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CENOMANIAN BIVALVES FROM BATNA MOUNTAINS (SAHARAN ATLAS, NE ALGERIA)

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ABSTRACT – In the Batna Mountains, the Cenomanian Marnes de Smail Formation yield fossiliferous deposits mostly dominated by bivalves. Thirty-five bivalve species were identified, belonging to nine orders, 19 families and 26 genera. Five of them are mentioned for the first time from the Cenomanian of the study area (*i.e.*, *Nucula* ? cf. *margaritifera* Douvillé, *Barbatia* (*Barbatia*) *aegyptiaca* Fourtau, *Cucullaea trigona* Seguenza, *Arctica inornata* d'Orbigny, and *A. cordata* Sharpe). Their distribution provided interesting insights on the marine paleoenvironment of the Cenomanian times. The paleobiogeographic distribution of the studied bivalves corresponds to the Tethys Realm.

Keywords: Bivalvia, Cretaceous, Cenomanian, Algeria, Batna, Tethys.

RESUMO – Na Cordilheira de Batna, a Formação de Marnes de Smail consiste em depósitos fossilíferos ricos em uma macrofauna bentônica diversificada, dominada principalmente por bivalves. Trinta e cinco espécies de bivalves são identificadas, representando nove ordens, 19 famílias e 26 gêneros, respectivamente. Entre os táxons identificados, cinco deles são descritos pela primeira vez para o Cenomaniano da área de estudo (*i.e.*, *Nucula* ? cf. *margaritifera* Douvillé, *Barbatia (Barbatia) aegyptiaca* Fourtau, *Cucullaea trigona* Seguenza, *Arctica inornata* d'Orbigny, e *A. cordata* Sharpe). Sua distribuição fornece informações interessantes sobre o ambiente marinho dos tempos cenomanianos. A distribuição paleobiogeográfica dos bivalves estudados corresponde ao Reino de Tétis.

Palavras-chave: Bivalvia, Cretáceo, Cenomaniano, Argélia, Batna, Tétis.

INTRODUCTION

The Batna Mountains are located in the southern Tethyan margin and belongs to the far eastern part of the Saharan Atlas. The area was marked by carbonate sedimentation during the whole Cenomanian (Herkat, 2004). The environment triggered the proliferation of a diverse invertebrate macrofauna, among which the bivalves dominated the benthic communities (Fournel, 1849; Coquand, 1862; Péron, 1883; Guiraud, 1973; Aouissi *et al*., 2018, 2020; Slami *et al*., 2018; Bensekhria *et al*., 2019; Salmi-Laouar *et al*., 2019). The Cenomanian age of all these bivalve assemblages is indicated by the associated ammonite faunas (Aouissi *et al*., 2020).

The first published paleontological work from the Cenomanian of the Batna Mountains is Fournel (1849). He identified 31 fossil species in his masterpiece on the mineral wealth of Algeria. Aouissi *et al*. (2018) were the first to provide a systematic description of 24 Cenomanian bivalve species from Metrassi (Batna). The present study on the Batna Mountains is the first exclusively dealing with Cenomanian bivalves.

GEOLOGICAL SETTING

The study area is located in the northeastern part of Algeria (Figure 1A), in the Batna Mountains, within the surroundings of Batna city. It belongs to the eastern part of the Atlas Saharan Basin that extends into Tunisia as the Tunisian Atlas (Herkat & Guiraud, 2006). Paleogeographically, the Batna Mountains are part of the South Tethyian Realm, where the

Cretaceous marine deposits (Figure 1B) are well-exposed and their thickness varies from 600 m to 1,000 m (Laffitte, 1939; Bureau, 1975). Such a considerable thickness can be explained by synchronous transgression and the tectonic subsidence events (Bureau, 1986; Yahiaoui, 1990; Herkat, 1999, 2004).

The Marnes de Smail Formation represents the Cenomanian succession in the Batna Mountains. This formation has been recognized and studied in several sections (Hamla, Théniët El Manchar, Metrassi and Bouarif) with varying thickness (Figure 2). Previous works (Slami *et al*., 2018; Aouissi *et al*., 2018, 2020) on the Marnes de Smail Formation divided it into four informal units, from base to top: (i) Unit A (marls with ammonites and exogyrine oysters) corresponding to the *Mantelliceras mantelli* (Sowerby)/*Sharpeicera laticlavium* (Sharpe) and *Mantelliceras dixoni* (Spath) zones; (ii) Unit B (marls with *Aspidiscus cristatus*) dated by the *Cunningtoniceras inerme* (Pervinquière), *Acanthoceras rhotmagense* (Brongniart) and *Acanthoceras amphibolum* (Morrow) zones; (iii) Unit C (Marls with oysters), and (iv) Unit D (limestones and marls with *Caprinula* or *Pycnodonte*).

The Cenomanian paleogeographical and paleoenvironmental reconstruction model adopted by Slami *et al*. (2018) and Aouissi (2020) for this region shows that the marine transgression was interrupted by a regressive phase during the

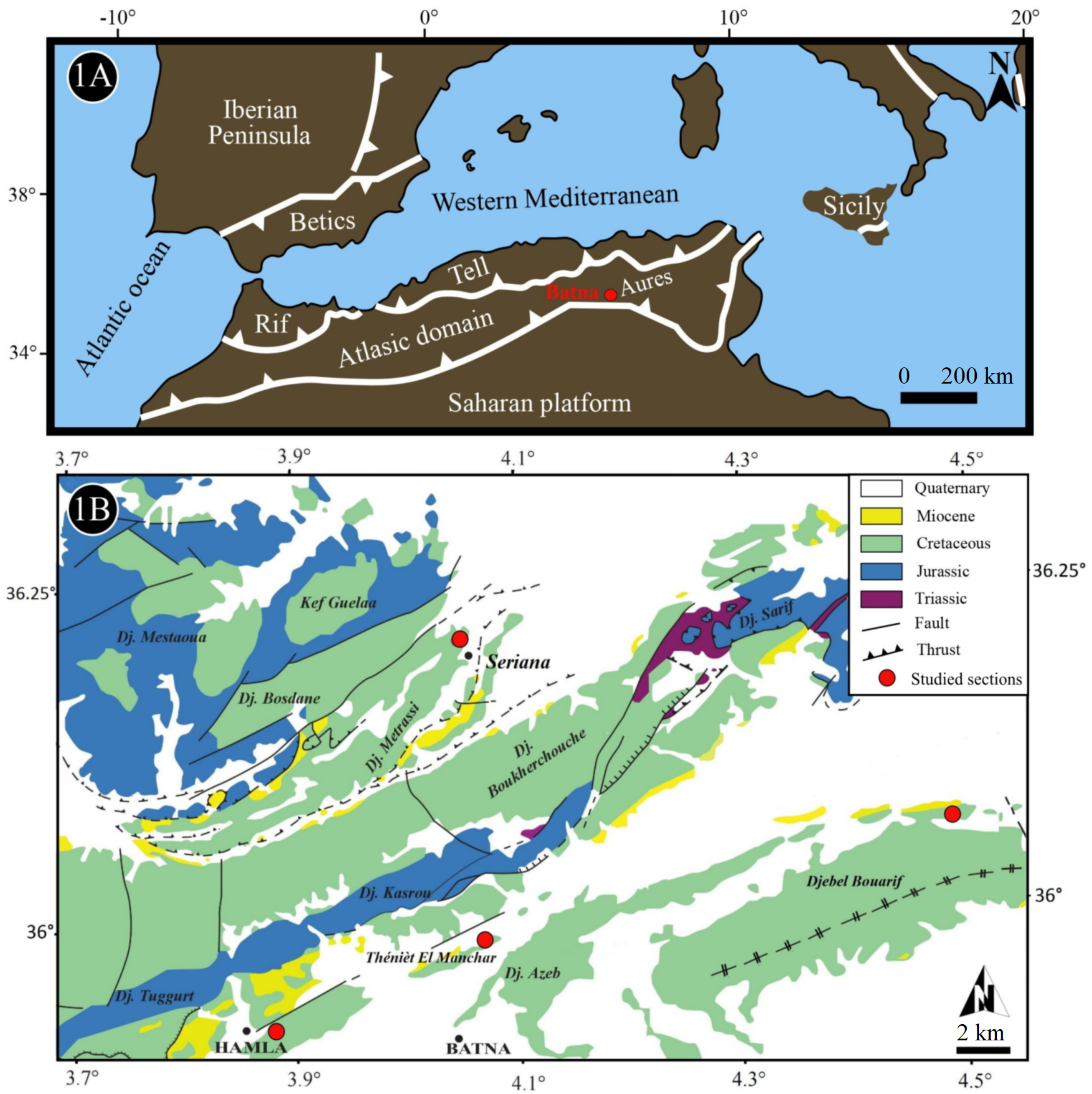

Figure 1. Geographic location and geological map of the studied area. **A**, geographic location of Batna in Algeria and its position in the main structural ranges of eastern Algeria (from Herkat, 2007). **B**, geological sketch (combined from Merouana and Ain El Ksar, 1/50.000 geological maps) showing the Cretaceous formations and position of the studied sections.

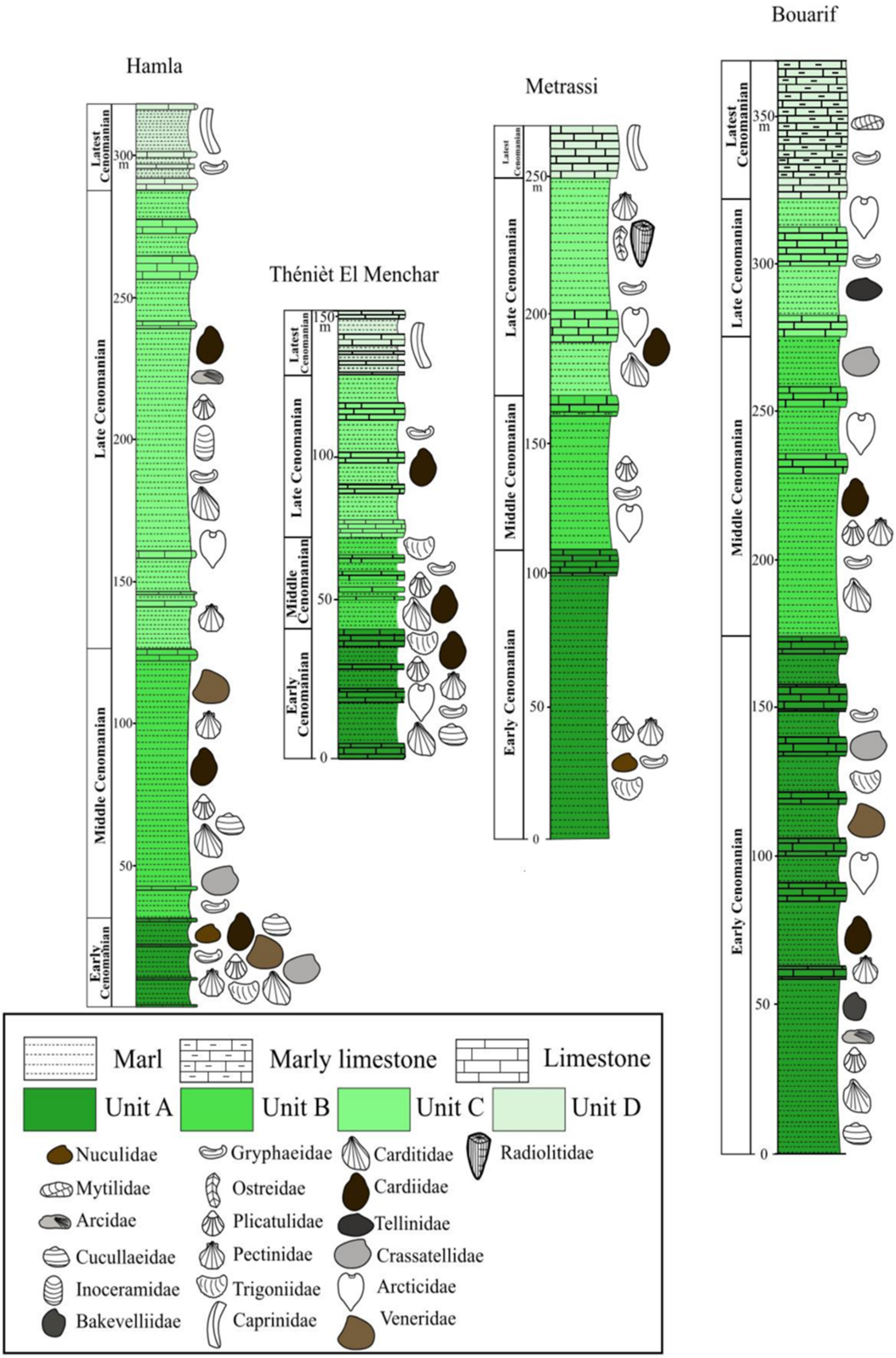

Figure 2. Lithostratigraphic columns of the studied sections.

middle Cenomanian. The paleogeographic scheme of the Eastern Saharan Atlas domain indicates that the Batna Mountains are located around the ramp-basin transition (Herkat, 2004).

MATERIAL AND METHODS

The studied material was collected from the Marnes de Smail Formation in four sections located in the northern and southern surroundings of Batna city: Hamla (UMTS coordinates: 35.86°N/3.83°E), Théniét El Manchar (UMTS coordinates: 35.187°N/4.019°E), Metrassi (UMTS coordinates: 36.197°N/4.042°E), and Bouarif (UMTS coordinates: 36.056°N/4.394°E). These sections were described and sampled bed-by-bed to record the vertical range of its faunal content. A total of 2,369 poorly to moderately preserved (mostly as internal moulds) bivalve specimens were collected exclusively from the marls and further identified in the laboratory. The studied specimens are housed at the Department of Geology, University of Badji Mokhtar, Annaba, under the registration labels: (**BAT**) for Batna locality, (**Ham**) for Hamla, (**TM**) for Théniét El Menchar, (**Me**) for Metrassi, and (**Ba**) for Bouarif respectively.

We describe here the five species recorded for the first time from Batna. The other 30 species previously known are indicated in Table 1 and shown in Figures 3–8. The classification of bivalves follows Carter *et al*. (2011). The morphological terminology follows the glossary of Cox (1969). All linear measurements (taken with Vernier Calipers) are given in millimeters.

Abbreviations: n, number of measured specimens; **L**, shell length; **H**, shell height; **C**, inflation of articulated shell.

SYSTEMATIC PALEONTOLOGY

Class BIVALVIA Linnaeus, 1758
Order NUCULOIDA Dall, 1889
Family NUCULIDAE Gray, 1824

Nucula Lamarck, 1799

Type species. *Arca nucleus* Linnaeus, 1758.

Nucula? cf. *N. margaritifera* Douvillé, 1916
(Figures 3A1–2)

1916 cf. *Nucula margaritifera* Douvillé: p. 177, pl. 21, figs. 19–21.
1955 cf. *Nucula margaritifera* Douvillé – Mahmoud: p. 116, pl. 9, figs. 10–13.
1962 cf. *Nucula* (*Nucula*) *margaritifera* Douvillé – Abbass: p. 7, pl. 1, figs. 1–7.
2002 cf. *Nucula* (*Nucula*) *margaritifera* Douvillé – Abdel-Gawad & Gameil: p. 77, pl.1, fig. 1.
2006 cf. *Nucula* (*Nucula*) *margaritifera* Douvillé – El Qot: p. 16, pl. 1, figs. 1–2, 5–6 (with additional synonymy).
2007 cf. *Nucula* (*Nucula*) *margaritifera* Douvillé – Mekawy: p. 201, pl. 1, fig. 1.
2008 cf. *Nucula* (*Nucula*) *margaritifera* Douvillé – Mekawy & Abu-Zied: p. 294, pl. 1, fig. 1.
2014 cf. *Nucula margaritifera* Douvillé – Ayoub-Hannaa *et al*.: p. 67, pl. 1, fig. 1.
2018. cf. *Nucula margaritifera* Douvillé – Aouissi *et al*.: p. 7, fig. 4(2).

Material. One internal mould collected from Metrassi (Unit A) and one specimen from Hamla **(**Unit A).

Measurements.

n = 2	H	L	C	H/L	C/H	C /L
Range	14–16.33	24.72–25.87	10.15–11.21	0.56–0.63	0.69–0.72	0.41–0.43
Mean	15.16	25.29	10.68	0.59	0.71	0.42

Description. Shell medium-sized, ovate, feebly inflated, equivalve and inequilateral. Umbo prominent, opisthogyrate and located at one-third of shell length from posterior end. Antero-dorsal margin gently inclined, longer than postero--dorsal one and nearly straight in contrast with postero-dorsal one shorter, steeper, and feebly concave. Posterior margin rounded. Anterior margin relatively angular. Ventral margin quite convex, meeting anterior margin in more rounded angle than at posterior one.

Remarks. The studied materials are relatively poorly preserved, but it resembles the *Nucula margaritifera* originally described by Douvillé (1916), particularly in its general shape and size. It differs in being less inflated and lacking any ornamentation.

Occurrence. *Nucula margaritifera* is abundant in the Albian-Cenomanian of Egypt (*e.g*., Douvillé, 1916; Fawzi, 1963; El Qot, 2006; Ayoub-Hannaa *et al*., 2014). The species is also reported from the Barremian (Mekawy & Abu-Zied, 2008).

Order ARCOIDA Stoliczka, 1871
Family ARCIDAE Lamarck, 1809

Barbatia Gray, 1842

Type species. *Arca barbata* Linnaeus, 1758.

Barbatia Gray, 1842

Type species. *Barbatia (Barbatia) tenuitexta* Morris & Lycett, 1853.

Barbatia (*Barbatia*) *aegyptiaca* (Fourtau, 1917)
(Figures 3C1–2)

1917 *Arca aegyptiaca* Fourtau: p. 6, pl. 2, fig. 12.
1962 *Arca* (*Barbatia*) *aegyptiaca* Fourtau – Abbass: p. 16, pl. 2, figs. 1–2.

Table 1. Taxonomical list with frequency of bivalve species from Cenomanian of Batna.

Species	**CENOMANIAN**															
	Lower				Middle				Upper							
	Unit A				Unit B				Unit C				Unit D			
	Ham	Me	TM	Ba	Ham	Me	TM	Ba	Ham	Me	TM	Ba	Ham	Me	TM	Ba
Nucula ? cf. *margaritifera* Douvillé, 1916	01	01														
Modiolus (*M.*) *aequalis* (J. Sowerby, 1818)																01
Barbatia (*B.*) *aegyptiaca* (Fourtau, 1917)				01												
Barbatia (*Barbatia*) *trigeri* (Coquand, 1862)									01							
Cucullaea (*I.*) *trigona* (Seguenza, 1882)	05		03	11	01											
Mytiloides ? sp.									01							
Phelopteria gravida (Coquand, 1862)				08												
Pycnodonte (*P.*) *vesicularis vesiculosa* (Sowerby, 1823)																50
Costagyra olisiponensis (Sharpe, 1850)	32	02	04	91	19	09		07	03	04			01			01
Ceratostreon flabellatum (Goldfuss, 1833)		02	84	07	08	01	52	01	30	40	16	35				
Ilymatogyra africana (Lamarck, 1801)									01	01		03				
Rhynchostreon suborbiculatum (Lamarck, 1801)	140	138	112	173	101	05	05	40	106	78	167	56				
Rastellum carinatum (Lamarck, 1806)										04						
Plicatula (*P.*) *auressensis* Coquand, 1862	07	02	06	13	07	11	04	01	02							
Plicatula (*P.*) *ferryi* Coquand, 1862	02		05	13												
Neithea (*N.*) *coquandi* (Péron, 1877)	03	07	05	20	04			02	03							
Neithea (*N.*) *dutrugei* (Coquand, 1862)			02	05	02			03		02						
Neithea (*N.*) *quinquecostata* Sowerby, 1814			01		02			01								
Neithea sp.		01														
Pterotrigonia (*S.*) *scabra* (Lamarck, 1819)	08	03	06	18			02									
Caprinula boissyi (d'Orbigny, 1840)													56	70	40	
Radiolites sp.										04						
Maghrebella forgemoli (Coquand, 1862)	03		09	44	05		05	06	09	01						
Maghrebella sp.				01												
Granocardium (*G.*) *desvauxi* (Coquand, 1862)	09			03			01	01		06						
Granocardium (*G.*) *productum* (Sowerby, 1832)				01				01	01	01						
Protocardia hillana (Sowerby, 1813)	06		02	08	01		04		01		01					
Protocardia (P.) pauli (Coquand, 1862)							03									
Tellina? sp.												02				
Crassatella baudeti Coquand, 1862	21			22					19			20				
Arctica cordata (Sharpe, 1850)				01												
Arctica inornata (d'Orbigny, 1844)				05												
Tenea delettrei (Coquand, 1862)			05	06		03		01	01	02		03				
Paraesa faba (Sowerby, 1827)	04			05												
Meretrix desvauxi (Coquand, 1862)	07			11	03											

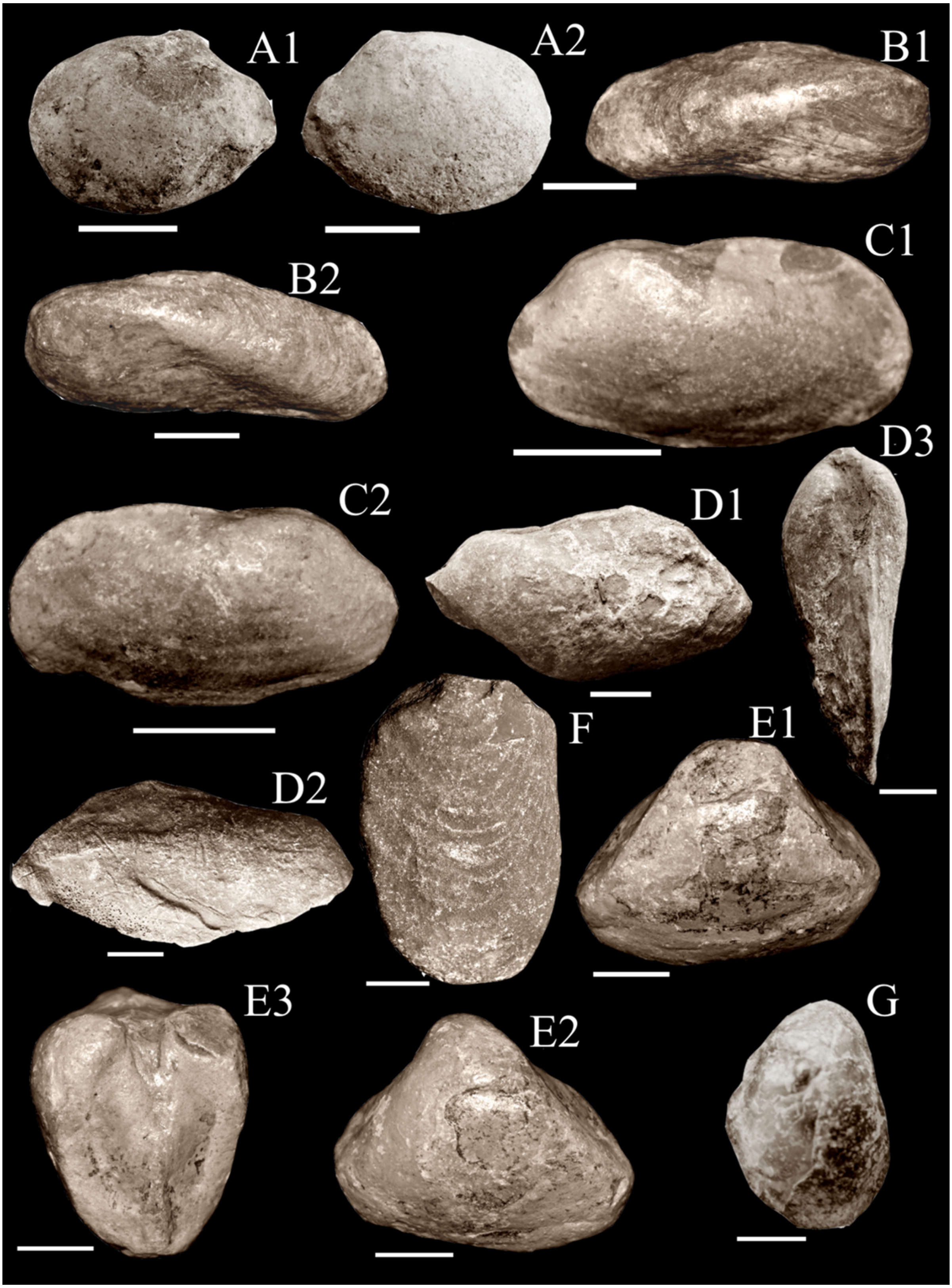

Figure 3. A1–2, *Nucula*? cf. *margaritifera* Douvillé, 1916; Metrassi section (Unit A); **A1**, external view of right valve, **A2**, external view of left valve; BAT-Me44. **B1**–**2**, *Modiolus* (*Modiolus*) *aequalis* (Sowerby, 1818); Bouarif section (Unit D); **B1**, side view of right valve, **B2**, side view of left valve; BAT-Ba1092. **C1**–**2**, *Barbatia (Barbatia) aegyptiaca* (Fourtau, 1917); Bouarif section (Unit A); **C1**, side view of left valve; **C2**, side view of right valve; BAT-Ba150. **D1**–**3**, *Barbatia (Barbatia*) *trigeri* (Coquand, 1862); Hamla section (Unit C); **D1**, side view of left valve; **D2**, side view of right valve; **D3**, dorsal view; BAT-Ham755. **E1**–**3**, *Cucullaea* (*Idonearca*) *trigona* (Seguenza, 1882); Bouarif section (Unit A), **E1**, side view of right valve; **E2**, side view of left valve; **E3**, posterior view; BAT-Ba53. **F**, *Mytiloides* sp.; Hamla section (Unit C), side view; BAT-Ham654. **G**, *Pycnodonte* (*Phygraea*) *vesicularis vesiculosa* (Sowerby, 1823); Bouarif section (Unit D), side view of left valve; BAT-Ba1091. Scale bars = 10 mm.

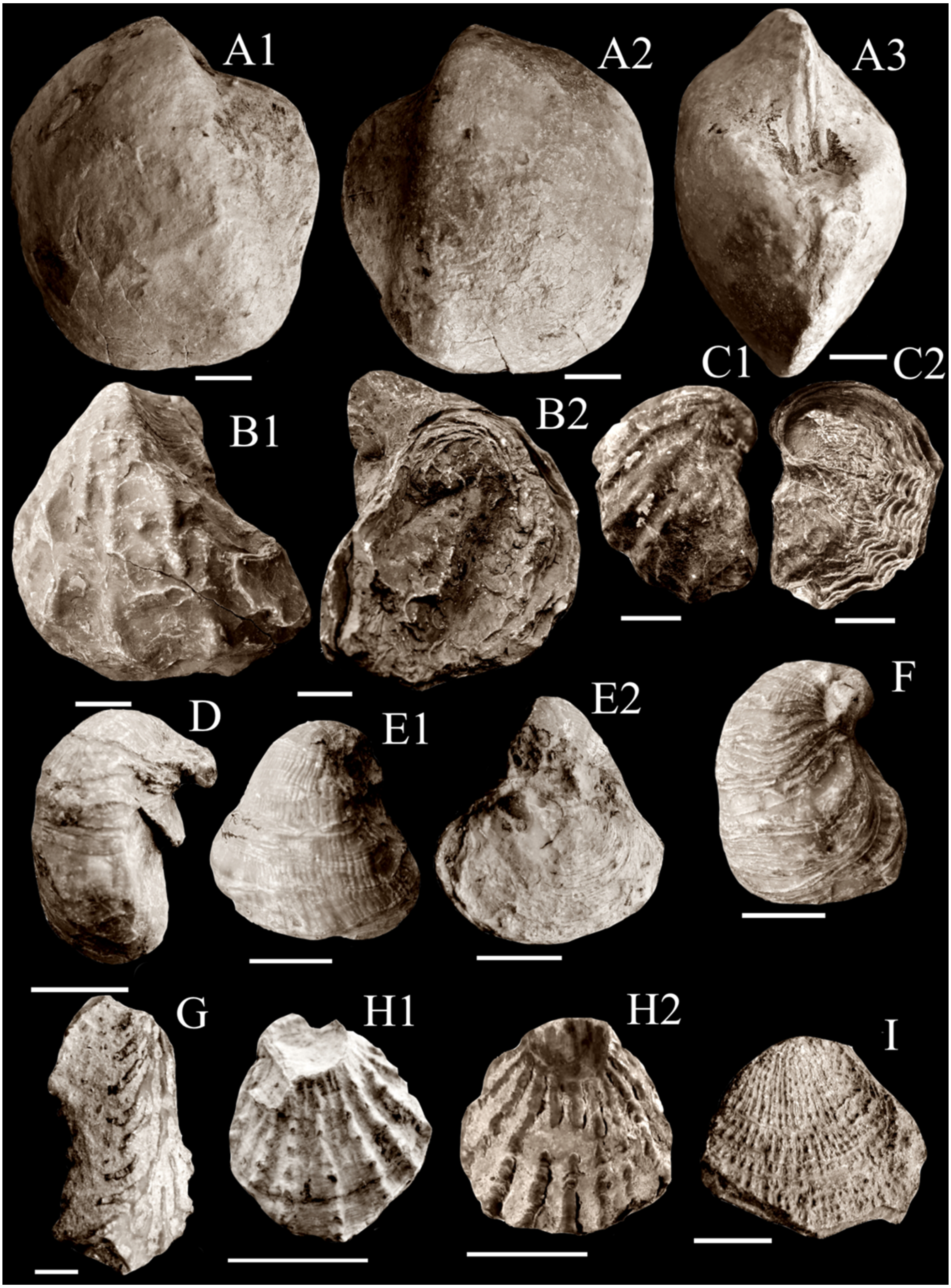

Figure 4. A1–**3**, *Phelopteria gravida* (Coquand, 1862); Bouarif section (Unit A); **A1**, side view of right valve; **A2**, side view of left valve; **A3**, dorsal view; BAT-Ba70. **B1**–**2**, *Costagyra olisiponensis* (Sharpe, 1850); Hamla section (Unit A); **B1**, side view of left valve; **B2**, side view of right valve; BAT-Ham22. **C1**–**2**, *Ceratostreon flabellatum* (Goldfuss, 1833); Bouarif section (Unit C); **C1**, side view of left valve; **C2**, side view of right valve; BAT-Ba918. **D**, *Ilymatogyra africana* (Lamarck, 1801); Bouarif section (Unit C), side view of left valve; BAT-Ba986. **E1**–**2**, *Rhynchostreon suborbiculatum* (Lamarck, 1801); Hamla section (Unit C); **E1**, side view of left valve; **E2**, side view of right valve; BAT-Ham664. **F**, *Rhynchostreon suborbiculatum* (Lamarck, 1801); Bouarif section (Unit A), side view of left valve; BAT-Ba43. **G**, *Rastellum carinatum* (Lamarck, 1806); Metrassi section (Unit C), side view; BAT-Me494. **H1**–**2**, *Plicatula* (*Plicatula*) *auressensis* (Coquand, 1862); Hamla section (Unit A), side views; BAT-Ham114. **I**, *Plicatula* (*Plicatula*) *ferryi* (Coquand, 1862); Hamla section (Unit A), side view; BAT-Ham192. Scale bars = 10 mm.

1981 *Barbatia (Barbatia) aegyptiaca* (Fourtau) – Collignon: p. 264, pl. 8, fig. 3.
2002 *Barbatia aegyptiaca* (Fourtau) – Abdelhamid & El Qot: p. 261, pl. 1, fig. 1.
2006 *Barbatia (Barbatia) aegyptiaca* (Fourtau) – El Qot: p. 22, pl. 2, figs. 3–5.
2007 *Barbatia (Barbatia) aegyptiaca* (Fourtau) – Mekawy: p. 6, pl. 1, fig. 6.
2013 *Barbatia* (*Barbatia*) cf. *aegyptiaca* (Fourtau) – El Qot *et al*.: p. 190, pl. 1, fig. 8 (with synonymy).
2016 *Barbatia* (*Barbatia*) cf. *aegyptiaca* (Fourtau) – Benzaggagh: p. 5, figs. 5A–B.

Material. One internal mould from Bouarif (Unit A).
Measurements.

n = 1	H	L	C	H/L	C/H	C/L
Measurement	14.9	28.5	9.6	0.52	0.64	0.34

Description. Shell medium-sized, elongated oval, longer than high, equivalve and strongly inequilateral. Umbo prosogyrate and situated at about one-third of the shell length from the anterior end. Antero-dorsal margin concave below the umbo, posterior margin inclined and nearly straight. Posterio-umbonal keel well-developed. Ornamentation consisting of numerous (up to 45) fine radial ribs, crossed by faint commarginal lines.
Remarks. Our specimen appears identical to that of Fourtau (1917) in terms of overall shape, quite prominent umbones and relatively inflated shell.
Occurrence. According to El Qot *et al*. (2013), *Barbatia aegyptiaca* was recorded from the Cenomanian of Egypt, Libya, Syria, and Iran, as well as from the Cenomanian of Morocco (Benzaggagh, 2016).

Family CUCULLAEIDAE Stewart, 1930

Cucullaea Lamarck, 1801

Type species. *Cucullaea auriculifera* Lamarck, 1801.

Idonearca Conrad, 1862

Type species. *Cucullaea tippana* Conrad, 1858.

Cucullaea (*Idonearca*) *trigona* (Seguenza, 1882)
(Figures 3E1–3)

1882 *Arca trigona* Seguenza: p. 98, pl. 13, fig. 6a.
1912 *Arca* (*Trigonarca*?) *trigona* Seguenza – Pervinquière: p. 103, pl. 7, figs. 20–21.
2006 *Cucullaea* (*Idonearca*) *trigona* (Seguenza) – El Qot: p. 25, pl. 3, fig. 2.
2014 *Cucullaea* (*Idonearca*) *trigona* (Seguenza) – Ayoub-Hannaa *et al*.: p. 71, pl. 1, figs. 7–8.
2016 *Cucullaea* (*Idonearca*) *trigona* (Seguenza) – Benzaggagh: p. 189, fig. 5(D–E).
2021 *Cucullaea* (*Idonearca*) *trigona* (Seguenza) – Mendir *et al*.: p. 4, figs. 3/A1–2, B1–2, C.

Material. Twenty internal moulds: 11 specimens from Bouarif (Unit A), six specimens from Hamla (five from Unit A and one from Unit B) and three specimens from Théniè̀t El Menchar (Unit A).
Measurements.

n = 20	H	L	C	H/L	C/H	C/L
Range	66.09–70.28	60.09–69.37	41.97–51.27	1–1.12	0.64–0.73	0.7–0.8
Mean	68.18	64.73	46.62	1.06	0.68	0.75

Remarks. The material resembles *Cucullaea* (*Idonearca*) *trigona*, described by Pervinquière (1912) from the Turonian of Tunisia, in general shape and outline. *Cucullaea* (*Idonearca*) *thevestensis* (Coquand, 1862) can be separated from *C.* (*I.*) *trigona* by its higher and more inflated shell.
Occurrence. *Cucullaea (Idonearca) trigona* has a wide stratigraphic range, from the Albian to the Santonian. It was recorded from Europe (Italy) and Northern Africa (Tunisia, Morocco, Egypt, and Libya).

Order VENEROIDA Adams & Adams, 1856
Family ARCTICIDAE Newton, 1891

Arctica Schumacher, 1817

Type species. *Arctica vulgaris* Schumacher, 1817 (= *Venus islandica* Linnaeus, 1767).

Arctica cordata (Sharpe, 1850)
(Figures 6F1–3)

1850 *Cyprina cordata* Sharpe: p. 182, pl. 15, fig. 2.
2006 *Arctica cordata* (Sharpe) – El Qot: p. 81, pl. 16, figs. 10, 11.
2014 *Arctica cordata* (Sharpe) – Hewaidy *et al*.: p. 225, pl. 3, fig. 1.
2019 *Arctica cordata* (Sharpe) – Ayoub-Hannaa *et al*.: p. 185, pl. 6, figs. L–M; pl. 7, fig. A.

Material. One complete internal mould collected from Bouarif (Unit A).
Measurements.

n = 1	H	L	C	H/L	C/H	C/L
Measurement	42.13	50.62	25.17	0.83	0.6	0.5

Remarks. *Arctica cordata* (Sharpe, 1850) from the Cenomanian of Portugal, differs from *Arctica picteti* (Coquand, 1862) by its more inflated shell, nearly subrounded outline and more prominent umbo.

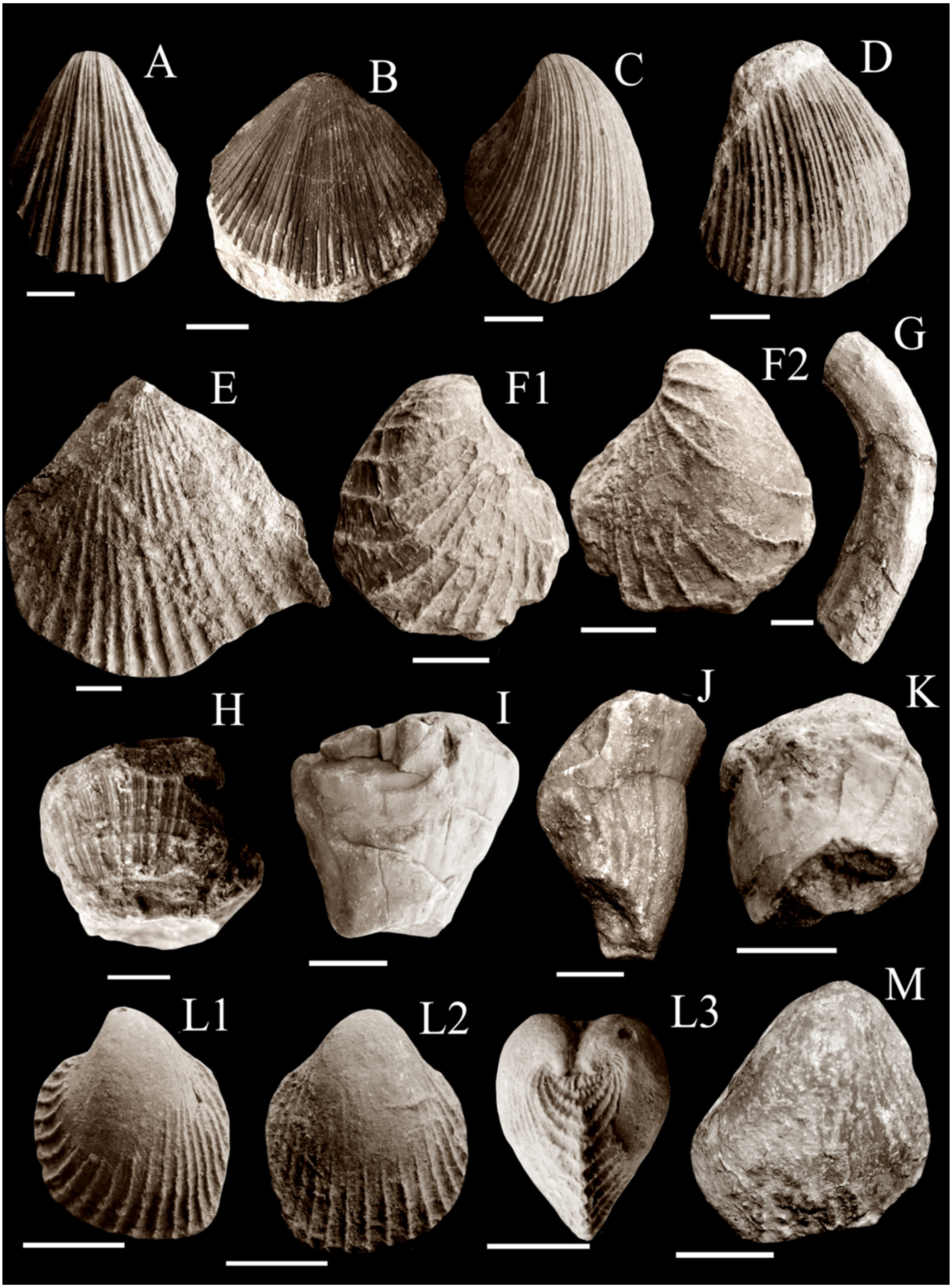

Figure 5. A, *Neithea* (*Neithea*) *coquandi* (Péron, 1877), Bouarif section (Unit A), side view of right valve; BAT-Ba199. **B**, *Neithea* (*Neithea*) *dutrugei* (Coquand, 1862); Bouarif section (Unit A), side view of right valve; BAT-Ba265. **C**, *Neithea* (*Neithea*) *quinquecostata* (Sowerby, 1814); Bouarif section (Unit B), side view of right valve; BAT-Ba741. **D**, *Neithea* (*Neithea*) *quinquecostata* (Sowerby, 1814); Hamla section (Unit B), side view of right valve; BAT-Ham474. **E**, *Neithea* sp.; Thénièt El Menchar section (Unit A), side view of right valve; BAT-TM94. **F1**–**2**, *Pterotrigonia* (*Scabrotrigonia*) *scabra* (Lamarck, 1819); Hamla section (Unit A); **F1**, side view of left valve; **F2**, side view of right valve; BAT-Ham218. **G**, *Caprinula boissyi* (d'Orbigny, 1940); Hamla section (Unit D), side view; BAT-Ham908. **H**–**K**, *Radiolites* sp.; Metrassi section (Unit C), side views; BAT-Me361-364. **L1**–**3**, *Maghrebella forgemoli* (Coquand, 1862); Hamla section (Unit A); **L1**, side view of left valve; **L2**, side view of right valve; **L3**, dorsal view; BAT-Ham314. **M**, *Maghrebella* sp.; Bouarif section (Unit A), side view of right valve; BAT-Ba381. Scale bars = 10 mm.

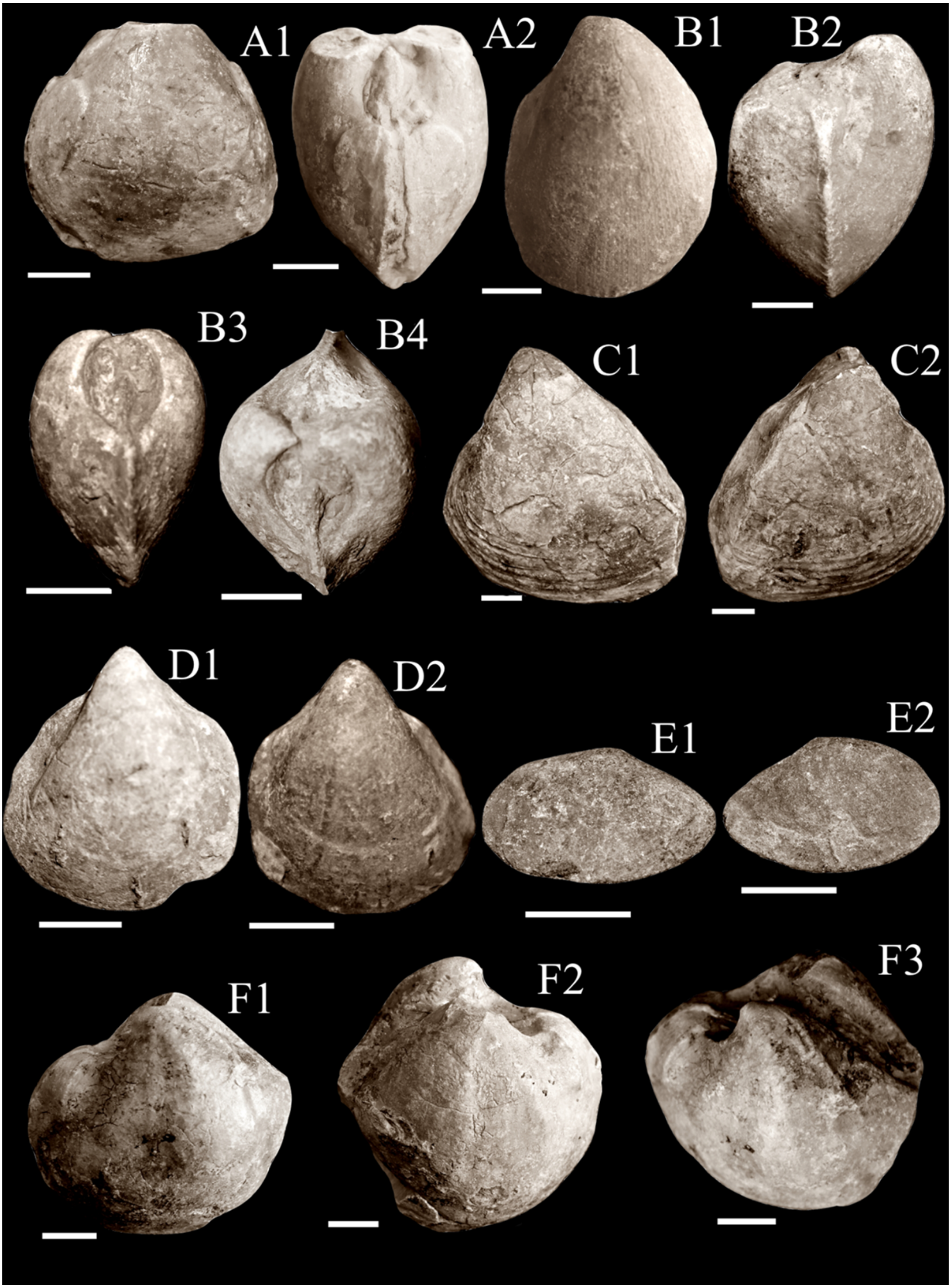

Figure 6. A1–**2**, *Granocardium* (*Granocardium*) *desvauxi* (Coquand, 1862); Hamla section (Unit A); **A1**, side view; **A2**, anterior view; BAT-Ham101. **B1**–**4**, *Granocardium* (*Granocardium*) *productum* (Sowerby, 1832); Bouarif section (Unit A); **B1**, side view of right valve; **B2**–**B3**, posterior views; **B4**, dorsal view; BAT-Ba467. **C1**–**2**, *Protocardia hillana* (Sowerby, 1813); Hamla section (Unit A); **C1**, side view of left valve; **C2**, side view of right valve; BAT-Ham85. **D1**–**2**, *Protocardia pauli* (Coquand, 1862); Bouarif section (Unit A), side views; BAT-Ba330**. E1**–**2**, *Tellina* sp.; Bouarif section (Unit C); **E1**, side view of right valve; **E2**, side view of left valve; BAT-Ba991. **F1**–**3**, *Arctica cordata* (Sharpe, 1850); Bouarif section (Unit A), **F1**, side view of left valve; **F2**–**F3**, dorsal views; BAT-Ba219. Scale bars = 10 mm.

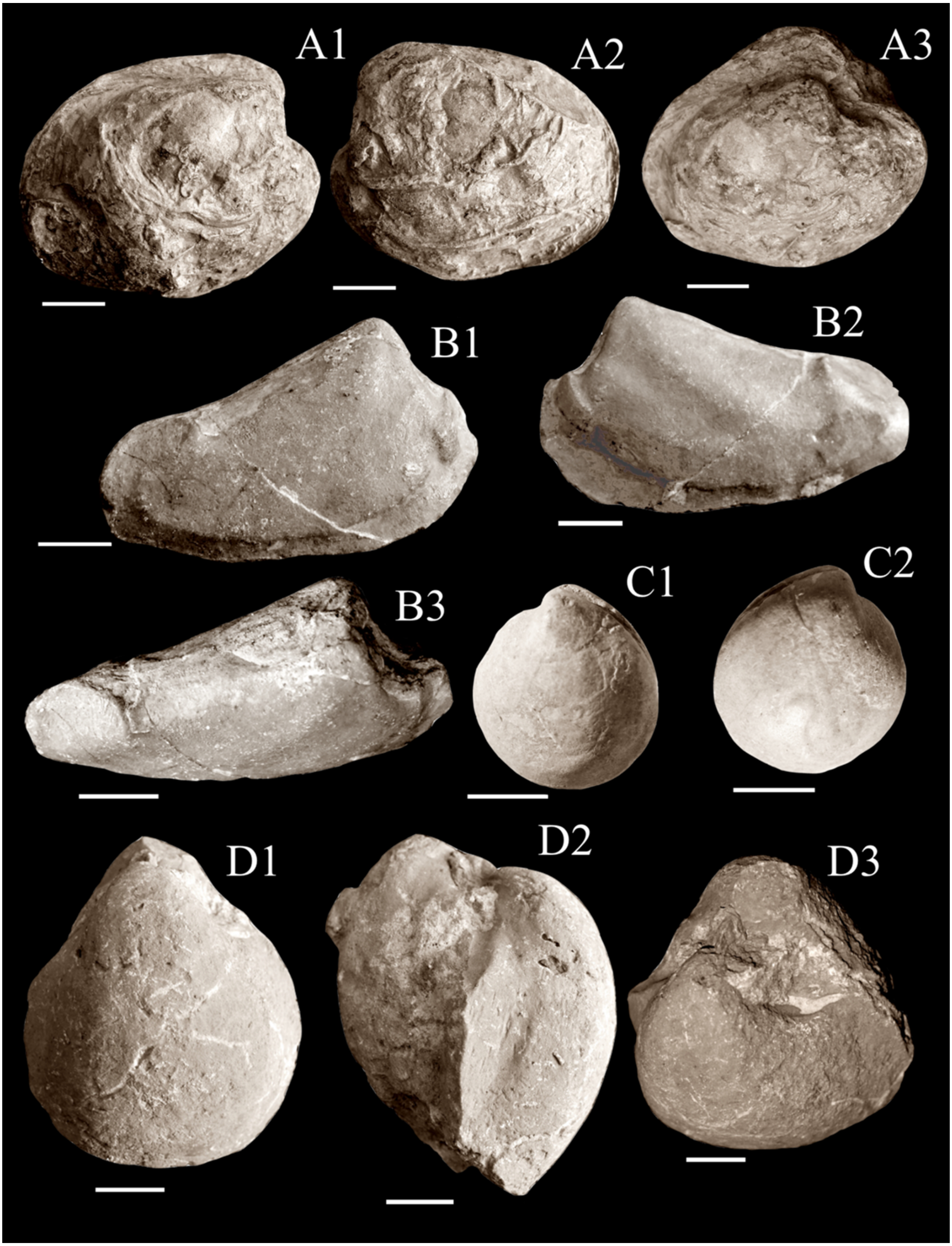

Figure 7. A1–3, *Arctica inornata* (d'Orbigny, 1844); Bouarif section (Unit A); **A1**, side view of right valve; **A2**, side view of left valve; **A3**, dorsal view; BAT-Ba316. **B1**–**3**, *Crassatella baudeti* Coquand, 1862; Hamla section (Unit A); **B1**, side view of right valve; **B2**, side view of left valve; **B3**, dorsal view; BAT-Ham171. **C1**–**2**, *Tenea delettrei* (Coquand, 1862); Bouarif section (Unit C); **C1**, side view of left valve; **C2**, side view of right valve; BAT-Ba928. **D1**–**3**, *Granocardium* (*Granocardium*) *productum* (Sowerby, 1832); Bouarif section (Unit A); **D1**, side view of left valve; **D2**, anterior view; **D3**, dorsal view; BAT-Ba468. Scale bars = 10 mm.

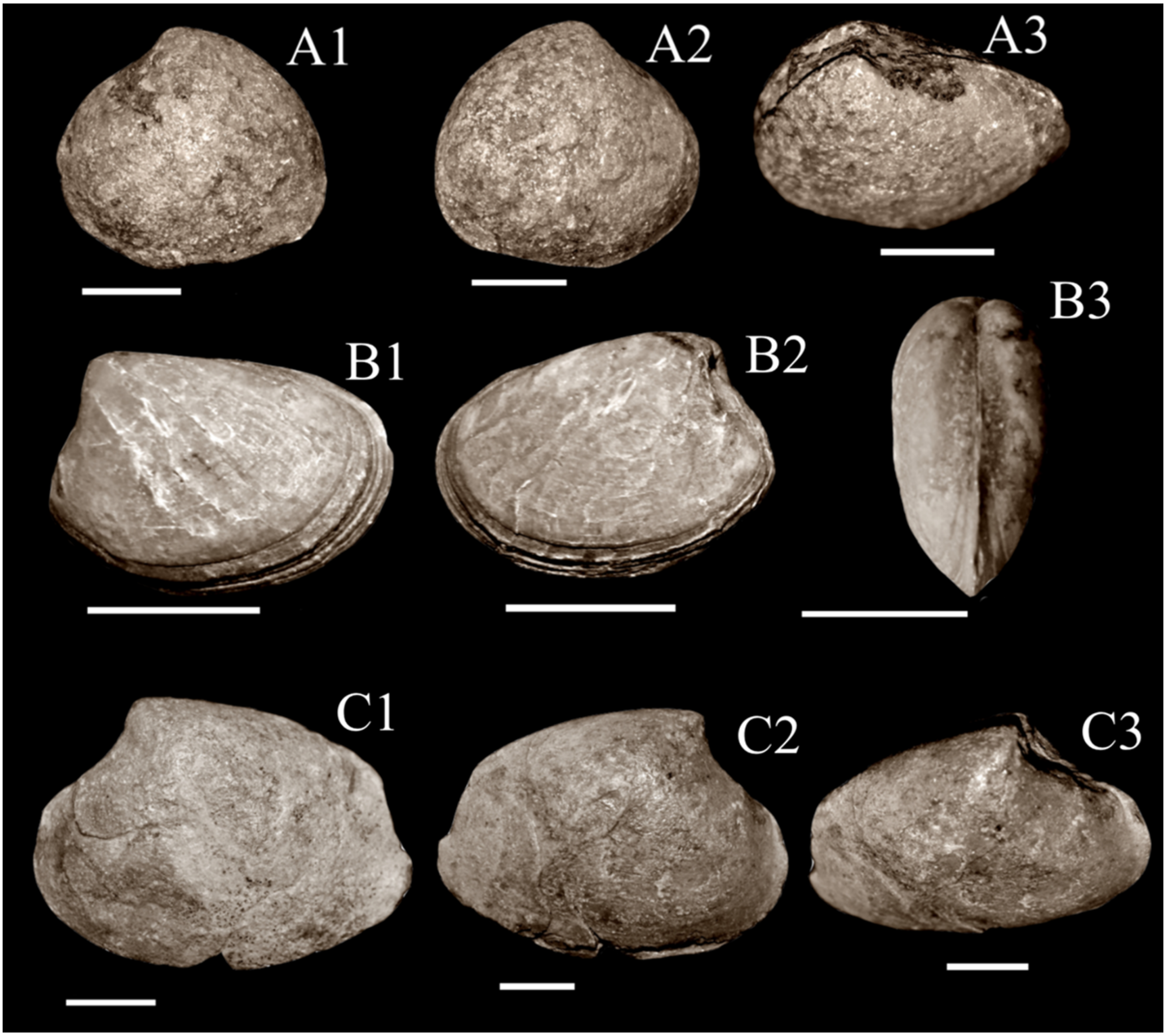

Figure 8. A1–**3**, *Paraesa faba* (Sowerby, 1827); Hamla section (Unit A); **A1**, side views of left valve; **A2**, side views of right valve; **A3**, dorsal views; BAT-Ham185. **B1**–**3**, *Paraesa faba* (Sowerby, 1827); Bouarif section (Unit A); **B1**, side views of left valve, **B2**, side views of right valve; **B3**, dorsal views; BAT-Ba478. **C1**–**3**, *Meretrix desvauxi* (Coquand, 1862); Hamla section (UnitA); **C1**, side view of left valve; **C2**, side view of right valve; **C3**, dorsal view; BAT-Ham120. Scale bars = 10 mm.

Occurrence. *Arctica cordata* is recorded from the Cenomanian of Portugal (Sharpe, 1850) and Egypt (El Qot, 2006; Hewaidy *et al*., 2014), and the upper Turonian of Brazil (Ayoub-Hannaa *et al*., 2019).

Arctica inornata (d'Orbigny, 1844)
(Figures 7A1–3)

1844 *Cyprina inornata* d'Orbigny: p. 99, pl. 272, figs. 1–2.
2006 *Arctica inornata* (d'Orbigny) – El Qot: p. 82, pl. 16, fig. 13; pl. 17, fig. 1.
2007 *Arctica inornata* (d'Orbigny) – Mekawy: p. 232, pl. 5, fig. 8.
2014 *Arctica inornata* (d'Orbigny) – Ayoub-Hannaa *et al*. 2014: p. 118, pl. 11, fig. 2.

Material. Five internal moulds collected from Bouarif (all from Unit A).

Measurements.

n = 5	H	L	C	H/L	C/H	C/L
Range	51.71–54.17	60.43–63.24	29.20–30.22	0.85–0.86	0.56	0.48
Mean	52.94	61.83	29.71	0.85	0.56	0.48

Remarks. According to El Qot (2006) *Arctica inornata* is distinguished from other *Arctica* species in having a less prominent umbo and a shallow antero-dorsal margin.

Occurrence. *Arctica inornata* is recorded from the Cenomanian of France (d'Orbigny, 1844), Tunisia (Pervinquière, 1912) and Egypt (Greco, 1918; El Qot, 2006; Mekawy, 2007).

REMARKS ON PALECOLOGY

Early Cenomanian

The early Cenomanian of Batna is characterized by a diverse and abundant fauna of bivalves (77.74% of the benthic community). This assemblage is characterized by the dominance of oysters (74.07% of the bivalve assemblage), mainly *Costagyra olisiponensis* and *Rhynchostreon suborbiculatum* (Figure 9A). These species are associated, in decreasing order, with *Ceratostreon flabellatum*, *Maghrebella forgemoli*, *Crassatella baudeti* and *Pterotrigonia scabra.* The strong dominance of *Costagyra olisiponensis* in the basal part of the lower Cenomanian and the abundance of *Rhynchostreon suborbiculaum* in the upper levels of the same substage, are quite appealing. Concerning water depth, these species thrived in a shallow, weakly agitated environment ranging between – 25 and – 50 m (Stenzel, 1971; Bottjer, 1981; Dhondt *et al*., 1999; El-Sabbagh *et al*., 2015), consistent with the scarcity of bioerosive traces.

These beds mostly contain suspensivorous organisms (99.81%; *e.g*., *Costagyra olisiponensis*), thus suggesting a relatively high-water energy with a low rate of sedimentation.

The abundance of ammonites in the lower Cenomanian strata and their association with benthonic macrofauna, especially Exogyrinae, indicate a more or less shallow marine environment situated in the lower levels of proximal part of the platform.

Middle Cenomanian

The bivalve assemblages are less diverse and abundant in the middle Cenomanian than in the lower Cenomanian (44.77% of the benthic community). Oysters represent 75.14% of the bivalve assemblage (Figure 9B). They are mostly represented by *Rhynchostreon suborbiculatum*. Besides the abundance of the coral *Aspidiscus cristatus*, we also notice the presence of *Ceratostreon flabellatum* and *Plicatula auressensis*. The marked occurrence of predators, especially carnivorous gastropods of the genera *Pterodonta*, *Tylostoma* and *Columbellina*, is considered the principal factor that limited the proliferation of oysters (Mekawy, 2010). Hence their size increase could be interpreted as an adaptative strategy for surviving and overcoming predatory pressure, enhanced by the relatively high temperature favourable to the carbonate secretion by marine organisms (Palmer, 1982; Mekawy, 2010). The high percentage of suspensivorous (99.81% of bivalves) indicates a rich nutritional content of the environment. The occurrence of some shallow endofaunal organisms (20%) would rather indicate a soft and rather stable bottom, along with the associated presence of depositivorous organisms, as well as the large form *Strombus incertus*.

During the middle Cenomanian, along with the abundance of *Aspidiscus cristatus*, proliferates a benthic association composed of *Rhynchostreon suborbiculatum* and *Neithea* that confirms a shallow marine environment (Andrade *et al*., 2004), under low energy currents (Salmi-Laouar *et al*., 2019). Slow bottom currents would have been responsible for the suspension-and-nutrient-rich waters required by most bivalves (Berndt, 2002; Fürsich & Thomsen, 2005; Ayoub-Hannaa *el al*., 2014). This kind of environment favoured the presence of certain shallow, infaunal organisms in quite soft substratum, especially stable due to the presence of depositivorous organisms, as well as the large form *Strombus incertus*. Thus, considering this environment and geological context, middle Cenomanian assemblages would correspond to the upper part of the infralittoral zone, with quite warm waters, low energy, and quite high sedimentation rate. The frequent bioerosive traces both on the external and internal side of the index coral species support a more agitated environment with quite strong energy sufficient to dislodge colonies (Pandey *et al*., 2011; Salmi-Laouar *et al*., 2019).

Late Cenomanian

The late Cenomanian is clearly dominated by bivalves, representing 55.30% of the benthic community. Oysters represent 93.5% of the bivalve assemblage (Figure 10A). In all massifs, except for Théniét El Menchar, the upper Cenomanian deposits are twofold: the lower part is dominated by *Ceratostreon flabellatum*, whereas the upper part is characterized by the appearance of *Ilymatogyra africana.* Besides, *Rhynchostreon suborbiculatum* is abundant all through the whole unit. The water depth would range between 25 and 50 m, based on the occurrence of the latter species (Stenzel, 1971; Dhondt *et al*., 1999). The abundance of suspensivorous organisms (99.6%) documents a nutrient-rich, well oxygenated environment. The presence of deep infaunal and depositivorous organisms suggests a soft substratum.

Latest Cenomanian

The bivalves are more abundant in the latest Cenomanian (61.37% of the benthic assemblage) and are essentially represented by two genera: *Caprinula* and *Pycnodonte* (Figure 10B). Oysters are only abundant in Bouarif, mostly represented by *P. vesicularis vesiculosa*. In Metrassi, Hamla and Théniét El Menchar, *Caprinula boissyi* is omnipresent. These species are most often associated with *Costagyra olisiponensis* and *Modiolus aequalis.*

The distribution of the rudist *Caprinula boissyi* and the oyster *Pycnodonte vesicularis vesiculosa* is wide and seems to be guided by water depth. The presence of caprinids suggest mobile susbstrates with high energy (Laviano & Guarnieri, 1989). *P. vesicularis vesiculosa* prefers muddy bottoms on the shallow marine shelf with a low sedimentation rate (*e.g*., Brezina *et al*., 2014; de Winter *et al*., 2018).

The latest Cenomanian macrofauna in Metrassi, Hamla and Théniét El Menchar, dominated by rudists (*Caprinula boissyi*) suggests a platform environment with mobile substrates,

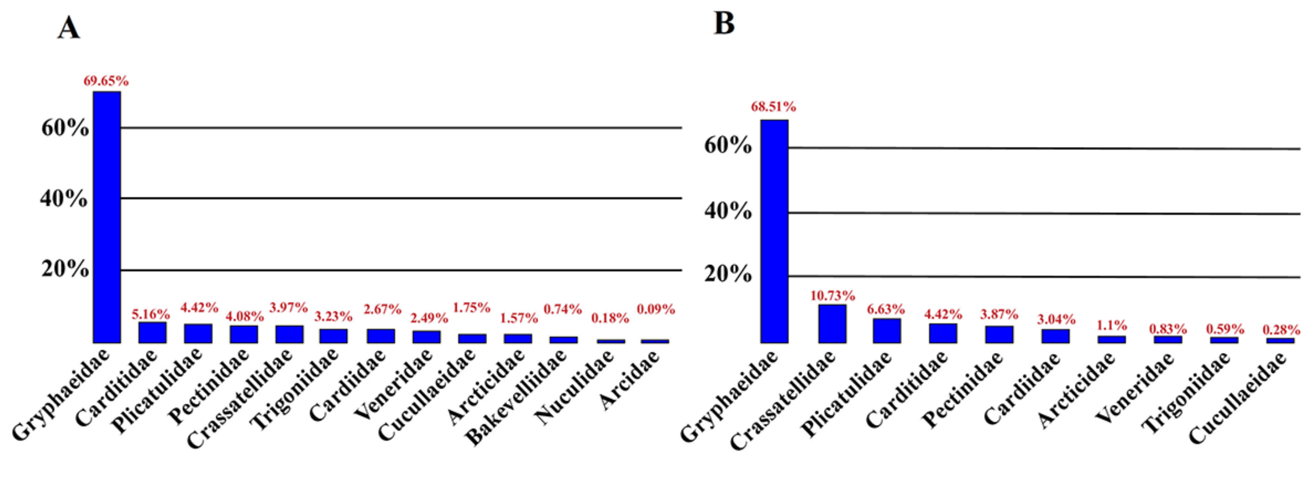

Figure 9. Distribution of the respective bivalve families during the early (**A**) and middle Cenomanian (**B**).

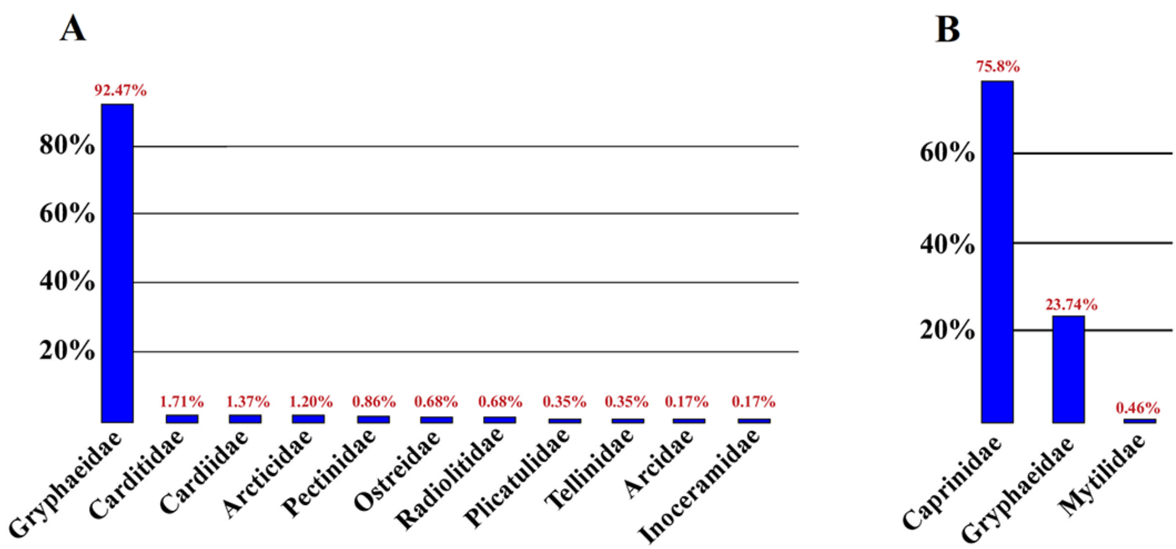

Figure 10. Distribution of the respective bivalve families during the late (**A**) and latest Cenomanian (**B**).

and warm, shallow, and rather agitated waters (Laviano & Guarnieri, 1989; Chikhi-Aouimeur, 1995; Buchblinder *et al*., 2000; Benyoucef *et al*., 2012). Such a water agitation was vital for nerineaceans that, according to Wieczorek (1979), tolerated a stable substrate with low sedimentary rate, and appeared vulnerable to turbulences, substratum instability and high sedimentary rate. In Bouarif, this time interval is clearly dominated by *Pycnodonte vesicularis vesiculosa*; suggesting a deep, rather agitated, and more or less confined environment with instable bottom and a low sedimentation rate (*e.g*., Brezina *et al*., 2014; de Winter *et al*., 2018). The acme of this latter taxon is located below the lower part of the infralittoral zone, only colonizing open environments under fully marine conditions. It shows a dual capacity to tolerate both anoxic and agitated environments even when the substratum is most unstable, managing to implant massively by encrusting other organisms (Videt, 2004).

The evidence suggests that the environmental conditions at Metrassi, Hamla and Théniè̀t El Menchar were shallower and less calm than those at Bouarif.

PALEOBIOGEOGRAPHY

Bivalves were very abundant in the shallow Cretaceous seas (Dhondt, 1982). During the Late Cretaceous, their paleobiogeographic distribution was wider than during the Early Cretaceous (Nagm & Boualem, 2018). It is the most abundant fossil group during the Cenomanian over the whole Tethys (d'Orbigny, 1843; Coquand, 1862, 1869; Péron, 1891; Pervinquière, 1912; Fourtau, 1917; Blanckenhorn,

Table 2. Paleobiogeographic distribution of the main Cenomanian bivalves of Batna.

Species	Mediterranean Region			West Africa (Nigeria, Cameroon, Gabon)	East Africa (Ethiopia, Somalia, Madagascar)	North Europe (England)	South Asia (Iran, India)	South America (Brazil, Peru)
	North Africa (Morocco, Tunisia, Libya, Egypt)	South Europe (Portugal, Spain, France, Italy)	Middle East (Palestine, Libanon, Jordan, Syria)					
Nucula margaritifera	•							
Modiolus (M.) aequalis	•		•					
Barbatia (B.) aegyptiaca	•		•					
Barbatia (B.) trigeri	•		•					
Cucullaea (I.) trigona	•	•						
Phelopteria gravida	•		•					
Pycnodonte (P.) vesicularis vesiculosa	•	•	•		•	•	•	•
Costagyra olisiponensis	•	•	•	•				•
Ceratostreon flabellatum	•	•	•				•	•
Ilymatogyra africana	•	•	•	•	•		•	•
Rhynchostreon suborbiculatum	•	•	•	•			•	•
Rastellum carinatum	•				•	•	•	•
Plicatula (P.) auressensis	•	•	•	•				•
Plicatula (P.) ferryi	•		•	•				
Neithea (N.) coquandi	•	•	•	•	•			•
Neithea (N.) dutrugei	•	•	•				•	
Neithea (N.) quinquecostata	•	•				•		
Pterotrigonia (S.) scabra	•	•			•		•	
Caprinula boissyi	•	•	•					
Maghrebella forgemoli	•							•
Granocardium (G.) desvauxi	•							
Granocardium (G.) productum	•	•		•	•		•	
Protocardia hillana	•				•	•	•	
Protocardia (P.) pauli	•	•		•				•
Crassatella baudeti	•	•		•				
Arctica cordata	•							•
Arctica inornata	•	•						
Tenea delettrei	•	•	•					•
Paraesa faba	•	•				•		
Meretrix desvauxi	•							

1934; Trevisan, 1937; Vokes, 1941; Abbass, 1962; Fawzi, 1963; Collignon, 1971; Freneix, 1972; Amard *et al*., 1981; Dhondt, 1982; Abdel-Gawad, 1995, 2008; Abdel-Gawad *et al*., 2004a, b; El Qot, 2006; El Qot *et al*., 2013; Ayoub-Hannaa *et al*., 2014; El Qot & Abdulsamad, 2016; Benzaggagh, 2016; Aouissi *et al*., 2018; Ghenim *et al*., 2019; Al-Harithi *et al*., 2019). The studied material, found in the Marnes de Smail Formation, evidence paleobiogeographic affinities with assemblages of a wide geographical area of the Tethys, in addition to other areas from the world (Table 2). In this context, just five of the species studied here are endemic to Algeria. The studied fauna shows great similarities with those already reported in the East and the West of Algeria (Fournel, 1849; Coquand, 1869; Aouissi *et al*., 2018; Mendir *et al*., 2021; Benyoucef *et al*., 2012). It also shows affinity with faunas of bivalves from correlative strata in North Africa (among the 35 bivalves identified in this work, 30 of them were reported there; 85%), South Europe (19 species; 54%), Middle East (15 species; 43%); and to a lesser degree to West and East Africa with 8 species each (23%), North Europe with five species (14%), South Asia with nine species (26%) and South America with 12 species (34%).

CONCLUSIONS

The Cenomanian deposits (Marnes de Smail Formation) of Batna (Bouarif, Metrassi, Thénièt El Menchar, and Hamla), eastern Saharan Atlas, Algeria are rich in moderately to well-preserved bivalves. They yield 35 species belonging to nine orders, 19 families and 26 genera. Among them, five taxa are described for the first time from the Cenomanian of the study area (*i.e*., *Nucula* ? cf. *margaritifera* Douvillé, *Barbatia (Barbatia) aegyptiaca* Fourtau, *Cucullaea trigona* Seguenza, *Arctica inornata* d'Orbigny, and *A. cordata* Sharpe).

The studied bivalve assemblages indicate: (i) during the Early Cenomanian, a shallow marine environment situated in the lower levels of proximal part of the platform, with a relatively high water energy and a low rate of sedimentation; (ii) a middle Cenomanian environment corresponding to the upper part of the infralittoral zone, with quite warm waters, low energy, and quite high sedimentation rate; (iii) a Late Cenomanian characterized by an alternation of upper and lower infralittoral environments with a soft substratum and a good degree of oxygenation and food availability; and (iv) a latest Cenomanian that would be shallower in Metrassi, Hamla and Thénièt El Menchar than in Bouarif, with mobile substrates and rather agitated waters in both areas.

The paleobiogeographical distribution of these bivalves show a strong Tethyan affinity, in special with the North Africa area.

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