp. is characterized by very large foveolae spaced from each other distributed over the whole carapace except ventrally and dorsally.

Description: Large and strong carapace with shape typical of the genus. Ornamentation constituted by very large roundish foveolae, little engraved, spaced from each other and distributed over the whole carapace except ventrally and dorsally. In the posterior half of the carapace the foveolae are arranged concentrically and increase in density at the end; vice versa, in the anterior half, the foveolae are arranged parallel to the anterior margin. Other features are typical of the genus.
Remarks: *Cytherella ilariae* n. sp. is distinguished from other species of the genus because of the distribution of foveolae; some similarity exists with *Cytherella fovea* Barra and Bonaduce, 2001 but the two species are distinguishable for the density and distribution of foveolae.

Order PODOCOPIDA Müller, 1894
 Suborder PODOCOPA Sars, 1866
 Superfamily CYTHEROIDEA Baird, 1850
 Family CYTHERIDAE Baird, 1850
 Genus *Paijenborchellina* Kuznetsova, 1957
 Type species *Paijenborchellina excelens* Kuznetsova, 1957.

Paijenborchellina reitanoi n. sp.
 (Fig. 3.2)

Etymology: The species is dedicated to Agatino Reitano naturalist (Comiso Natural History Museum).

Material: Two complete carapace.

Holotype: One complete carapace, collection number PMC O 31 H 03/12/2019.

Paratypes: One complete carapace, collection number PMC O 89 P 03/12/2019

Type locality: The Wadi El Kebir (OK) sampling station outcrops in the eastern side of the Wadi El Kebir dam, in the Nabeul region south eastern part of the Cape Bon Peninsula (36°30'07" N 10°44'46"E).

Type horizon: late Messinian.

Diagnosis: Species characterized by simplex elongated wedge shaped carapace.

Description: Carapace elongated, wedge shaped; anterior margin rounded, ventral margin convex, dorsal margin convex with a slight concavity in the middle, posterior margin arranged to form an acute angle. Carapace mostly smooth in the central area with some minute wrinkles in the posteroventral area. Norman pore canals regularly distributed on the carapace surface. Internal features typical of the genus.

Remarks: The new species is similar to "*Paijenborchellina*" *libyca* Szczechura, 1980 from the Upper Miocene of Lybia but it is

distinguishable from it because of the presence of the wrinkles and the delicate normal pore canals distributed over the entire surface of the carapace.

Family HEMICYTHERIDAE Puri, 1953
 Genus *Cimbaurila* Ruggieri, 1975
 Type species *Cimbaurila cimbaeformis* (Seguenza, 1883)

Cimbaurila maamourii n. sp.
 (Fig. 3.3)

Etymology: The species is dedicated to Annie Luise Maamuri, micropalaeontologist de l'ONM

Material: 13 valves.

Holotype: One right valve, collection number PMC O 32 H 03/12/2019.
Paratypes: two left valves and two right valves. PMC O 90-93 P 03/12/2019

Type locality: The Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Sub trapezoidal carapace typical of the genus *Cimbaurila* with two large protruding ears-shaped foveolae in posterodorsal and posteroventral position.

Description: Sub trapezoidal strong carapace that shows, in lateral view, the dorsal margin subparallel to the ventral margin, the anterior margin rounded, the posterior margin with a small obtuse caudal process slightly protruding in central position. Ornamentation consisting of strong ribs that intersect, bordering large and engraved polygonal foveolae. The foveolae are arranged in three concentric rows along the anterior margin of the carapace, while in the central part, they are arranged V-shape open towards the rear. In the central posterior area, the foveolae are arranged in an arc within the V. Two large ear shaped foveolae protruding beyond the edges, are present in posteroventral and in posterodorsal position. Internal structures typical of the genus.

Remarks: The new species shows some affinities with *Cimbaurila latisolea* Ruggieri, 1975 from which it is distinguished because of the presence of the little ears.

Genus *Urocythere* Howe, 1951.
 Subgenus *Pokornyella* Oertli, 1956
 Type species *Urocythere (Pokornyella) limbata* (Bosquet, 1852)

Urocythere (Pokornyella) salaktaensis n. sp.
 (Fig. 3.4)

Etymology: From the name of the village of Salakta near the type locality.

Material: three carapace and one valve.

Holotype: One complete carapace, collection number PMC O 33 H 03/12/2019.

Paratypes: one complete carapace PMC O 94 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Specie of the Genus *Pokornyella* Oertli, 1956 characterized by a polygonal grid arranged concentrically in the back half, stretched anteroposteriorly in the anterior half.

Description: Carapace subtrapezoidal in external view with dorsal margin inclined towards the back side, ventral margin slightly sinuous, anterior margin rounded and short posterior margin with a little prominent caudal process in posteroventral position. The ornamentation consists by intersecting ribs which delimit polygonal foveolae distributed over the whole carapace, outside larger than inside. The outer foveolae follow the outer margin of the carapace; the internal ones give rise to a geometric grid, almost concentric in the back half, stretched anteroposteriorly in the in the anterior half. A thin acute ridge follows the anterior and dorsal margin, then descends vertically to delimit the posterior marginal area. Eye spot well evident. Other characters are typical of the genus.

Remarks: *P. salaktaensis* n. sp. is distinguishable from *P. italica* Ruggieri



Fig. 3. New ostracods species from Eastern Tunisia (Scale bar 200 μ m). **3.1**, *Cytherella ilariae* n. sp. (right valve) from Salakta. **3.2**, *Paijenborchellina reitanoi* n. sp. (entire carapace) from Salakta. **3.3**, *Cimbourila maamouri* n. sp. (right valve) from Salakta. **3.4**, *Urocythere (Pokornyyella) salaktaensis* n. sp. (right valve) from Salakta. **3.5**, *Dorukella crasquinae* n. sp. (right valve) from Salakta. **3.6**, *Dorukella nevioi* n. sp. (left valve) from Salakta. **3.7**, *Dorukella razgallahae* n. sp. (right valve) from Salakta. **3.8**, *Dorukella ruggeroi* n. sp. (left valve) from Salakta. **3.9**, *Graptocythere octopus* n. sp. (right valve) from Salakta. **3.10**, *Capsacythere baldanzae* n. sp. (right valve) from Salakta. **3.11**, *Capsacythere fekihi* n. sp. (right valve) from Salakta. **3.12**, *Capsacythere giovanna* n. sp. (left valve) from Salakta. **3.13**, *Capsacythere salaji* n. sp. (left valve) from Salakta. **3.14**, *Chrysocythere glozziae* n. sp. (right valve) from Salakta. **3.15**, *Chrysocythere russoi* n. sp. (right valve) from Wadi El Kebir (OK). **3.16**, *Chrysocythere arutai* n. sp. (right valve) from Wadi El Kebir (OK). **3.17**, *Okadaleberis decimai* n. sp. (left valve) from Salakta. **3.18**, *Okadaleberis memmiae* n. sp. (left valve) from Salakta.

et al., 1977 and from *P. devians* Bonaduce et al., 1985 because of the different shape and distribution of the foveolae and for the different external shape of the carapace.

Genus *Dorukella* Ruggieri, 1984
 Type species *Orionina bireticulata* DORUK, 1974

Dorukella crasquinae n. sp.
 (Fig. 3.5)

Etymology: The species is dedicated to Sylvie Crasquin micropalaeontologist (Centre de Recherche en paléontologie-Paris).
 Material: five valves

Holotype: One right valve, collection number PMC O 34 H 03/12/2019.
Paratypes: One left valve, PMC O 95 P 03/12/2019
Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.
Type horizon: late Messinian.

Diagnosis: Species of the genus *Dorukella* Ruggieri, 1984 characterized by a central convex ridge which forms an open quadrilateral in the low part of the posterior half of the carapace.

Description: *Dorukella crasquinae* n. sp. is characterized by an arcuate carapace, bean shaped, with a well rounded anterior margin which joins continuously the dorsal margin also rounded; posterior margin obtuse, little prominent, curved in the center and straight at the upper and lower extremities. Convex ventral margin. Ornamentation consisting of strong convex antero-postero ribs located in the dorsal area, that curve ventrally. A subcentral rib, anteroposterior directed, goes down curving towards the posteroventral area, thus delimiting the posterior marginal area; after it curves again, at a right angle, towards the anterior margin and stops at the middle of the ventral margin. This arrangement generates a quadrilateral open forwards. A curved rib marks the anterior margin area of the carapace. The marginal posterior area is thin and smooth. Internal structures typical of the genus.

Remarks: The new species shows characters of the ornamentation of the carapace that allow to distinguish it from all others. In particular, the trend of the dorsal and central ribs.

Dorukella nevioi n. sp.
(Fig. 3.6)

Etymology: This species is dedicated to Nevio Pugliese micropalaeontologist (University of Trieste).

Material: four valves.

Holotype: One left valve, collection number PMC O 35 H 03/12/2019.
Paratypes: two right valves PMC O 96, 97 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.
Type horizon: late Messinian.

Diagnosis: Species of the Genus *Dorukella* Ruggieri, 1984 characterized by polygonal ornamentation arranged mostly anteroposteriorly.

Description: Carapace stretched, sub trapezoidal with anterior margin strongly rounded, dorsal margin slightly sinuous like the ventral margin; posterior margin tilted shortly outwards originating in the posteroventral zone a prominent and slightly obtuse caudal process. Narrows marginal areas. A sharp crest follows the anterior, posterior and ventral margin; this crest delimits, anteriorly and posteriorly, the marginal areas flat but crossed by thin ribs. The ornamentation is constituted by thin ribs that intersect, originating foveolae elongated and arranged mostly in anteroposterior direction. Two rows of foveolae are arranged almost parallel to the anterior margin. At the height of the posterior terminal area the ornamentation is abruptly interrupted by a vertical rib.

Remarks: The new species resemble to *Dorukella bella* Bonaduce et al. (1992) however the two species differ for the different arrangement of the foveolae.

Dorukella razgallahae n. sp.
(Fig. 3.7)

Etymology: This species is dedicated to Saloua Razgallah, micropalaeontologist of the Sciences Faculty of Tunis.

Material: 4 valves

Holotype: One right valve, collection number PMC O 36 H 03/12/2019.
Paratypes: one right valve, PMC O 98 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.
Type horizon: late Messinian.

Diagnosis: Carapace stretched and arched with acute posterior end.

Description: Carapace stretched and arched with anterior margin strongly rounded and slightly bending downward, dorsal margin slightly sinuous

like the ventral margin; posterior margin strongly inclined with acute and prominent caudal process. Ornamentation consisting of ribs that intertwine to form a grid of foveolae with a radial arrangement in the anterior half of the carapace and elongated anteroposteriorly in the posterior half. Anterior marginal area flat and wide, strengthened by seven radial ribs. Posterior marginal area flattened and almost smooth. Internal structures typical of the genus.

Remarks: *D. razgallahae* n. sp. is very similar to *D. bella* Russo et al., 1984 however the two species differ in a different arrangement and dimension of the foveolae.

Dorukella ruggeroi n. sp.
(Fig. 3.8)

Etymology: This species is dedicated to Ruggero Sciuto literatus (Oxford University) son of the first author.

Material: six valves.

Holotype: One left valve, collection number PMC O 37 H 03/12/2019.

Paratypes: one left valve, PMC O 99 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E), Tunisia.

Type horizon: late Messinian

Diagnosis: Carapace with geometrical ornamentation markedly truncated in the posterior area.

Description: Carapace shape typical of the genus with anterior margin rounded, dorsal and ventral margin curved, posterior end triangular and obtuse. Ornamentation consisting of ridges that intersect, creating a polygonal mesh of foveolae. Three lines of foveolae start at the mid-dorsal margin and curve towards the anterior margin, following it, and then breaking off at the level of the oral convexity. In the posterior area of the carapace, the foveolae are delimited by an external rib that follows the profile of the carapace dorsally and ventrally, while, posteriorly, it goes down subvertically from the posterodorsal angle to the posteroventral angle, thus delimiting the posterior marginal area, flat and covered with thin ribs. Internal structures as those of the genus.

Remarks: The new species differs from congeners due to the different ornamentation.

Genus *Graptocythere* Ruggieri, 1972.
Type species *Cythere H-scripta* Capeder, 1900.

Graptocythere octopus n. sp.
(Fig. 3.9)

Etymology: From the Latin octopus = piovra

Material: 15 valves.

Holotype: One right valve, collection number PMC O 38 H 03/12/2019.
Paratypes: two left valves, PMC O 100-101 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: A species of the genus *Graptocythere* Ruggieri, 1972 that is characterized by ridges which form a complex ornamentation, octopus's tentacles shaped.

Description: *Graptocythere octopus* n. sp. shows the typical features of the genus described by Ruggieri, 1972. Strong carapace with well rounded anterior margin, dorsal margin slightly convex, posterior end disposed at an obtuse angle with a small and slightly protruding caudal process in posteroventral position, ventral margin undulate. The character which distinguishes it from the other species is the trend of the strong ribs which radiate from the centre of the carapace and form the design of the tentacles of an octopus. The lowest of the tentacles follows the ventral margin, it goes up along the posterior margin, delimiting the outer marginal area and, then, reaching the middle of the dorsal margin. An acute crest starts in the middle of the ventral margin, runs along the entire anterior margin and stops in the middle of the dorsal margin.

Remarks: The octopus's tentacles shaped ornamentation pattern on the carapace, makes the species easily distinguishable from the others.

Family TRACHYLEBERIDIDAE [Sylvester-Bradley, 1948](#)
Genus *Capsacythere* [Bonaduce et al., 1988](#)
Type species *Falunia sicula* [Aruta, 1966](#)

Capsacythere baldanzae n. sp.
(Fig. 3.10)

1992 *Capsacythere sicula* ([Aruta, 1966](#)); [Bonaduce et al., p. 49. Pl. 14, Fig. 1.](#)

Eymology: This species is dedicated to Angela Baldanza, micropalaeontologist (University of Perugia).

Material: three valves.

Holotype: One right valve, collection number PMC O 39 H 03/12/2019.

Paratypes: One left valve, PMC O 102 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Species of the genus *Capsacythere* characterized by a wide-polygons ornamentation.

Description: Elongate, subrectangular carapace with anterior margin rounded, dorsal margin straight, ventral margin slightly convex, postero-dorsal margin straight and strongly inclined outwards, posteroventral margin rounded, posterior end strongly obtuse. Ornamentation consisting of a mesh of large foveolae covering the entire carapace; anterior marginal area narrow and flat. The anterior and posteroventral borders bear some spines. Eye spot little marked.

Remarks: The genus *Capsacythere* is known in the Late Miocene of Sicily ([Aruta, 1966](#)), Malta ([Russo and Bossio, 1976](#)), Gulf of Gabes ([Bonaduce et al., 1988, 1992](#)), in the Messinian of Spain ([Conesa and Babinot, 1999](#)), Lampedusa ([Dall'Antonia and Bossio, 2001](#)) and in the Messinian of Tunisia (present paper). The specimen figured in [Bonaduce et al., 1992](#) differs from *C. sicula* ([Aruta, 1966](#)) because of the different distribution of the foveolae in the external surface of the carapace.

Capsacythere fekihi n. sp.
(Fig. 3.11)

1992 *Capsacythere sicula* ([Aruta, 1966](#)); [Bonaduce et al., p. 49. Pl. 14, Fig. 2.](#)

Eymology: The species is dedicated to Mouhamed Fekih, paléontologist of the Sciences Faculty of Tunis.

Material: four valves.

Holotype: One right valve, collection number PMC O 40 H 03/12/2019

Paratypes: One left valve, collection number PMC O 103 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Species of the genus *Capsacythere* characterized by a smoothed carapace.

Description: Subtrapezoidal carapace with arched anterior margin, undulated dorsal margin, straight ventral margin, posterior margin arranged to form an obtuse angle without caudal process. In the right valve, some marginal denticles are present in postero-ventral margin. The external surface of the carapace is smooth with broad slightly etched depressions. Marginal pores canals are present in the anteroventral margin. Simplex normal pore canals well-spaced between them and regularly distributed along the external surface of the carapace. Internal feature as those of the genus.

Remarks: The specimen figured in [Bonaduce et al., 1992](#) (p. 49. Pl. 14, Fig. 2), collected from the Gulf of Gabes, is indicated as *Capsacythere sicula* ([Aruta, 1966](#)); however, in our opinion, the figured specimen described by [Aruta \(1966\)](#) shows characteristics that approach it to the new species rather than to that of the Gulf of Gabes.

Capsacythere giovanna n. sp.
(Fig. 3.12)

Eymology: The species is dedicated in memory of Giovanna Lo Cicero, geologist at the University of Palermo.

Material: Two valves.

Holotype: One left valve, collection number PMC O 49 H 03/12/2019.

Paratypes: One right valve, collection number PMC O 104 P 03/12/2019

Type locality: Salakta sampling station(SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Species of the genus *Capsacythere* [Bonaduce et al., 1988](#) characterized by a concentric arrangement of the polygons in the middle posterior area of the carapace.

Description: Elongated subrectangular carapace with anterior margin well rounded. Ventral margin subparallel to the dorsal margin, posterior margin arranged to form an obtuse angle. Ornamentation of the carapace consisting of a polygonal grip which has a concentric distribution in the posterior part of the carapace, while in the anterior part, the meridians of the grid radiate from the eye spot. Some foveolae, especially anteriorly, are tegminated. Spines and tubercles are present along the anterior, posteroventral and postero-dorsal margins.

Remarks: *Capsacythere giovanna* is distinguishable from the other species of the genus described by [Bonaduce et al., 1988](#) because of the different arrangement of the polygonal grip and the absence of carenae along the carapace.

Capsacythere salaji n. sp.
(Fig. 3.13)

Eymology: The species is dedicated to Joseph Salaj, micropaleontologist of the ONM.

Material: Two entire carapaces.

Holotype: One entire carapace, collection number PMC O 50 H 03/12/2019.

Paratypes: One entire carapace, collection number PMC O 105 P 03/12/2019

Type locality: Salakta sampling station(SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Species of the genus *Capsacythere* [Bonaduce et al., 1988](#) characterized by polygonal tegminate foveolae arranged concentrically.

Description: Carapace sub rectangular, anterior margin rounded, ventral and dorsal margin slightly undulate, posterior margin obtuse, angle shaped. Ornamentation consisting of a reticulation of tegminate foveolae concentrically arranged from the centre of the carapace that covered the entire surface of the carapace. Spines along the anterior margin and tubercles along the posterior and dorsal margin are present.

Remarks: The new species is here referred to the genus *Capsacythere* [Bonaduce et al., 1988](#) despite a good resemblance to *Tegmenia siderea* [Bonaduce et al., 1992](#) and *Tegmenia tegminata* [Bonaduce et al., 1992](#); but in the diagnosis of the new genus *Tegmenia*, [Bonaduce et al., 1988](#) state that the principal ornamentation is constituted by "three ridges antero-posterior"; these ridges are missing in the genus *Capsacythere*, therefore, it is probable that also the species *T. siderea* and *T. tegminata*, which do not have three ridges, must be ascribed to the genus *Capsacythere*.

Genus *Chrysocythere* [Ruggieri, 1962](#)
Type species *Chrysocythere cataphracta* [Ruggieri, 1962](#)

Chrysocythere gliozziae n. sp.
(Fig. 3.14)

Eymology: The species is dedicated to Elsa Gliozzi, Ostracodologist at Roma 3 University.

Material: two valves.

Holotype: One right valve, collection number PMC O 41 H 03/12/2019

Paratypes: One left valve PMC O 106 P 03/12/2019.

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Species belonging to the Genus *Chrysocythere* Ruggieri, 1962, characterised by stretched carapace.

Description: Stretched trapezoidal carapace with dorsal and ventral margin subparallel, anterior margin rounded and asymmetric: the anterodorsal margin more developed than the anteroventral margin. Similarly, the posterior margin is arranged in two asymmetrical rectilinear parts that meet at a very obtuse angle. No caudal processes. Ornamentation consisting of a strong convex and acute carena stretched, in median position, antero-posteriorly; a second carena stretches in ventral position from the posteroventral angle to over half of the ventral margin; here, curves upwards and bends again antero-posteriorly again and continues along the carapace perimeter except the denticulate part of the posterior margin. Transversal to the carenae there are large and spaced muri. Spines are present in the anterior margin and in the low part of the posterior margin. Eyes spots marked.

Remarks: The genus is known in the Tortonian of Enna (Ruggieri, 1962), Sahelian of Sicily (Aruta, 1982), Late Miocene of the Gulf of Gabes (Bonaduce et al., 1992), Messinian of Tunisia (present paper). In the modern ocean, it is known on the continental shelf of west Africa (Congo and Senegal) (Bertholon and Carbonel, 1995; Bertholon, 1997). The new species, while showing some affinity with *C. lignea* Bonaduce et al., 1992, it's easily distinguishable from it for the elongated carapace and the long and steep posterodorsal margin.

Chrysocythere russoi n. sp.
(Fig. 3.15)

Etymology: The species is dedicated to Antonio Russo, ostracodologist at the University of Modena.

Material: Six valves

Holotype: One entire carapace, collection number PMC O 42 H 03/12/2019

Paratypes: Two left valves PMC O 107, 108 P 03/12/2019

Type locality: The Wadi El Kebir (OK) sampling station outcrops in the eastern side of the Wadi El Kebir dam, in the Nabeul region south eastern part of the Cape Bon Peninsula (36°30'07" N 10°44'46"E).

Type horizon: Late Messinian.

Diagnosis: Squat and strong carapace with strong carenae and muri.

Description: Squat and strong carapace with dorsal margin slightly convex, ventral margin slightly undulate; ventral and dorsal margin sub parallel, anterior margin rounded, posterior margin first sinuous then straight. Ornamentation consisting of three strong and protruding carenae: the first, convex, in median dorsal position, the second, straight, in median ventral position and the third that follows the carapace perimeter. Transversal strong, but less protruding, secondary ribs form with the firstonesrectangular polygons developed in dorsoventral direction. Spines are along the anterior margin and along the low part of the posterior margin. Eyes spots well marked.

Remarks: The new species, despite some affinity relating to the robust appearance of the carapace, differs from the others belonging to the same genus due to the different distribution and trend of the ridges and in particular to the trend of the central ridge and those near the eye-tubercle. Therefore it differs from *C. cataphracta* Ruggieri, 1962, from *C. lignea* Bonaduce et al., 1992, *C. paradisi*, Doruk, 1973, *C. ornata*, Hartmann, 1974.

Chrysocythere arutai n. sp.
(Fig. 3.16)

Etymology: The species is dedicated to Luigi Aruta, ostracodologist.

Material: four valves

Holotype: One right valve, collection number PMC O 43 H 03/12/2019

Paratypes: One left valve PMC O 109 P 03/12/2019.

Type Locality: The Wadi El Kebir (OK) sampling station outcrops in the eastern side of the Wadi El Kebir dam, in the Nabeul region south eastern part of the Cape Bon Peninsula (36°30'07" N 10°44'46"E).

Type horizon: late Messinian.

Diagnosis: Species of the genus *Chrysocythere* characterized by a general and slight concave shape of the carapace.

Description: Strong elongated carapace with anterior margin rounded, dorsal margin straight, ventral margin slightly concave which extends continuously in the posteroventral margin; posterior margin arranged to form a slight obtuse angle. Ornamentation consisting of three acute carene stretched anteroposteriorly in dorsal, median and ventral area. Between the carenae there are muri which, intersecting, form a polygonal grid of large and deep foveolae. Anterior and posteroventral margin denticulate. Eye spot not very marked.

Remarks: *Chrysocythere arutai* n. sp. differs from congeners due to the different ornamentation.

Genus *Okadaleberis* Bonaduce et al., 1992
Type species *Okadaleberis aspera* Bonaduce et al., 1992

Okadaleberis decimai n. sp.
(Fig. 3.17)

Etymology: The species is dedicated to Arvedo Decima, geologist and ostracodologist.

Material: Five valves

Holotype: One complete carapace, collection number PMC O 44 H 03/12/2019

Paratypes: One left valve PMC O 110 P 03/12/2019.

Type Locality: Salakta sampling station(SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Species of the genus *Okadaleberis* Bonaduce et al., 1992 characterized by elongate carapace with three carenae.

Description: Carapace elongated with anterior margin well rounded, ventral margin slightly convex which continues curving towards the posteroventral margin, that is straight. This latter engages the posterodorsal margin, which is straight, with an obtuse angle. Ornamentation consisting of three carenae in dorsal, median and medioventral area; the first one parallel to the dorsal margin, the second and the third slanting towards the anteroventral margin. The medioventral carena extends along all the anterior margin following it. Anteroventral margin denticulate, posteroventral margin with two spines. Eye spot slightly raised.

Remarks: *Okadaleberis decimai* n. sp. is distinguishable from *O. rosaliae* Bonaduce et al., 1992 because of the more elongated carapace, the denticulation on anterior margin and spines on posteroventral margin.

Okadaleberis memmiae n. sp.
(Fig. 3.18)

Etymology: The species is dedicated to Lucia Memmi, Italian palaeontologist at the ONM.

Material: Three valves.

Holotype: One left valve, collection number PMC O 45 H 03/12/2019.

Paratypes: One right valve, PMC O 111 P 03/12/2019

Type Locality: Salakta sampling station(SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Subtriangular carapace with only one carena in middle ventral-position, slanting towards the anteroventral margin.

Description: Subtriangular carapace with anterior margin rounded, dorsal margin straight, ventral margin concave, posterior margin arranged to form an obtuse angle. Ornamentation consisting of two carenae, the first in middle ventral-position, slanting towards the anteroventral margin, the second follows irregularly the anterior margin. Foveolae of various sizes, poorly engraved, cover the surface of the carapace. Spines are present on anterior margin, tubercles on posterior

and postero-dorsal margin. Postero-ventral marginal area flat and marked by several thin ribs. Eye spot slightly raised.

Remarks: *Okadaleberis memmiae* n. sp. is similar to *Okadaleberis aspera* Bonaduce et al., 1992, but is distinguishable by the different position of the carena, because of the different distribution of tubercles and by the presence of foveolae.

Okadaleberis guerneti n. sp.
(Fig. 4.1)

Etymology: The species is dedicated to Claude Guernet, ostracodologist at Sorbonne Université, Paris

Material: Two complete carapace and five valves.

Holotype: One complete carapace, collection number PMCO 46 H 03/12/2019.

Paratypes: One complete carapace PMC O 112 P 03/12/2019.

Type Locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Subtrapezoidal carapace with only one carena in ventral position.

Description: Subtrapezoidal carapace with anterior margin regularly arched, dorsal margin almost straight, ventral margin slightly convex, posterior margin arranged to form an obtuse angle. Ornamentation consisting of one acute carena in ventral position and tubercles distributed on the carapace surface and at the posteroventral end. Marginal anterior and postero-ventral area flat and engraved with wide and barely noticeable grooves. Eye spot slightly raised.

Remarks: The new species is easily distinguishable from the others due to the presence of a single carena.

Okadaleberis hendae n. sp.
(Fig. 4.2)

Etymology: The species is dedicated to Hend Rihai, the young daughter of the second author.

Material: One complete carapace and three valves.

Holotype: One complete carapace, collection number PMCO 47 H 03/12/2019.

Paratypes: One left valve PMC O 113 P 03/12/2019

Type Locality: The Wadi El Kebir (OK) sampling station outcrops at the eastern side of the Wadi El Kebir dam, in the Nabeul region south eastern part of the Cape Bon Peninsula (36°30'07" N 10°44'46"E).

Type horizon: late Messinian.

Diagnosis: *Okadaleberis hendae* n. sp. is characterized by a strong carena that, starting from the postero-ventral area, it extends along the entire

ventral margin, goes up along the entire anterior margin and stops at the eye spot.

Description: Subtrapezoidal carapace with anterior margin rounded, dorsal margin straight, ventral margin slightly concave, posterior margin arranged to form an obtuse angle. Carapace almost completely smooth; ornamentation consists of a strong and prominent carena that, starting from the postero-ventral area, it extends along the entire ventral margin, then goes up along the anterior margin and stops at the eye spot; a second short carena, less prominent, is in central position. Some tubercles are present on the posterodorsal and posterior margin and between the two carenae. Anterior and posteroventral marginal areas very narrow. Eye spot prominent upwards.

Remarks: The new species resembles *Okadaleberis aspera* Bonaduce et al., 1992, but it differs from it by the different conformation of the posterior margin. Furthermore, it differs from the other Messinian species of the Gulf of Gabes illustrated by Bonaduce et al. (1992), due to the different position of the central carena.

Okadaleberis khayatii n. sp.
(Fig. 4.3)

Etymology: The species is dedicated to Hayet Khayati micropaleontologist of the ONM.

Material: One complete carapace and one valve.

Holotype: One complete carapace, collection number PMCO 48 H 03/12/2019.

Paratypes: One right valve PMC O 114 P 03/12/2019.

Type Locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Carapace elongated subtriangular with three short carenae. Description: Carapace elongated subtriangular; anterior margin well rounded, ventral and dorsal margin undulate, posterior margin disposed at an obtuse angle. Ornamentation constituted by a long main carena and two secondary short carenae. The first one starts over the middle of the ventral margin, rises along the anterior margin, then continues along the dorsal margin up to its half. The second ones are located in central and dorsal position. The central part of the carapace is ornamented by a polygonal grid; tubercles are present in the posterior area of the carapace. Eye spot marked.

Remarks: *Okadaleberis khayatii* n. sp. is distinguishable from the other species of the genus described by Bonaduce et al., 1992 because of the presence of the polygonal grid.

Okadaleberis (?) benzartiae n. sp.
(Fig. 4.4)

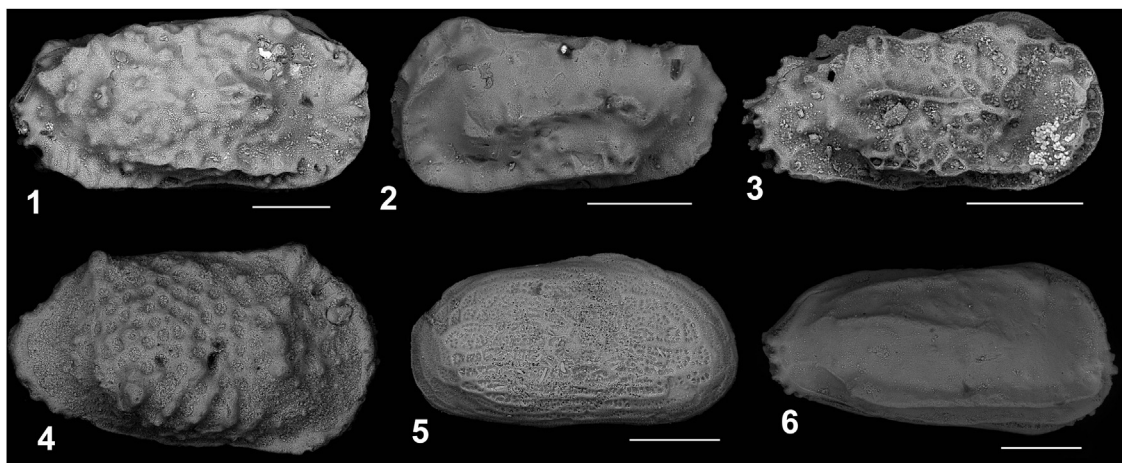


Fig. 4. New ostracods species from Eastern Tunisia (Scale bar 200 μ m). 4.1, *Okadaleberis guerneti* n. sp. (right valve) from Salakta. 4.2, *Okadaleberis hendae* n. sp. (left valve) from Wadi El Kebir (OK). 4.3, *Okadaleberis khayatii* n. sp. (right valve) from Salakta. 4.4, *Okadaleberis (?) benzartiae* n. sp. (right valve) from Salakta. 4.5, *Cytheretta mariaantoniettae* n. sp. (right valve) from Salakta. 4.6, *Ruggieria quadricarinata* n. sp. (right valve) from Wadi El Kebir (OK).

Etymology: The species is dedicated to Rakia Benzarti, micropaleontologist (retired) at the Société de Recherches et d'Exploitation des Pétroles en Tunisie.

Material: Five valves.

Holotype: One right valve, collection number PMC O 49 H 03/12/2019.

Paratypes: One left valve PMC O 115 P 03/12/2019

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: late Messinian.

Diagnosis: Species doubtfully attributed to the genus *Okadaleberis Bonaduce et al., 1992*, characterized by large ribs arranged radially.

Description: Strong subtrapezoidal carapace with anterior margin rounded, dorsal margin straight, ventral margin slightly curved, which continues without interruption towards the posteroventral margin, posterodorsal margin slightly concave. The junction point between the dorsal and posterodorsal margins is marked by a large tubercle. In dorsal view the carapace is strongly inflated in the central part, while the anterior and posterior marginal area are flattened and wide. Ornamentation consisting of large ribs that extend radially, some from the big tubercle on the postero-dorsal position, other from the middle of the carapace. The crossing between these two sets of ribs determines the formation of foveolae. Eye spot prominent.

Remark: the new species shows some affinities especially at the level of the external contour of the carapace with *Pterygocythereis* sp. 1 *Bonaduce et al., 1992*, but it differs for a greater thickness of the ribs and for the presence of the large postero-dorsal tubercle.

Family CYTHERETTIDAE *Triebel, 1952*

Genus *Cytheretta Müller, 1894*

Type species *Cytheretta rubra Müller, 1894*

Cytheretta mariaantoniettae n. sp.

(Fig. 4.5)

Etymology: This species is dedicated to Maria Antonietta Rosso palaeontologist at University of Catania.

Material: two valves.

Holotype: One right valve, collection number PMC O 52 H 03/12/2019.

Paratypes: One right valve PMC O 116 P 03/12/2019.

Type locality: Salakta sampling station (SAL) located about 3 km Northward Salakta village (35°24'18"N 11°00'12" E) Tunisia.

Type horizon: Late Messinian.

Diagnosis: Species of the genus *Cytheretta Müller, 1894* characterized by complex ornamentation consisting of branched costae and foveolae.

Description: Bean-shaped carapace with anterior margin rounded, ventral and dorsal margins slightly undulated, posterior margin slightly rounded. Ornamentation consisting of delicate ribs; branched in the posterior and ventral area, arranged in festoons in the anterior area. Transversally to the principal ribs, there are secondary thin ribs delimiting small foveolae. Other characters are typical of the genus.

Remark: *Cytheretta mariaantoniettae* n. sp. is well distinguishable from the others species of the genus because of the ornamentation; particularly, the new species is similar to *Cytheretta ornata* (*Héjjas, 1894*) figured by *Zorn, 1998*, and *Cytheretta ciampoi Bonaduce et al., 1992* but these species are distinguishable from other species by the ornamentation and shape of the carapace.

Genus *Ruggieria Keij, 1957*

Type species *Ruggieria micheliniana* (*Bosquet, 1852*) *Keij, 1957*

Ruggieria quadricarinata n. sp.

(Fig. 4.6)

Etymology: "quadricarinata": with four carenae.

Material: Two entire carapaces.

Holotype: One entire carapace, collection number PMC O 50 H 03/12/2019.

Paratypes: One entire carapace, PMC O 116 P 03/12/2019

Type locality: The Wadi El Kebir (OK) sampling station outcrops at the eastern side of the Wadi El Kebir dam, in the Nabeul region, south eastern part of the Cape Bon Peninsula (36°30'07" N 10°44'46"E).

Type horizon: late Messinian.

Diagnosis: Species of the genus *Ruggieria Keij, 1957*, characterized by four carenae

Description: Sub triangular carapace with anterior margin almost flat in the middle and curved at the lower and upper ends, dorsal margin sinuous, ventral margin straight and inclined towards the back, posterior margin obtuse angle shaped. Carapace ornamentation consisting of four carenae of different lengths elongated anteroposteriorly, respectively in ventral, midventral, middorsal and dorsal position. Anterior and posteroventral margin shows spines.

Remarks: *Ruggieria quadricarinata* n. sp. is well distinguishable from the others species of the genus because of the four carenae.

4. Discussions and conclusions

The two studied sections from eastern Tunisia show obvious faunistic affinities with the sedimentary levels identified in the Ashart 1 well in the Gulf of Gabes by *Bonaduce et al. (1992)*. According to *Frigui et al. (2016)* and *Moissette et al. (2010)*, both sections belong to the Oued El Bir Formation deposited during the late Messinian. The present study has allowed the identification of interesting late Messinian ostracod associations whose taxonomic analysis lead to identify several dozen species, and to describe species new for the science.

The paleoenvironmental interpretation based on ostracod assemblages is very complex. Indeed, the co-occurrence, observed in particular levels of both investigated sections, of marine species together with brackish and/or freshwater faunas (some indicative of the Lago-Mare facies) raises the question about the real co-existence of these benthic faunal components during the Lago-Mare event (third stage of the Messinian Salinity Crisis, 5.55–5.33 Ma).

At present, this possible coexistence is heavily debated in the scientific community and two conflicting hypotheses are currently proposed (*Masclé and Masclé, 2019*). A first hypothesis considers the Paleo-Mediterranean basin as being completely separated from the Atlantic Ocean at that time, but connected with the Parathetys to the East. In those conditions, the coexistence of marine and Lago-Mare faunas was prevented (*Ben Moshe et al., 2020; Hsü et al., 1973; Krijgsman and Meijer, 2008; Krijgsman et al., 2006, 2010; Faranda et al., 2013; Roveri et al., 2014; Stoica et al., 2016; van Baak et al., 2016; Grothe et al., 2018*) and the marine fauna found in the studied sections should be considered as reworked.

A second hypothesis postulates that the exchanges between the Paleo-Mediterranean and the Atlantic Ocean, although strongly reduced, were never cut off, thus allowing the diffusion of marine species entering the Paleo-Mediterranean (*Clauzon et al., 1996; Carnevale et al., 2006, 2008, 2018; Popescu et al., 2007, 2009; Krijgsman et al., 2018*). In this last hypothesis, the coexistence of marine and Lago-Mare fauna could be supported.

Regarding the analyzed sections, no evidence of reworking was found, neither at the stratigraphic nor at the taphonomic level, except at the top of the SAL section where it is possible to define two important phenomena. First, the Messinian levels are overlaid by silty sediments characterized by the occurrence (samples 22 and 23) of the foraminifer *G. crassaformis*, a deep-dweller species (*Da Costa Portilho-Ramos et al., 2014*, and references therein) that is indicative of the Piacenzian (*Lirer et al., 2019*). However, these sediments also contain shallow-water benthic foraminifera (*Elphidium* spp., *Ammonia* spp.) and ostracods not belonging to the Lago-Mare facies, that are clearly reworked from oldest deposits. Second, the absence of strata clearly referable to the Zanclean, which can be attributed to notable sediments displacement or non-sedimentation phenomena.

Concluding, according to the second palaeoenvironmental evolution hypothesis (*Clauzon et al., 1996; Carnevale et al., 2006, inter alia*) and considering the only fauna data now collected in the studied sections,

we can reconstruct, with some approximation, the following paleoenvironmental evolution of the sedimentation basins during the late Messinian: on the pre- evaporitic and evaporitic deposits, as already verified in other areas of the Paleo-Mediterranean basin (Rouchy et al., 2001; Rouchy and Caruso, 2006; Sciuto et al., 2018 inter alias) were formed, due to tectonic, shallow-water basins; these basins, can be assimilated to open lagoons where shallow-water marine and brackish species coexisted. They possibly became temporarily isolated from the sea and colonized by brackish and even fresh water species, if the continental water inputs have prevailed. Conversely hypersaline condition could have established in the absence of fresh-water inputs.

After the Messinian Lago-Mare phase the Mediterranean basin was characterized at the beginning of the Pliocene by the Zanclean flood (Krijgsman et al., 2018, *inter alia*). This return to full marine conditions led to the deposition of sediments with deep sea faunas above the Messinian and pre-Messinian levels. Nevertheless, according to Caruso et al., 2020 (*inter alia*) the Zanclean flood also caused sedimentary and faunal displacement phenomena on the substrate which are recorded in the sedimentary successions. An example of such phenomena is probably present at the top of the SAL section.

Further multidisciplinary studies on the Mio-Pliocene boundary outcropping in Tunisia will allow us to define in greater detail the environmental evolution of these basins at the end of the Messinian.

Conflict of interests

None declared.

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