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MIXED MARINE, BRACKISH WATER, NON-MARINE, AND SUBAERIAL MICROFAUNAL ASSOCIATION IN THE RED MARLS FORMATION OF THE WESTERN AURÈS BASIN (UPPER PALEOCENE)

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ABSTRACT – In the western part of the Aurès Basin (northeastern Algeria), the Red Marls of El Kantara Formation records a mixed microfaunal association of non-marine-brackish ostracoda, marine foraminifera, lacustrine charophytes, and subaerial *Microcodiums*. Based on the recovered biotic component, it is considered that the Red Marls of El-Kantara Formation date from the upper Paleocene (Thanetian). Seven species of brackish water (*Neocyprideis raoi*) and non-marine ostracoda (*Frambocythere tumiensis anjarensis*, *Paracypretta jonesi*, *Paracypretta verruculosa*, *Limnocythere deccanensis*, *Darwinula torpedo* and *Zonocypris spirula*), have been discovered for the first time in Algeria and on the south Tethyan margin. Paleoenvironmentally, the overall biotic assemblage recovered indicates the presence of a freshwater palustrine/lacustrine depositional system connected to a low energy stream/river. This indicates that marginal marine conditions were prevalent in northeastern Algeria's far inland regions. Paleobiogeographically, the seven known ostracod species have limited distributions that are until now common only with India. However, this disproved the theory that these species are endemic to the Indian Subcontinent, which is confirmed by their association with cosmopolitan charophytes.

Keywords: limnic ostracoda, charophytes, paleobiogeography, Thanetian, western Aurès, Algeria.

RESUMO – Na parte ocidental da Bacia de Aurès (nordeste da Argélia), a Formação Red Marls de El Kantara registra uma associação microfaunística mista de ostracodes não-marinhos salobros, foraminíferos marinhos, carófitas lacustres e *Microcodiums* subaéreos. Com base na biota recuperada, considera-se que a Formação Red Marls de El Kantara data do Paleoceno superior (Tanetiano). Sete espécies de água salobra (*Neocyprideis raoi*) e ostracodes não-marinhos (*Frambocythere tumiensis anjarensis*, *Paracypretta jonesi*, *Paracypretta verruculosa*, *Limnocythere deccanensis*, *Darwinula torpedo* e *Zonocypris spirula*) foram descobertas pela primeira vez na Argélia e na margem sul do Tethys. Paleoambientalmente, a associação geral recuperada indica a presença de um sistema deposicional palustre/lacustre de água doce conectado a um córrego/rio de baixa energia. Isso indica que as condições marinhas marginais eram predominantes nas regiões interiores do nordeste da Argélia. Paleobiogeograficamente, as sete espécies conhecidas de ostracodes têm distribuição limitada, até agora comuns apenas com a Índia. No entanto, isso refutou a teoria de que essas espécies são endêmicas do subcontinente indiano, o que é confirmado por sua associação com carófitas cosmopolitas.

Palavras-chave: ostracoda límnicos, carófitas, paleobiogeografia, Tanetiano, Aurès ocidentais, Argélia.

INTRODUCTION

In the western Aurès Basin, Eastern Saharan Atlas (Northeastern Algeria), the Red Marls Formation of El Kantara has long been mentioned as yielding marine and lacustrine microfauna (Belkhodja & Bignot, 2004). However, the records of brackish-non-marine ostracoda from western Aurès are without any descriptions and/or illustrations.

The non-marine ostracoda in Algeria were firstly studied by Mebrouk *et al*. (2011). Their research focused on the lower Eocene deposits of the central part of the Saharan Atlas's and mentioned the occurrence of four genus: *Neocyprideis*, *Hemicyprideis*, *Perissocytheridea* and *Limnocythere*. Mebrouk *et al*. (2013) reported that these four ostracoda genera were associated with nine charophyte flora species. From the Paleogene "Hamadian deposits" cropping out west of Bechar (southwestern Algeria) Hammouda *et al*. (2016) discovered a new non-marine ostracoda fauna that included the following taxa: *Herpetocypris* sp., *Cyprinotus*? sp., *Heterocypris*? sp. 1 and sp. 2, *Cypris*? sp., *Ilyocypris* sp., *Cytheroidea* indet. sp. 1 and sp. 2, *Limnocytheridae* indet. sp. 1, *Cypridoidea* indet. sp. 1, *Cyprididae* indet. sp. 1, and *Heterocypris* sp. 1.

The microfauna found in the western Aurès Basin during the late Paleocene, has no relation with those reported in previous studies. Therefore, the main purpose of the present paper is to place the occurrence of this mixed microfaunal association.

GEOLOGICAL SETTING

The Upper Cretaceous–Paleocene sedimentary rocks are well exposed in the western part of the Aurès Basin, in the eastern part of the Saharan Atlas (northeastern Algeria) (Figure 1A). The Aurès Basin has been previously mapped by Laffitte (1939); subsequent studies on the stratigraphy, sedimentology and structural aspects were done by Bertraneu & Cruys (1955), Dubourdieu (1956), Emberger (1960), Guiraud (1973, 1974, 1975), Vila (1980), Aissaoui (1985), Bureau (1986), Kazi-Tani (1986), Ghandriche (1991), Addoum (1995), Herkat (1999), Benmansour (2016, 2023) and Benmansour *et al*. (2017).

The system of tilted blocks in the Aurès Basin is bordered by faults that trend from NW-SE to WNW-ESE [Bellion *et al*. (1973), Guiraud (1973, 1990), Vila (1980), Bureau (1986) et Kazi-Tani (1986)]. Otherwise, NE-SW faults located within the basin are characterized by transtentional movements. During the late Maastrichtian-Paleocene, the structural evolution in the Aurès Basin led to the development of slumps with slip parallel to the dip of the structure limbs, as seen in the upper Maastrichtian formations of the Tebessa Mountains (Herkat, 1999). Additionally, the southern flank of the Djebel El Azreg anticline has developed progressive Paleogene unconformities on top of the Maastrichtian (Benmansour, 2016, 2023). These features suggest that to the end of the

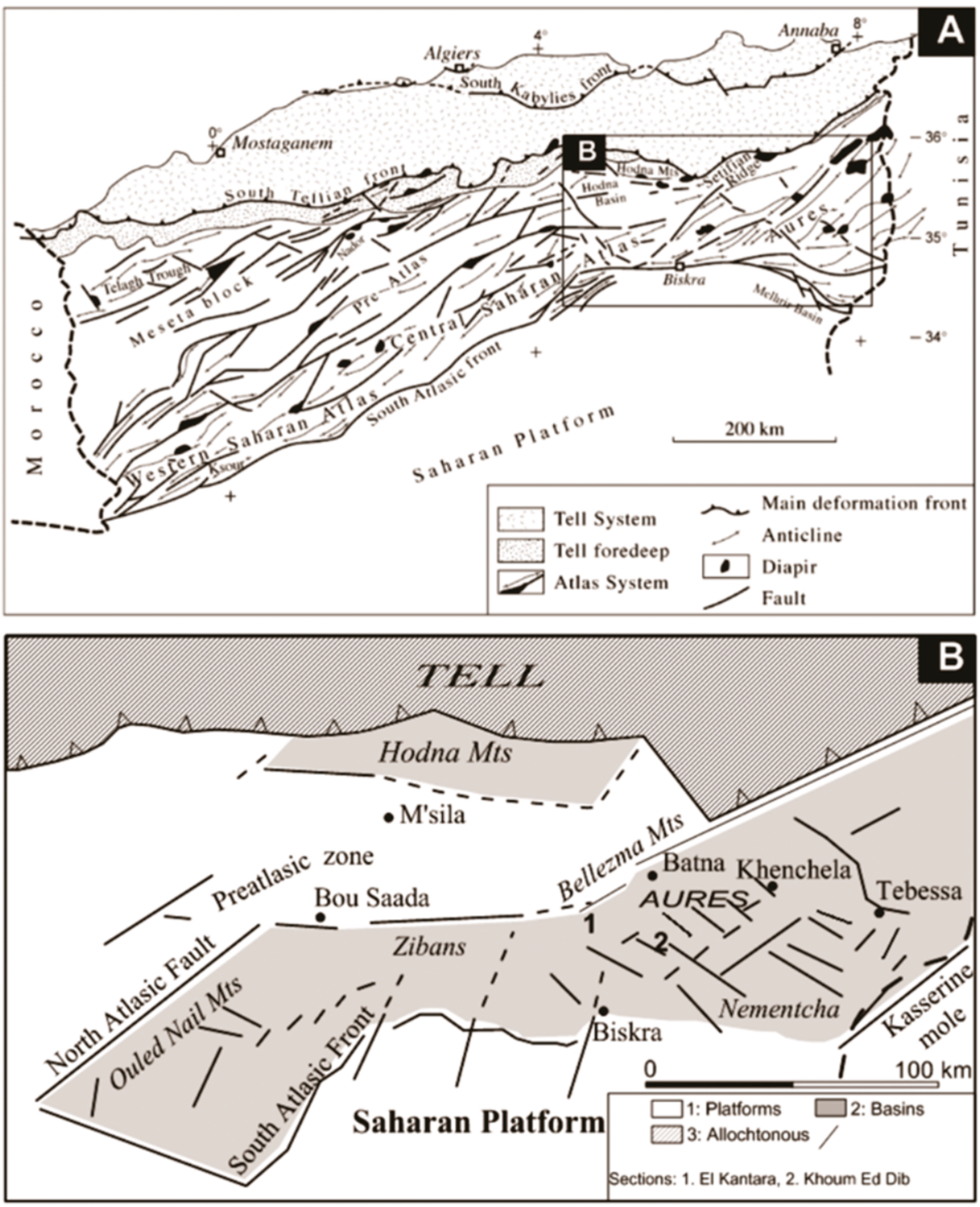

Figure 1. A, main structural domains of northern Algeria and location of the studied area in the eastern part (modified from Michard *et al*., 2008). **B**, paleoenvironments of the Eastern Atlasic Domain (Herkat & Guiraud, 2006) and location of the sections, from West to East: **1**) El Kantara; **2**) Khoum Ed Dib (Bouzina).

Cretaceous, when the Aurès anticlines started to fold (Herkat *et al*., 2006). A Paleocene sedimentary break is observed at Djebel Azreg, in the central zone of the Aurès Massif, where the Eocene sediments unconformably overlie the Maastrichtian, whereas further west this stage is recognized at Djebel Metlili, in the northern part of the Ziban range (Belkhodja & Bignot, 2004).

MATERIAL AND METHODS

In this study, we use the same lithostratigraphic nomenclature adopted by Belkhodja & Bignot (2004) for the Red Marls of El Kantara Formation, which are Upper Paleocene deposits found in the Aurès Basin. El Kantara and Khoum Ed Dib sections in the western Aurès serve as samples for this formation, representing the Thanetian limestones-red marls rocks (Figure 1B). A total of ten thin sections were prepared from samples of hard limestones and indurat marls that were collected from the localities mentioned above using a monocular polarizing microscope, in order to describe the populations of *Laffitteina* and *Microcodium* in random sections.

The twenty-five (25) samples of soft marl levels were soaked in tap water for 24 hours (500 g of sediment). After disintegration, the rinsing procedure involved a column of standard sieves with mesh openings of 500 mm, 200 mm and 63 mm, and a gentle jet of water from the top. Afterwards the residue was then sorted and determined at 200 mm and 63 µm. The index species were analyzed using scanning electron microscopy (**SEM**); and images were produced between Med Kheider University Biskra, and central University Batna Abrouk Madani (**CUB**).

LITHOSTRATIGRAPHIC FRAMEWORK

In the current work, two classic sections of the Red Marls Formation from the western Aurès Basin were studied, their locations are given in the sequel (coordinates as per GPS reading). The area's geological map is shown in Figure 1B.

(i) El Kantara section: located near the railway, the national road RN 3 and oued El Hai, on the right side of the El Kantara Gorge (35°23'03.34" N/5°70'25.65" E). The El Kantara syncline is located 1 km north of El Kantara city and 35 km notheastern of Biskra Province.

(ii) Khoum Ed Dib section: relatively close to the Bouzina-Theniet El Abedroad on the northern side of Khoum Ed Dib anticline at 35°15'40.62" N and 6°07'54.85" E. About 3 Km east of the city of Bouzina, it is located west of Theniet Sidi Lahmadi.

The Red Marls Formation of El Kantara

The Red Marls Formation was first mentioned in its type locality (El Kantara syncline), by Belkhodja & Bignot (2004), where they defined it as follows: 50 m of Red Marls of El Kantara with *Laffitteina bibensis*, gyrogonites of charophytes and *Microcodium* (= *Paronipora*) admitting in their lower part several microbrecciated passes; it is crowned by a conglomeratic bed that is 5 m thick. They recovered only six samples (three at the base of the formation and three at its top, see Belkhodja & Bignot, 2004, p. 4), without studying the geographic extension of the formation. For this formation, the authors of the present paper have proposed to give a more detailed description with a spatial follow-up.

Definition. Above the massive chalky limestones of Maastrichtian Ncham Member (defined by Benmansour, 2016, 2023; Benmansour *et al*., 2017) comes a set of about 50 m of marls, which constitutes a sedimentary formation easily recognized in the field by its red color and shape. It corresponds to a slight median depression between the Ncham Member at the base and the marl-limestone Formation Oued El Hai at the top (Figures 2 and 3).

It is presented by 1 m of soft yellowish marls surmounted by 50 m of friable red marls. These marls are interspersed by two thin indurated layers of dark red marls with *Microcodium* (Figure 4). This lithostratigraphic entity ends with 5 m of monogenic conglomerate of ochre or reddish hue, made of centimetric rounded pebbles held together by oxidized cement. It is limited at the top by a bioturbated surface with several types of excavation. There have been no reports of macrofossils in this formation.

Thickness. El Kantara = 50 m, Khoum Ed Dib = 20 m.

Geographic extension. This formation is well exposed in El Kantara than Bouzina syncline. Towards the center of the Aurès Basin, this formation does not crops out anymore.

Age and affinity

According to Belkhodja & Bignot, (2004), the Red Marls Formation of El Kantara has been previously assigned to Thanetian age based on benthic foraminifera and *Microcodium*. The existence of *Glomalveolina primaeva*, which is considered as a good chronological marker of the Thanetian age, was reported (Hottinger, 1960; Serra-Kiel *et al*., 2003). Thus, since these genera have never been cited in Cretaceous rocks, *Rosalina bractifera* and the genus *Valvulina* were used as a criterion to define the limit between Cretaceous and Tertiary deposits.

The Thanetian age of this formation is confirmed by a brief citation of Belkhodja & Bignot, (2004) – without figuration – refering to *Microcodium* in the Red Marls Formation of El Kantara in El Kantara section.

These data were examined by the authors of the present paper, who then reviewed and compared them to those obtained in the Khoum Ed Dib section:

1. The *Microcodium* with its type species *Microcodium elegans* is found only in the two thin indurated layers of dark red marls described within the Red Marls Formation of El Kantara in the El Kantara and Khoum Ed Dib sections, in which the thin sections were made (Figures 2 and 3). This genus is most extensively reported from the latest Cretaceous–Eocene of European Mediterranean regions, as summarized by Bodergat (1974), Esteban (1974), Klappa (1978), Smit (1979), Plaziat (1984), Morin (1993), Bignot (1994, 1995),

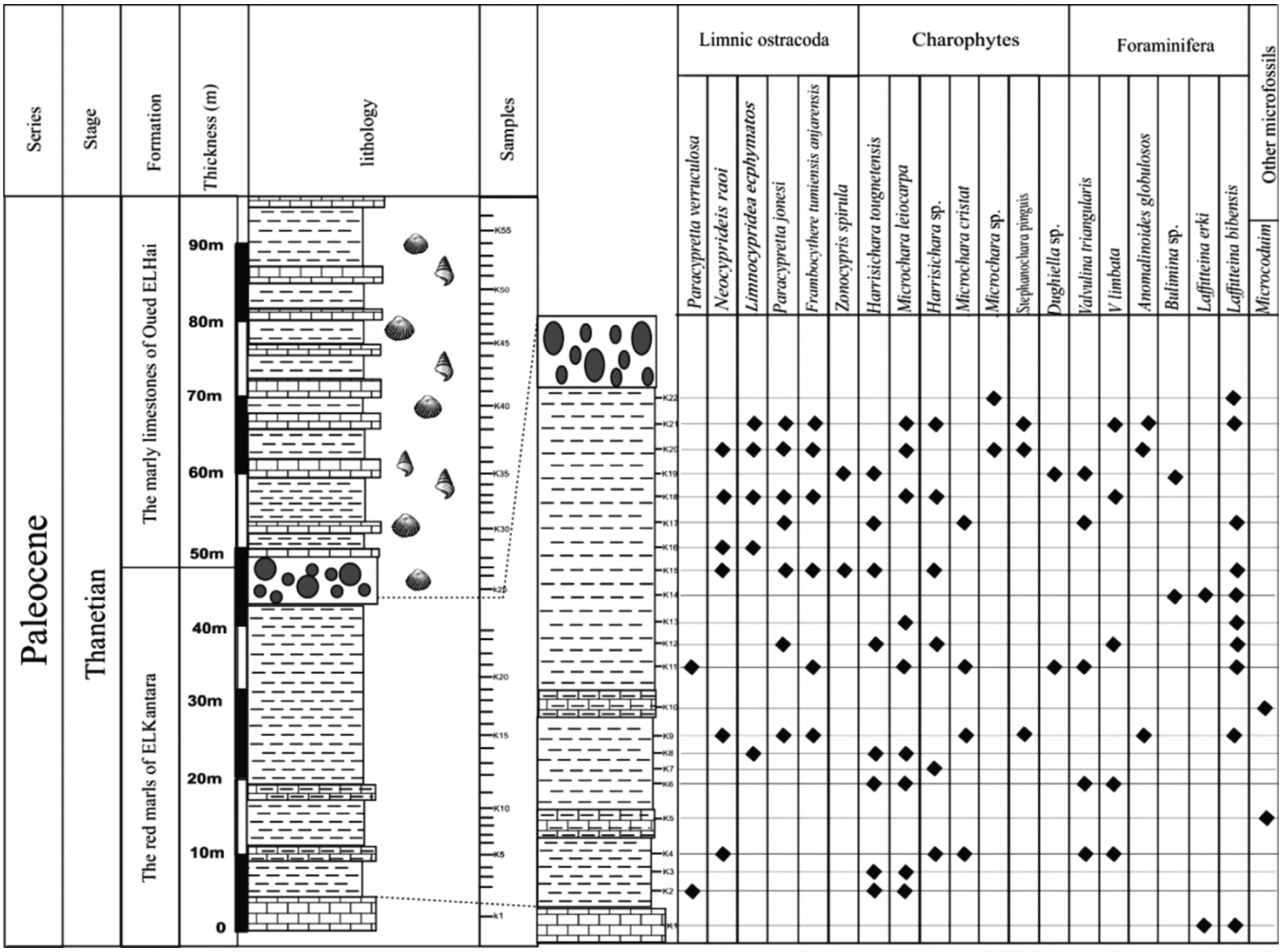

Figure 2. Lithologic succession and distribution of main microfossils in the Red Marls of El Kantara from El Kantara section.

Ramos *et al*. (2001), Košir (2004), Marty *et al*. (2006), Baceta *et al*. (2007) and Tewari *et al*. (2007). Outside Europe, *Microcodium* is known from the lower Maastrichtian of Mexico (Schafhauser *et al*., 2007). The typical *Microcodium* seems to be especially abundant in the Paleocene portions of the non-marine sequences in the South-Pyrenean areas (Plaziat, 1984; Arribas-Mocoroa *et al*., 1996; Rossi, 1997; López-Martínez *et al*., 2006, Kabanov *et al*., 2008).

2. In the two studied sections, the Red Marls Formation of El Kantara delivered a microflora of charophytes (Figure 5) including: *Dughiella* sp., *Microchara leiocarpa* (Grambast, 1971), *Stephanochara pinguis* (Grambast, 1958), *Harrisichara* sp., *Sphaerochara* sp., *Microchara* sp., and *Microchara cristat* (Grambast, 1971). This floristics association suggests that the Red Marls Formation of El Kantara dates from the Late Cretaceous to Upper Paleocene. However, two discovered taxa, *Harrisichara tougnetensis* (Massieux & Villatte, 1977) and *Sphaerochara hybogona* (Charrière *et al*., 2009) have been proposed to support a Thanetian age.

3. The base of the Red Marls Formation of El Kantara yielded numerous benthic foraminifera, which are dominated by *Laffitteina*. *Laffitteina bibensis* (Figure 4A) and *Laffitteina erki* indicate a Thanetian age (Inan, 2004) (Figure 4B). They were found in association with *Valvulina*, which has never been mentioned in Cretaceous rocks (Benmansour, 2023).

4. A total of seven species of non-marine-brackish water ostracoda have been identified. All of them were recorded for the first time in the study area: *Frambocythere tumiensis anjarensis* Bhandari and Colin, 1999, *Paracypretta jonesi* Bhatia & Rana, 1984, *Paracypretta verruculosa* (Whatley, Bajpai a& Srinivasan, 2002), *Zonocypris spirula* Whatley & Bajpai, 2000, *Darwinula torpedo* Whatley, Bajpai & Srinivasan, 2002a, *Limnocythere deccanensis* Khosla, Nagori & Mohabey, 2005 and *Neocyprideis raoi* (Jain, 1978). They are reported from the Maastrichtian to the lower Paleocene in India (Khosla *et al*., 2015).

TAXONOMIC NOTES ON RED MARLS FORMATION OF EL KANTARA OSTRACODA

All described specimens are deposited in the Paleontology laboratory collection, Geological Department, at Mostafa Ben Boulaïd Batna 2 University, Algeria. The ostracoda material was collected from the two studied sections of El Kantara's Red Marls Formation (El Kantara and Khoum Ed Dib).

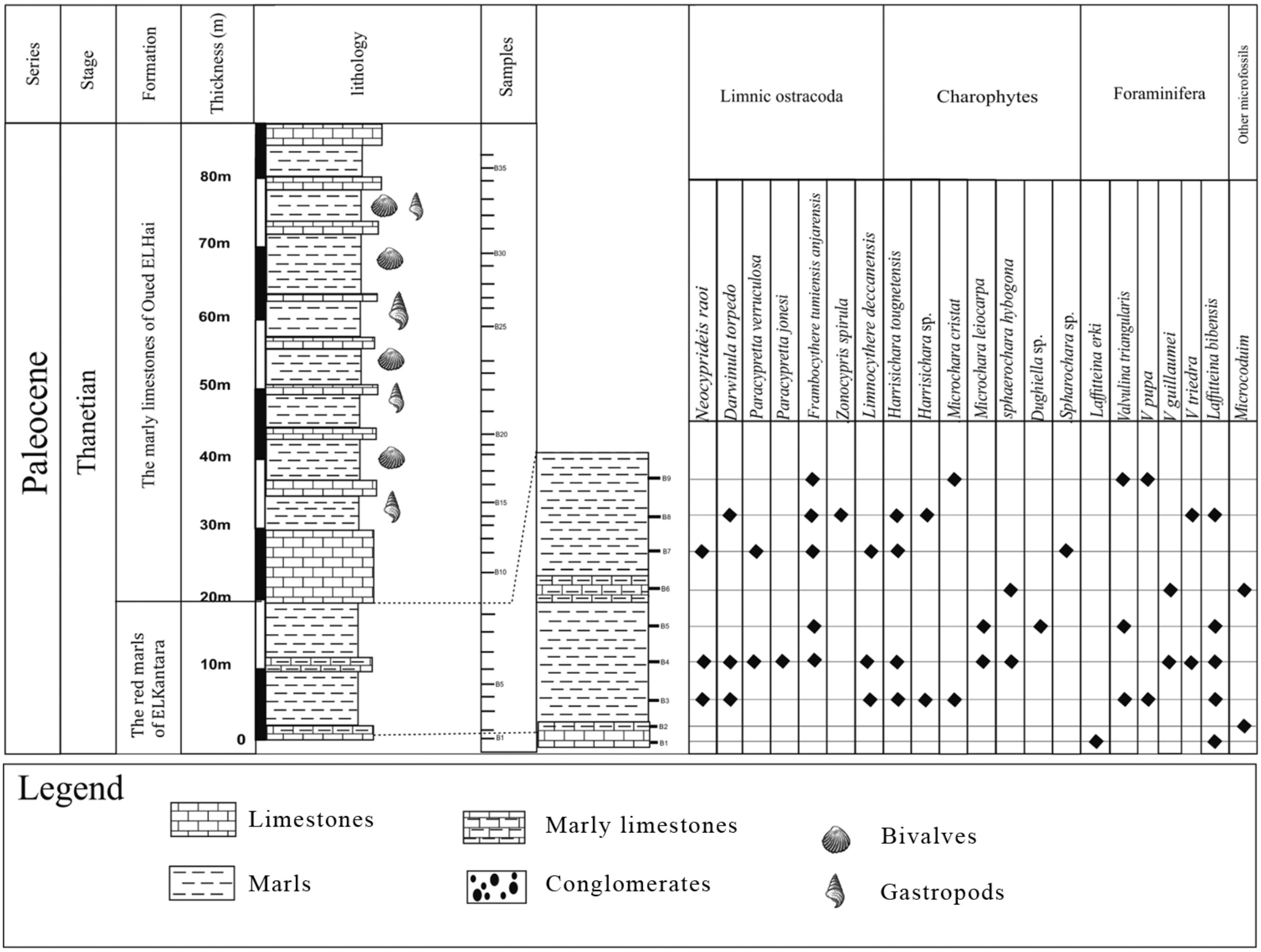

Figure 3. Lithologic succession and distribution of main microfossils in the Red Marls Formation of El Kantara from Khoum Ed Dib section.

Order PODOCOPIDA Müller, 1894
Suborder PODOCOPINA Sars, 1866
Superfamily CYTHEROIDEA Baird, 1850
Family LIMNOCYTHERIDAE Klie, 1938
Subfamily TIMIRIASEVIINAE Mandelstam, 1962

Frambocythere Colin, 1980

Frambocythere tumiensis anjarensis
Bhandari & Colin, 1999
(Figures 6A–L)

1999 *Frambocythere tumiensis anjarensis* Bhandari & Colin, pp. 12-13, pl. 1, figs. 1–10.
2002a *Frambocythere tumiensis anjarensis* Bhandari & Colin, Whatley *et al*., p. 166–168, pl. 1, figs. 8–9.
2003a *Frambocythere* sp. cf. *F. tumiensis anjarensis* Bhandari & Colin, Whatley *et al*., pl. 1, figs. 10–11
2005 *Frambocythere tumiensis anjarensis* Bhandari &Colin, Khosla, Nagori & Mohabey, p. 137, pl. 1, figs. 3–4.
2005 *Frambocythere tumiensis anjarensis* Bhandari & Colin, Khosla, Nagori & Mohabey, p. 574, pl. 1, fig. 4.
2007a *Frambocythere tumiensis anjarensis* Bhandari & Colin, Khosla & Nagori, p. 215, pl. 1, figs. 10–12.
2007b *Frambocythere tumiensis anjarensis* Bhandari & Colin, Khosla & Nagori, p. 6, pl. 1, figs. 4–7.
2009 *Frambocythere tumiensis anjarensis* Bhandari & Colin, Khosla *et al*., p. 725, pl. 2, fig. 8.
2009 *Frambocythere tumiensis anjarensis* Bhandari & Colin, Sharma & Khosla, p. 202, pl. 1, figs. D–E.
2010 *Frambocythere tumiensis anjarensis* Bhandari & Colin, Khosla *et al*., p. 118.
2011a *Frambocythere tumiensis anjarensis* Bhandari & Colin, Khosla *et al*., p. 232, pl. 1, figs. 12–14.

Material. Seventeen specimens from El Kantara section and ten specimens from Khoum Ed Dib section (Figures 6A–L).
Description. It has been recorded for the first time in both the study area and all of Algeria. It is very abundant in both sections and characterized by its medium-sized carapace

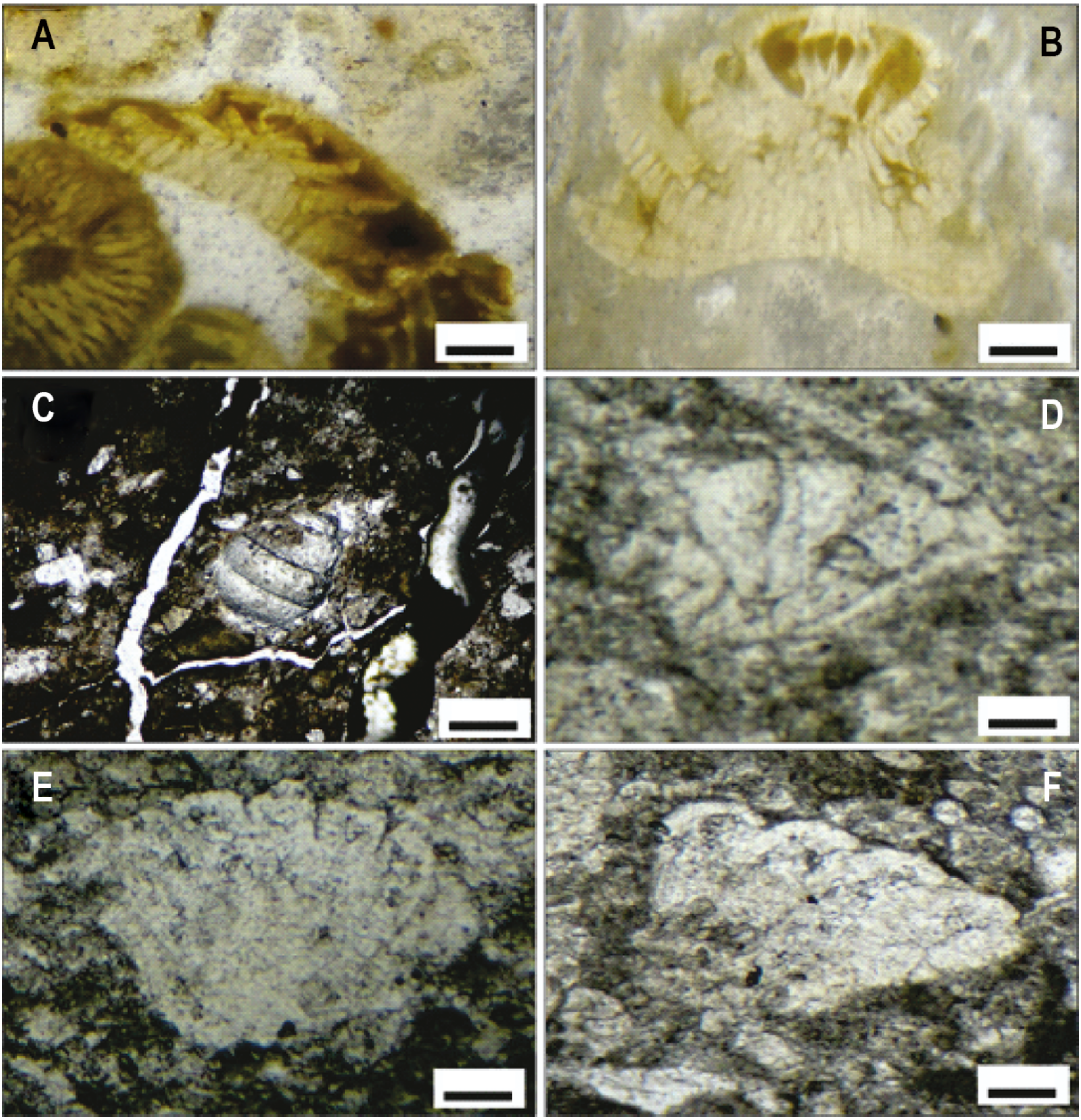

Figure 4. *Laffitteina* and *Microcodium* in thin sections in the limestone beds of the Red Marls of El Kantara Formation. **A**, *Laffitteina bibensis*. Axial section from El Kantara section. Sample K1. **B**, *Laffitteina erki*. Axial section from El Kantara section. Sample K1. **C**, *Microcodium*, from El Kantara section. Sample K5, K11. **D–F**, *Microcodium*, from Khoum Ed Dib section. Samples B2 and B6. Scale bars = 0.02 mm.

and sub-rectangular shape in lateral view, strongly inflated dorsal part and greatest height and maximum width nearly the middle. Left valve larger than right valve and distinctly overlapping along anterodorsal and posterodorsal margins; dorsal margin straight, ventral margin slightly concave, anterior margin regularly rounded. Females strongly inflated posteriorly whereas males significantly narrower. Strong posteroventral and posterodorsal spines are present on the posterior margin, and these spines are especially well developed in male individuals (Figure 6J). Only the posteroventral spine may be present in females (Figure 6C); the surface is frequently ornamented by papillate tubercles, though some species are smooth or have fine tubercles scars. Obvious median sulcus and tubercles on the dorsal part of the anteromarginal area.

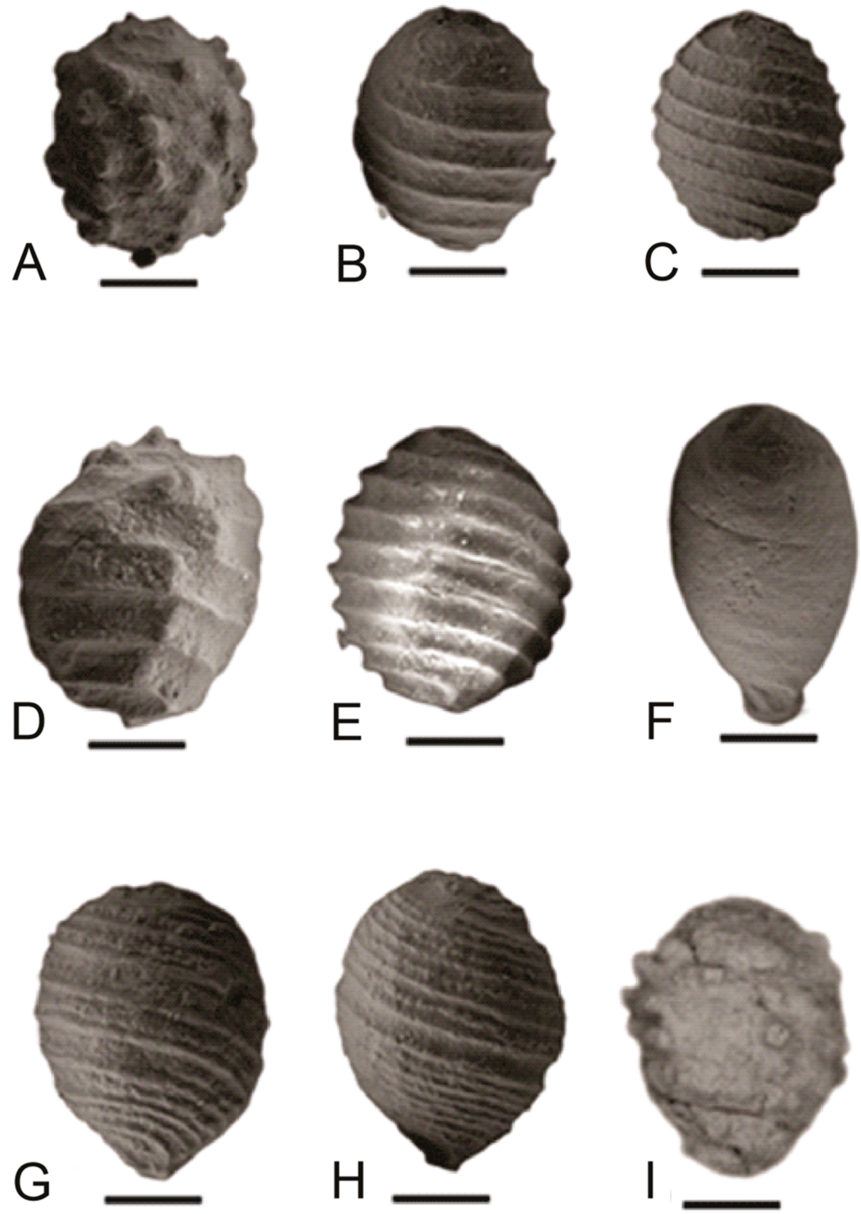

Figure 5. Charophytes from the Red Marls Formation of El Kantara. **A**, *Dughiella* sp. **B**, *Microchara leiocarpa*. **C**, *Stephanochara pinguis*. **D**, *Harrisichara* sp. **E**, *Sphaerochara* sp. **F**, *Microchara* sp. **G**, *Sphaerochara hybogona*. **H**, *Microchara cristat*. **I**, *Harrisichara tougnetensis*. Scale bars = 200µm.

Family CYTHERIDEIDAE Sars, 1925
Subfamily CYTHERIDEINAE Sars, 1925

Neocyprideis Apostolescu, 1956

Neocyprideis raoi (Jain, 1978)
(Figure 7A)

1978 *Ovocytheridea raoi* Jain, p. 53, pl. 1, figs. 7–10.
1995 *Ovocytheridea raoi* Bhandari, p. 95–96, pl. 2, figs. 1–2.
2002 *Neocyprideis raoi* (Jain), Khosla & Nagori, p. 201–203, figs. 2.12–2.13.
2011a *Neocyprideis raoi* (Jain), Khosla *et al*., pl. 1, figs. 1–6.

Material. Twelve specimens from El Kantara section and six specimens from Khoum Ed Dib section.

Description. Occurs abundantly in the present area, it is characterized by its sub-rectangular to subovate carapace, a left valve that is larger than the right valve, dorsal and ventral margins convex; posterior margin narrowly rounded, anterior end broadly rounded; greatest height slightly anterior to the middle; dorsal margin arched. Valve surface pitted and marked by a shallow depression in anterodorsal region; inner lamella is moderately wide.

Paracypretta Sars, 1924

Paracypretta jonesi Bhatia & Rana, 1984

1984 *Paracypretta jonesi* Bhatia & Rana, p. 30–33, pl. 2, figs. 1–3.

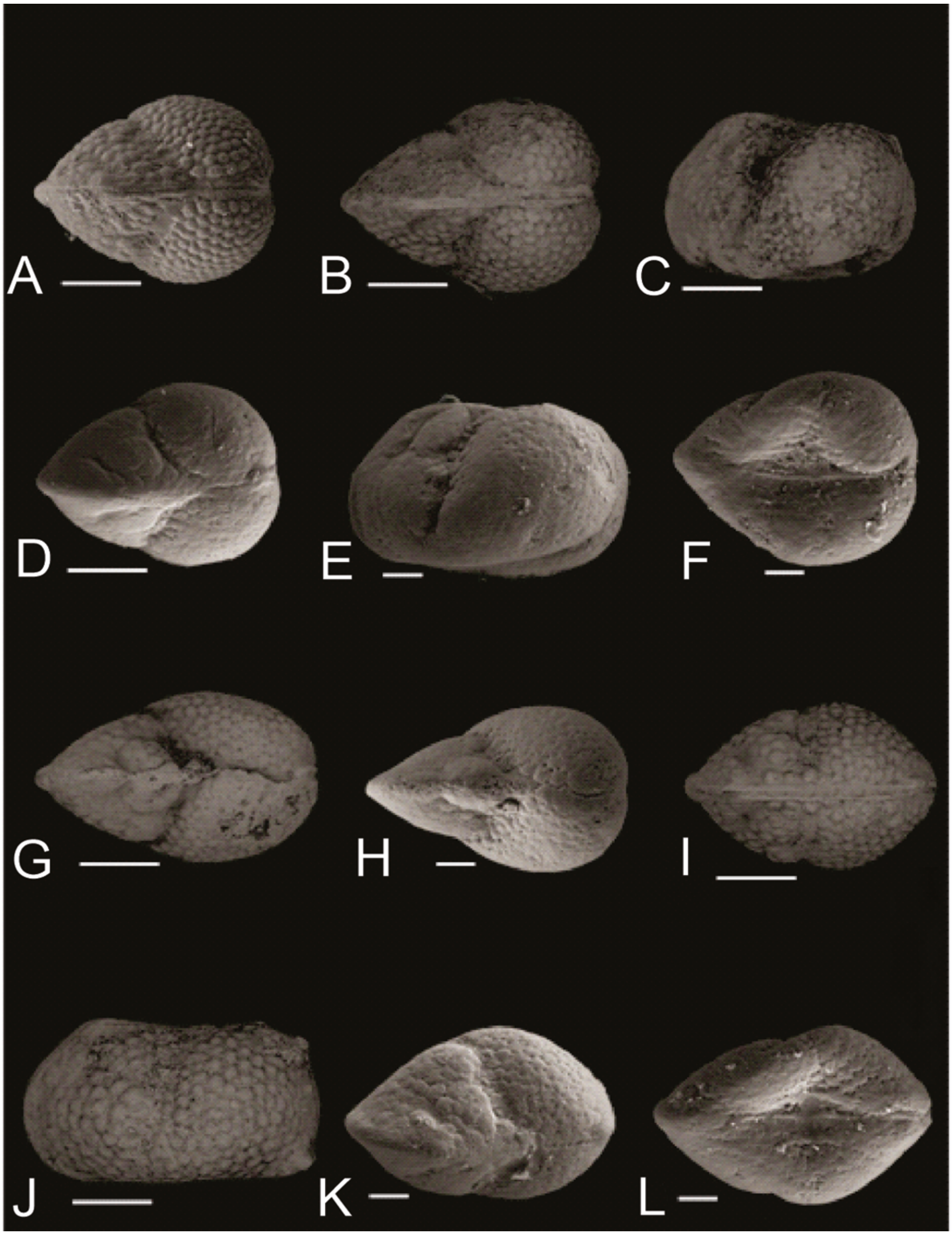

Figure 6. *Frambocythere tumiensis anjarensis*: **A–F**, female carapaces, **A-B and D**, dorsal view; **C and E** left lateral view; **F**, ventral view; **G–I.** male carapaces, **G, H and K**, dorsal view; **J**, left lateral view; **L**, ventral view. Scale bars = 200 μm.

1996 *Paracypretta jonesi* Bhatia & Rana, Udhoji & Mohabey, p. 413, pl. 2, figs. 4–6.

2001 *Paracypretta jonesi* Bhatia & Rana, Bajpai & Whatley, p. 95-96, pl. 1, figs. 2, 4.

2002b *Paracypretta jonesi* Bhatia & Rana, Whatley *et al*., p. 166–168, pl. 1, figs. 8–9.

2003b *Paracypretta jonesi* Bhatia & Rana, Whatley *et al*., p. 1293–1294, pl. 2, figs. 14, 17.

2007a *Paracypretta jonesi* Bhatia & Rana, Khosla & Nagori, p. 215–217, pl. 1, figs. 13–16; pl. 2, figs.1–3.

2007b *Paracypretta jonesi* Bhatia & Rana, Khosla & Nagori, p. 8, pl. 1, figs. 15–16.

2009 *Paracypretta jonesi* Bhatia & Rana, Khosla *et al*., p. 725, pl. 2, fig. 13.

2009 *Paracypretta jonesi* Bhatia & Rana, Sharma & Khosla, p. 204, pl. 2, figs. I–N.

2010 *Paracypretta jonesi* Bhatia & Rana, Khosla *et al*., p. 118, figs. 3a–c.

2011a *Paracypretta jonesi* Bhatia & Rana, Khosla *et al*., pl. 2, figs. 3–4.

Material. Fourteen specimens from El Kantara section and two specimens from Khoum Ed Dib section.

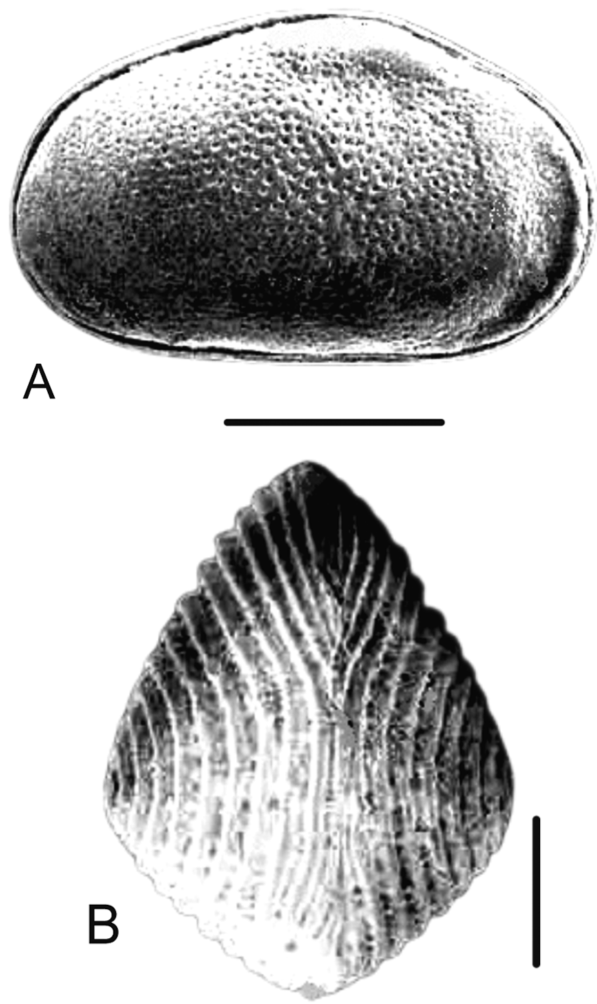

Figure 7. Ostracoda from the Red Marls Formation of El Kantara: A, *Neocyprideis raoi*, carapace, right lateral view; B, *Zonocypris spirula*, carapace, dorsal view. Scale bars = 100 μm.

Description. It is not abundant in the current collection, this species is characterized by a large carapace, subtriangular in lateral view, strongly inflated in the dorsal, with the left valve being larger than the right valve, the greatest height and maximum width being nearly equal. Additionally, it has a convex dorsal margin; a straight ventral margin; rounded anterior and posterior margins. The valves are ornamented by longitudinal striations parallel to ventral margin.

Paracypretta verruculosa
Whatley, Bajpai & Srinivasan, 2002a

2002a ?*Eucypris verruculosa* Whatley, Bajpai & Srinivasan, p. 177, pl. 4, figs. 8–9, 12–19.
2003c ?*Eucypris verruculosa* Whatley *et al*., Whatley *et al*., p. 81-82, figs. 2J–K.
2007b ?*Eucypris verruculosa* Whatley *et al*., Khosla & Nagori, p. 12, pl. 3, figs. 1–2.
2009 ?*Eucypris verruculosa* Whatley *et al*., Khosla *et al*., p. 725, pl. 2, fig. 7.
2009 *Paracypretta* sp. Sharma & Khosla, p. 204, pl. 2, figs. O–R.
2011a *Paracypretta verruculosa* Whatley *et al*., Khosla *et al*., p. 234, pl. 2, figs. 5–10.

Material. Five specimens from El Kantara section and four specimens from Khoum Ed Dib section.
Description. It is not abundant in the present collection. It is characterized by a large carapace, fusiform in dorsal view, elongate subtriangular in lateral outline, left valve larger than the right valve, greatest height at anterior cardinal angle, dorsal margin straight; ventral margin concave; anterior margin wide and obliquely rounded; posterior margin straight in upper part and ventrally rounded in lower part. Carapace surface is ornamented by scattered papillae.

Limnocythere Brady, 1868

Limnocythere deccanensis
Khosla, Nagori & Mohabey, 2005

2004 *Limnocythere bhatiai* Bajpai *et al*., p. 150, pl. 1, figs. l–r; pl. 2, figs. a–b (not *Limnocythere bhatiai* Mathur, 1972, p. 394–395, figs. 2a–c).
2005 *Limnocythere deccanensis* Khosla, Nagori & Mohabey, p. 136, pl. 1, figs. 1–2.
2007a *Limnocythere deccanensis* Khosla *et al*., Khosla & Nagori, p. 215, pl. 1, figs. 6–9.
2007b *Limnocythere deccanensis* Khosla *et al*., Khosla & Nagori, p. 6.
2009 *Limnocythere deccanensis* Khosla *et al*., Khosla *et al*., p. 725, pl. 2, fig. 12.
2009 *Limnocythere deccanensis* Khosla *et al*., Sharma & Khosla, p. 202, pl. 1, figs. G–J.
2010 *Limnocythere deccanensis* Khosla *et al*., Khosla *et al*., p. 118.
2011a *Limnocythere deccanensis* Khosla *et al*., Khosla *et al*., p. 231, pl. 1, figs. 7–11.

Material. Eleven specimens from El Kantara section and seven specimens from Khoum Ed Dib section.
Description. The carapace of this species, which is rare in the studied collection, is characterized by a subquadrate shape in lateral outline, flatted in dorsal outline with compressed ends. The carapace surface is marked by a median vertical sulcus and arcuate anterior depression.

Zonocypris Müller, 1898

Zonocypris spirula Whatley & Bajpai, 2000
(Figure 7B)

2000 *Zonocypris spirula* Whatley & Bajpai, p. 396–397, pl. 3, figs. 1–7, 9.
2002a *Zonocypris spirula* Whatley & Bajpai, Whatley *et al*., p. 173, pl. 3, figs. 6–7.

2002b *Zonocypris spirula* Whatley & Bajpai, Whatley *et al*., p. 168, pl. 1, figs. 11–12.
2005 *Zonocypris spirula* Whatley & Bajpai, Khosla, Nagori & Mohabey, p. 139, pl. 1, figs. 13–14.
2005 *Zonocypris spirula* Whatley & Bajpai, Khosla, Nagori & Mohabey, p. 576, pl. 1, fig. 19.
2007a *Zonocypris spirula* Whatley & Bajpai, Khosla & Nagori, p. 217, pl. 2, figs. 4–5.
2007b *Zonocypris spirula* Whatley & Bajpai, Khosla & Nagori, p. 9, pl. 2, figs. 5–6.
2008 *Zonocypris spirula* Whatley & Bajpai, Sharma *et al*., p. 182, pl. 2, figs. O–P.
2009 *Zonocypris spirula* Whatley & Bajpai, Khosla *et al*., p. 725, pl. 2, fig. 16.
2009 *Zonocypris spirula* Whatley & Bajpai, Sharma & Khosla, p. 204, pl. 3, figs. C–E.
2011a *Zonocypris spirula* Whatley & Bajpai, Khosla *et al*., p. 235, pl. 3, figs. 2–3.

Material. Four specimens from El Kantara section and two specimens from Khoum Ed Dib section.
Description. It is rare in our material; the studied collection (one carapace) is characterized by a subovate small carapace, subquadrate shape in dorsal view. Its surface is marked by numerous fine striations concentrically arranged in the peripheral region and irregularly disposed in the middle.

Darwinula Brady & Robertson, 1885

Darwinula torpedo Whatley, Bajpai & Srinivasan, 2002a

2002a *Darwinula torpedo* Whatley, Bajpai & Srinivasan, p. 165–166, pl. 1, figs. 1–7.
2007a *Darwinula torpedo* Khosla & Nagori p. 211, pl.1, fig. 1.
2007b *Darwinula torpedo* Khosla & Nagori, p. 5–6, pl. 1, figs. 1–3.

Material. Nine specimens from Khoum Ed Dib section.
Description. It is very abundant in the present collection. The carapace is medium sized, elongate, subcylindrical lateral outline; anterior margin that is narrowly rounded, with an apex below mid-height; posterior margin that is more broadly rounded to subtruncate, apex at or above mid-height; dorsal margin straight to very gently convex; ventral margin slightly concave; valve surface smooth.

PALEOECOLOGICAL INTERPRETATION

The microfossils of the Red Marls of El Kantara Formation reveal the simultaneous presence of non-marine (ostracoda), subaerial (*Microcodium*), lacustrine (charophytes), and marine (foraminifera) groups. The marine microfauna is represented by large foraminifera (*Laffitteina*). According to Babinot & Tambareau (1986), this genus is typically oligohaline.

Microcodium has been found in a variety of settings including paleosols, emersion levels within palustrine limestones, as well as corrosions in hard limestone substrates, in paleokarst and deep infiltrations (Freytet & Plaziat, 1982; Rossi, 1997, Kabanov *et al*., 2008). The paleoecology of the majority of non-marine ostracods has been discussed by Khosla & Nagori (2007a, b), Khosla *et al*. (2011a, b, 2015).

According to Morkhoven (1963), *Neocyprideis* is closely related to the living genus *Cyprideis*, which probably evolved from the former. The latter genus inhabits freshwater to hypersaline conditions but is most abundant in mesohaline salinities and hence regarded as typical brackish water ostracod. *Neocyprideis raoi* also occurs predominantly in brackish water environments (Keij, 1957; Morkhoven, 1963; Oertli, 1967; Keen, 1977; Neale, 1988; Khosla *et al*., 2009; Sharma & Khosla, 2009).

Six species – *Frambocythere tumiensis anjarensis* Bhandari & Colin, 1999, *Paracypretta jonesi* Bhatia & Rana, 1984, *Paracypretta verruculosa* (Whatley, Bajpai & Srinivasan, 2002a), *Zonocypris spirula* Whatley & Bajpai, 2000, *Darwinula torpedo* Whatley, Bajpai & Srinivasan, 2002a, *Limnocythere deccanensis* Khosla, Nagori & Mohabey, 2005 – are ubiquitous and have been reported from virtually all non-marine environments (Khosla *et al*., 2009, 2011a, b).

Paracypretta jonesi and *Paracypretta verruculosa* are low energy aquatic, active swimmer ostracods (Sharma & Khosla, 2009; Khosla *et al*., 2011a, b, 2015). *Darwinula orpedo* is a poor swimmer species, occurs in streams but prefers to live in permanent water bodies such as lakes and ponds (Whatley & Bajpai, 2005). *Limnocythere deccanensis* is non-marine, low energy aquatic, poor swimmer/epibenthonic/endobenthonic or walker/crawler (Sharma & Khosla, 2009; Khosla *et al*., 2011a, b, 2015). *Zonocypris spirula* is also a low energy aquatic, active swimmer species. *Frambocythere tumiensis anjarensis* is a poor swimmer genus (Colin, 2004), lived in fresh water to oligohaline with low energy environment (Sharma & Khosla, 2009; Khosla *et al*., 2011a, b, 2015). They are epibenthonic walker/crawler species.

The strongly ornamented ostracods as in *Frambocythere tumiensis anjarensis*, *Paracypretta jonesi*, *Zonocypris spirula*, and *Limnocythere deccanensis* indicate augmentation in the alkalinity of the environments (Khosla *et al*., 2015). Heavily ornamented ostracods, particularly *Zonocypris*, indicate stagnant conditions (Khosla *et al*., 2011a, b, 2015).

In the study area, the Cretaceous ends with shallow marine sediments (Belkhodja & Bignot, 2004; Benmansour, 2016; Benmansour *et al*., 2017) rich in *Sporolithon*, corals, and *Laffitteina* (Benmansour, 2023).

The global marine regression of the Lower Paleocene (Marzoqi & Pascal, 2000) affected the western part of the Aurès Basin, which emerges as many other peri-Mediterranean and Saharan areas. For this reason, the Danian and Selandian deposits are absent in the study area (Belkhodja & Bignot, 2004; Benmansour, 2023).

The gradual arrival of the sea in the Thanetian age could have been the probable reason for the presence of brackish water ostracods (*Neocyprideis raoi*). The Red Marls of El Kantara Formation also comprises benthic foraminifera, non-marine ostracod species and charophytes, which were inhabitants of pools/lakes, as represented in Khosla *et al*.

(2009). The existence of *Microcodium* is the index of the proximity of limestone outcrops that emerged in course of karstification (Belkhodja & Bignot, 2004). In conclusion, the occurrence of such mixed microfauna in the western Aurès Basin part suggests that marginal marine conditions prevailed far inland in northeastern Algeria.

PALEOBIOGEOGRAPHY

This research allowed to identify seven species of non-marine, brackish-water ostracoda for the first time in northeastern Algeria (Figure 8), in the south ethyan margin: *Frambocythere tumiensis anjarensis*, *Paracypretta jonesi*, *Paracypretta verruculosa* (, *Zonocypris spirula*, *Darwinula torpedo*, *Limnocythere deccanensis* and *Neocyprideis raoi*. Until now this species was only known from the Upper Cretaceous to the Lower Paleocene in India (Khosla *et al*., 2011a, b, 2015).

We adopt the hypothesis of the 'Out-of-India', which was proposed by Krause *et al*. (1990). This hypothesis viewed India as a ferrying Noah's Ark where biota originated and/or evolved, based on paleogeographic and paleontological considerations, and subsequently dispersed into Eurasia (popularly known as the 'Biotic Ferry Model', Briggs, 2003) because of India-Asia collision around the Paleocene–Eocene interval. However, the author mentioned that the high diversity of the ostracod genera *Zonocypris* and *Frambocythere* within India have not been viewed in terms of an Indian origin, since an older record of *Zonocypris* is known from the Aptian/Albian of Brazil (Colin & Depeche, 1997) and *Frambocythere* has been previously recorded within the Aptian-Albian of Africa (Chad) (Colin, 1993; Colin & Depeche, 1997) and Late Cretaceous (Maastrichtian) to middle Eocene sedimentary sequences of Iran, China, and Europe (Hou *et al*., 1978; Tambareau, 1984; Tambareau *et al*., 1991; Colin, 2011).

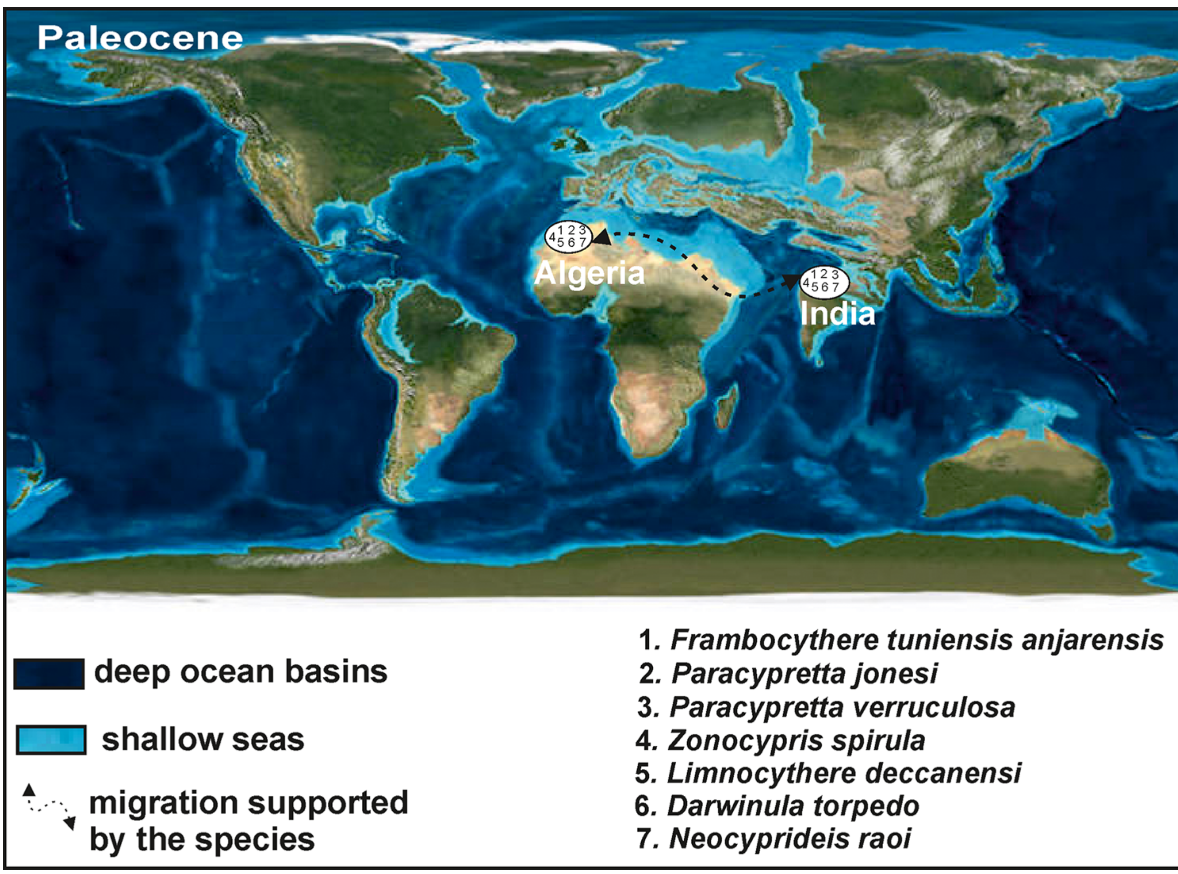

Figure 8. Paleobiogeographic distribution of non-marine ostracoda.

The data obtained from this study disproved the theory of endemism of these species within the Indian Subcontinent, which is confirmed by their association with cosmopolitan charophytes (Figure 8).

CONCLUSIONS

The following conclusions can be drawn from this study: (i) the overall assemblage of ostracods: *Frambocythere tumiensis anjarensis*, *Paracypretta jonesi*, *Paracypretta verruculosa*, *Zonocypris spirula*, *Darwinula torpedo*, *Limnocythere deccanensis*, and *Neocyprideis raoi* was recorded for the first time in Algeria; (ii) the occurrence of *Laffitteina erki* suggests a Thanetian age (Inan, 2004). Indeed, two discovered taxa of charophyres: *Harrisichara tougnetensis*, *Sphaerochara hybogona*, as well as the presence of *Microcodium elegans*, indicate a Thanetian age; (iii) the overall assemblage of ostracods, charophytes, foraminifera, and *Microcodiums* is indicative of the presence of a mixed marine, brackish water, non-marine environment; (iv) paleobiogeographically, the seven species of ostracoda have a limited distribution and up until now, are only in common with India. This disproved the theory that these species are endemic of the Indian Subcontinent, which is confirmed by their association with cosmopolitan charophytes.

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Data availability

No data was used for the research described in the article.

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