Turonian-Santonian echinoids from Egypt

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ABSTRACT
Thirty echinoid species (18 regular and 12 irregular) and an undetermined species belonging to 14 genera are studied from the Turonian-Santonian sequence (14 species from Turonian, two species from Turonian-Santonian and 14 species from Coniacian-Santonian) of Abu Roash, Wadi Dakhl and Wadi Abu Qaada, Egypt. Two new species are established: *Thylechinus* (*Thylechinus*) *sinaiensis* n. sp. from the Turonian of Wadi Abu Qaada and *Toxaster dakhlensis* n. sp. from the Turonian of Wadi Dakhl. *Orthopsis ovata* (Coquand, 1862), which is known in other parts of the Tethyan region, is reported for the first time from Egypt. The rank of one subspecies is raised to species level: *Coenholectypus roachensis* (Fourtau, 1914) n. stat. The generic name of three species is changed: *Echinobrissus humei* Fourtau, 1906 is changed to *Petalobrissus humei* (Fourtau, 1906) n. comb.; *Periaster duncani* (Fourtau, 1906) and *Periaster roachensis* Gauthier, 1900 are transfered to the genus *Mecaster* Pomel, 1883. The ontogenetic changes of *Mecaster turonensis* (Fourtau, 1921) are described. The biostratigraphy and paleobiogeography of the fauna are discussed.

KEY WORDS
Cretaceous,
Turonian,
Coniacian-Santonian,
taxonomy,
biostratigraphy,
paleobiogeography,
echinoids,
Egypt,
new combinations,
new species.

RÉSUMÉ
Échinoïdes de la séquence Turonien-Santonien d'Égypte.
Trente espèces d'échinoïdes (18 réguliers et 12 irréguliers) et une espèce indéterminée se répartissant dans 14 genres, et provenant des séquences Turonien-Santonien d'Abu Roash, de Wadi Dakhl et de Wadi Abu Qaada, Égypte, sont étudiées (14 espèces du Turonien, deux du Turonien-Santonien et 14 du Coniacien-Santonien). Deux nouvelles espèces sont décrites : *Thylechinus* (*Thylechinus*) *sinaiensis* n. sp. du Turonien de Wadi Abu Qaada et *Toxaster dakhlensis* n. sp. du Turonien de Wadi Dakhl. *Orthopsis ovata* (Coquand, 1862), déjà présent à d'autres endroits de la région de Thétis, est signalé pour la première fois en Égypte. Une sous-espèce est élevée au rang d'espèce : *Coenholectypus roachensis* (Fourtau, 1914) n. stat. L'attribution générique de trois espèces est modifiée : *Echinobrissus humei* Fourtau, 1906 devient *Petalobrissus humei* (Fourtau, 1906) n. comb.; *Periaster duncani* (Fourtau, 1906) et *Periaster roachensis* Gauthier, 1900 sont transférés dans le genre *Mecaster* Pomel, 1883. Les changements ontogéniques de *Mecaster turonensis* (Fourtau, 1921) sont décrits. La biostratigraphie et la paléobiogéographie de la faune sont discutées.

MOTS CLÉS
Crétacé,
Turonien,
Coniacien-Santonien,
taxonomie,
biostratigraphie,
paléobiogéographie,
échinoïdes,
Égypte,
combinaisons nouvelles,
espèces nouvelles.

INTRODUCTION

As few papers were published on the Cretaceous echinoids of Egypt, especially on the Turonian-Santonian echinoids (Fourtau 1898, 1900, 1901, 1906, 1912, 1914, 1921; Gregory 1906; Lambert 1931-1932; Geys 1992; Abdelhamid 1997; Abdelhamid & El Qot 2001; El Qot 2006, 2010), the present work is devoted to study the taxonomy of the Turonian-Santonian echinoids from Abu Roash (near Cairo), Wadi Dakhl (north Eastern Desert), and Wadi Abu Qaada (west Sinai) (Fig. 1). 30 species are recognized. Two new species are erected: *Thylechinus* (*Thylechinus*) *sinaiensis* n. sp. and *Toxaster dakhlensis* n. sp. *Orthopsis ovata* (Coquand, 1862) is recorded from Egypt for the first time. The generic name of three species is changed. The biostratigraphy and paleobiogeography of the fauna are discussed.

STRATIGRAPHY

The stratigraphic units from which the echinoids of the present work have been collected (Figs 2-4) can be described as follows:

Rudist unit (Turonian)

In Abu Roash section, this unit is composed of 30 m thick of mainly argillaceous limestone with marl, siltstone and shale interbeds, but the basal part is predominated by limestone and calcareous sandstone (Fig. 2). The basal bed is rich in *Phymosoma abbatei* (Gauthier, 1898) and yields also *Mecaster roachensis* (Gauthier, 1900) n. comb. The lowermost and topmost beds are rich in rudists. This unit represents the basal part in the succession of limestones in Abu Roash, subdivided by Beadnell (1902) into four units (rudist unit, limestone unit, Acteonella-Nerinea unit and flinty unit). They correlate with the Wata Formation (Turonian) in other parts of Egypt. The limestone unit is composed of about 55 m of hard, nonfossiliferous crystalline limestone. The Acteonella-Nerinea unit consisted of 7-60 m of hard limestone and marl rich in the gastropods *Acteonella salamonis* Fraas, 1867 and *Nerinea requiniana* d'Orbigny, 1842. The flinty unit is formed from about 55 m of white chalky limestone with flint bands and nodules.

Wata Formation (Turonian)

In Wadi Dakhl section, this formation is composed of 30 m thick of hard cliff forming white argillaceous

limestone, the basal part of which is very rich in large-sized ammonites and echinoids (Fig. 3). In Wadi Abu Qaada section, the Wata Formation is composed of 433 m thick of cliff forming limestone with calcareous siltstone, marl and shale interbeds (Fig. 4). The lowermost bed is marked by the first appearance of large-sized ammonites and the basal part is rich in echinoids.

Ostrea and Plicatula unit (Coniacian-Santonian)

In Abu Roash section, this unit is composed of a sequence of 45 m thick of low-lying hills of marl, limestone, and calcareous siltstone (Fig. 2). It is abnormally rich in typical Coniacian-Santonian marker echinoids and bivalves (specially *Plicatula ferryi* Coquand, 1862, *Curvostrea heinzi* (Péron & Thomas, 1891) and *Gyrostrea roachensis* Fourtau, 1917). The fossil content of this sequence is very similar to that of Matulla and Mezera formations (Coniacian-Santonian) in other parts of Egypt. It shows intermediate characters between the lithology of Matulla Formation (clastic facies) and Mezera Formation (carbonate facies) (see Abdelhamid & El Qot 2001). Ostrea and Plicatula unit represents the lateral equivalent of these two formations.

Matulla Formation (Coniacian-Santonian)

In Wadi Dakhl section, Matulla formation is composed of a sequence of 63 m thick of poorly fossiliferous siltstone and sandstone with sandy limestone interbeds, its basal part yielding echinoids (Fig. 3). In Wadi Abu Qaada section, Matulla Formation is composed of a sequence of 77 m thick of light brown slope forming marl, calcareous siltstone, and argillaceous limestone interbeds (Fig. 4). The upper beds are very rich in Coniacian-Santonian marker echinoids, i.e. *Petalobrissus waltheri* (Gauthier, 1900) and *Mecaster fourneli* (Deshayes, 1847).

MATERIAL AND METHODS

Taxonomy

The systematic classification of echinoids follows that of Durham *et al.* (1966), in addition to the classification used by Smith (1995). The terminology used in the description of the taxa follows the glossary of Durham & Wagner (1966).

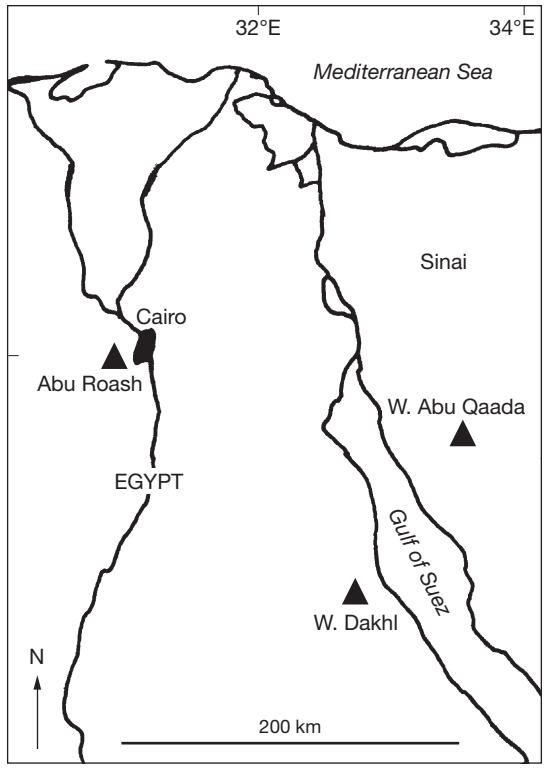


Fig. 1. — Location map showing the localities (▲) from which the present material was collected in Egypt.

Abbreviations

D	test diameter;
Dp	diameter of peristome;
Gabal, Gebel	mountain;
H	test height;
L	test length;
La	length of apical disc;
Lk	length of periproct;
LI	length of petal I;
LII	length of petal II;
Na	number of ambulacral tubercles per one column of the corona;
Ni	number of interambulacral tubercles per one column of the corona;
NI	number of pore pairs in one poriferous zone of petal I or V;
NII	number of pore pairs in one poriferous zone of petal II or IV;

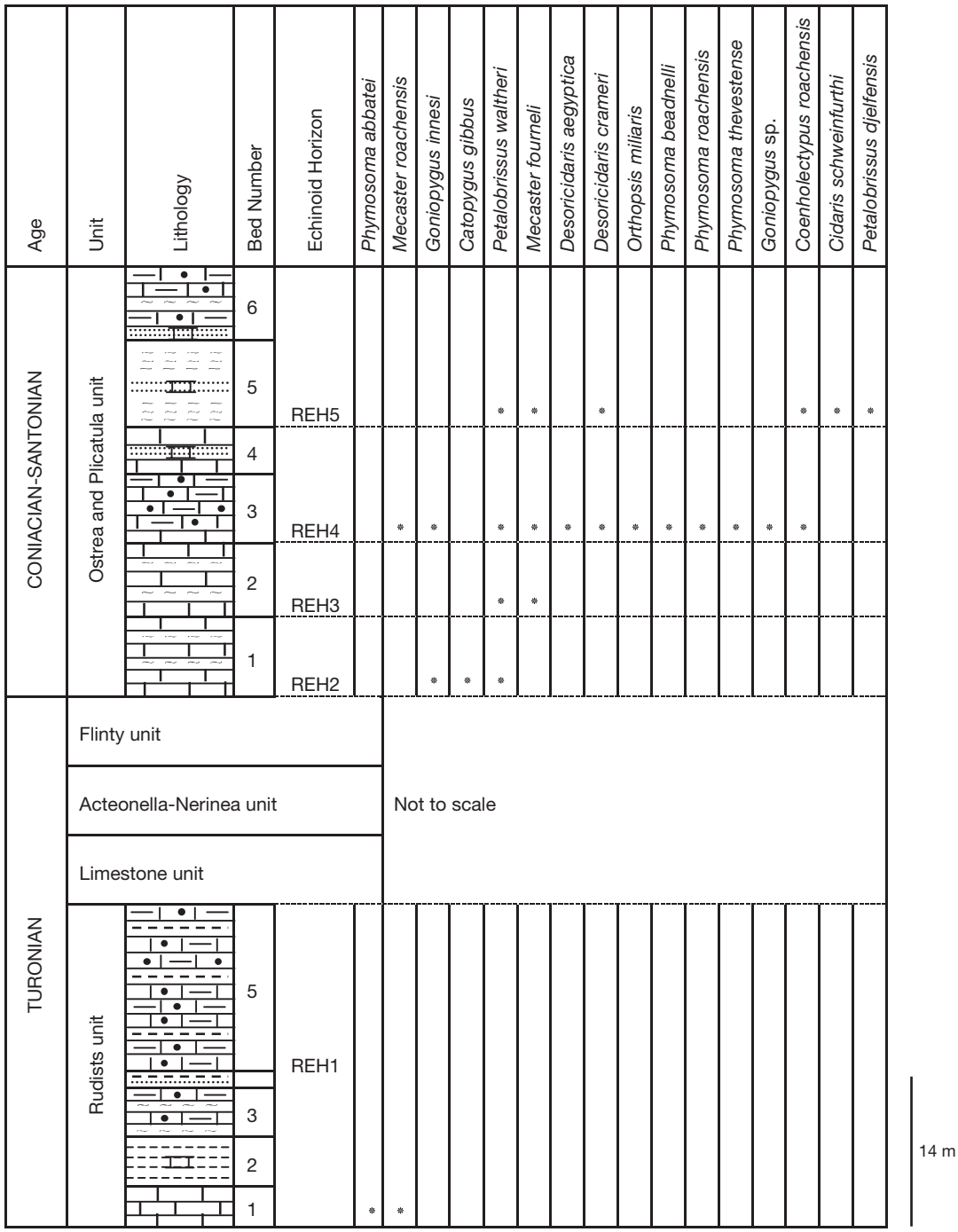


Fig 2. — Stratigraphic section of the Turonian-Santonian sequence in Abu Roash (Rudist unit, Limestone unit, Acteonella-Nerinea unit, Flinty unit and Ostrea and Plicatula unit) showing the distribution of the echinoid species and echinoid horizons. Symbols of lithology: see Figure 3.

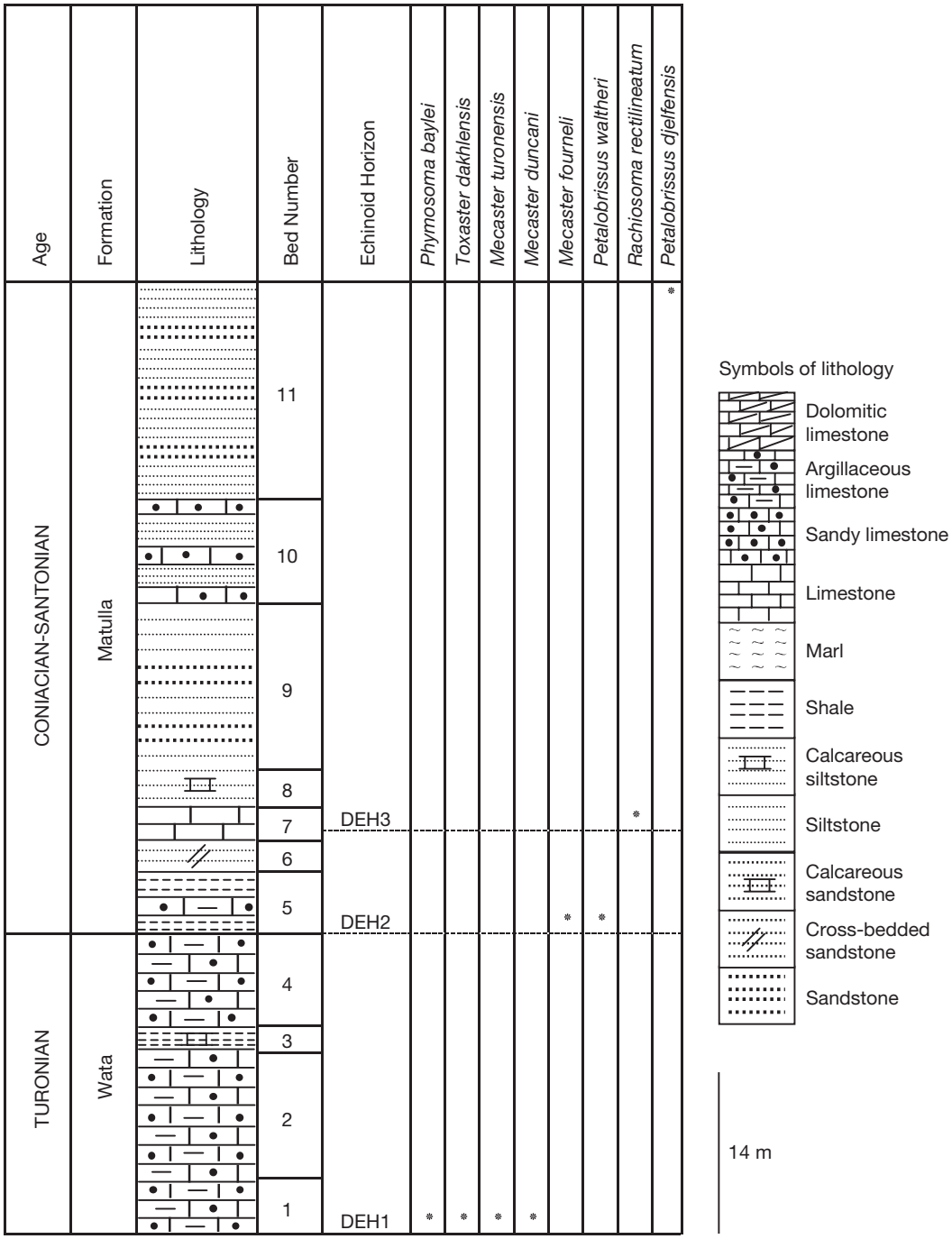


FIG. 3. — Stratigraphic section of the Turonian-Santonian sequence in Wadi Dakhl (Wata and Matulla formations) showing the distribution of the echinoid species and echinoid horizons.

W	test width;
Wa	width of ambulacrum;
Wi	width of interambulacrum;
Wk	width of periproct;
Wadi	valley.

NOTES
All test measurements are given in millimetres. The material is housed in the Geology Department, Ain Shams University, Cairo, Egypt. Detailed synonymy of species is avoided.

SYSTEMATICS

Order CIDAROIDA Claus, 1880
Family CIDARIDAE Gray, 1825
Subfamily RHABDOCIDARINAE Lambert, 1890
Genus *Desoricidaris* Geys, 1992

Desoricidaris aegyptica (Fourtau, 1914) (Fig. 5A)

Leiocidaris aegyptica Fourtau, 1914: 4, pl. 1, fig. 2.

Desoricidaris aegyptica – Geys 1992: 143.

MATERIAL EXAMINED. — Several test fragments from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE1, Abu Roash echinoid horizon 4 (REH4).

DESCRIPTION
Ambulacra narrow, flexuous. Pores in each pore pair equal, oval, conjugate. Pore pairs separated by ridges. Interporiferous zone occupied by four horizontal granules, the outer granules slightly larger than the inner. Interambulacra with two rows of well-developed, perforate, non-crenulated primary tubercles. Areoles shallow, nearly round, surrounded by conspicuous scrobicular tubercles. Adradial extrascrobicular surface null. Interradial extrascrobicular surface narrow.

REMARKS
The relation between the genera *Phyllacanthus* Brandt, 1835, *Leiocidaris* Desor, 1855, *Rhabdocidaris* Desor, 1855 and *Desoricidaris* Geys, 1992 was discussed by Abdelhamid (1997).

Desoricidaris crameri (de Loriol, 1887) (Fig 5B, C)

Rhabdocidaris crameri de Loriol, 1887: 60, pl. 26, figs 6-21.

Desoricidaris crameri – Abdelhamid & El Qot 2001: 5, fig. 3A, B.

MATERIAL EXAMINED. — Numerous test fragments and radioles from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE2-5, Abu Roash echinoid horizons 3, 4 (REH3, REH4).

DESCRIPTION
Ambulacral areas slightly flexuous. Pore pair conjugated. Interporiferous zone with ten horizontal granules at the ambitus, the outer granules are larger than the inner ones around the perradial suture. Interambulacral area with two columns of well-developed, perforate, non-crenulated primary tubercles (Fig. 5C). Areoles deep, elliptical, and surrounded by about 18 scrobicular tubercles. Adradial extrascrobicular surface narrow. Interradial extrascrobicular surface wide. Radioles thick, fan-shaped (Fig. 5B), very large, reaching 34 mm in length.

Subfamily CIDARINAE Gray, 1825
Genus *Cidaris* Leske, 1778

Cidaris schweinfurthi Gauthier, 1901 (Fig. 5D)

Cidaris schweinfurthi Gauthier *in* Fourtau, 1901: 55, pl. 1, figs 1-3.

Dorocidaris schweinfurthi – Fourtau 1914: 1, pl. 1, fig. 1.

Desoricidaris schweinfurthi – Geys 1992: 141, 143.

MATERIAL EXAMINED. — Numerous test fragments and radioles from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE6-7, Abu Roash echinoid horizon 4 (REH4).

DESCRIPTION
Ambulacra slightly flexuous. Pores in the pore pair separated by a granulated ridge. Pore pairs separated by horizontal linear groove. Interporiferous zone occupied by four to six horizontal granules. Areole deep, round, nonconfluent. Adradial extrascrobicular

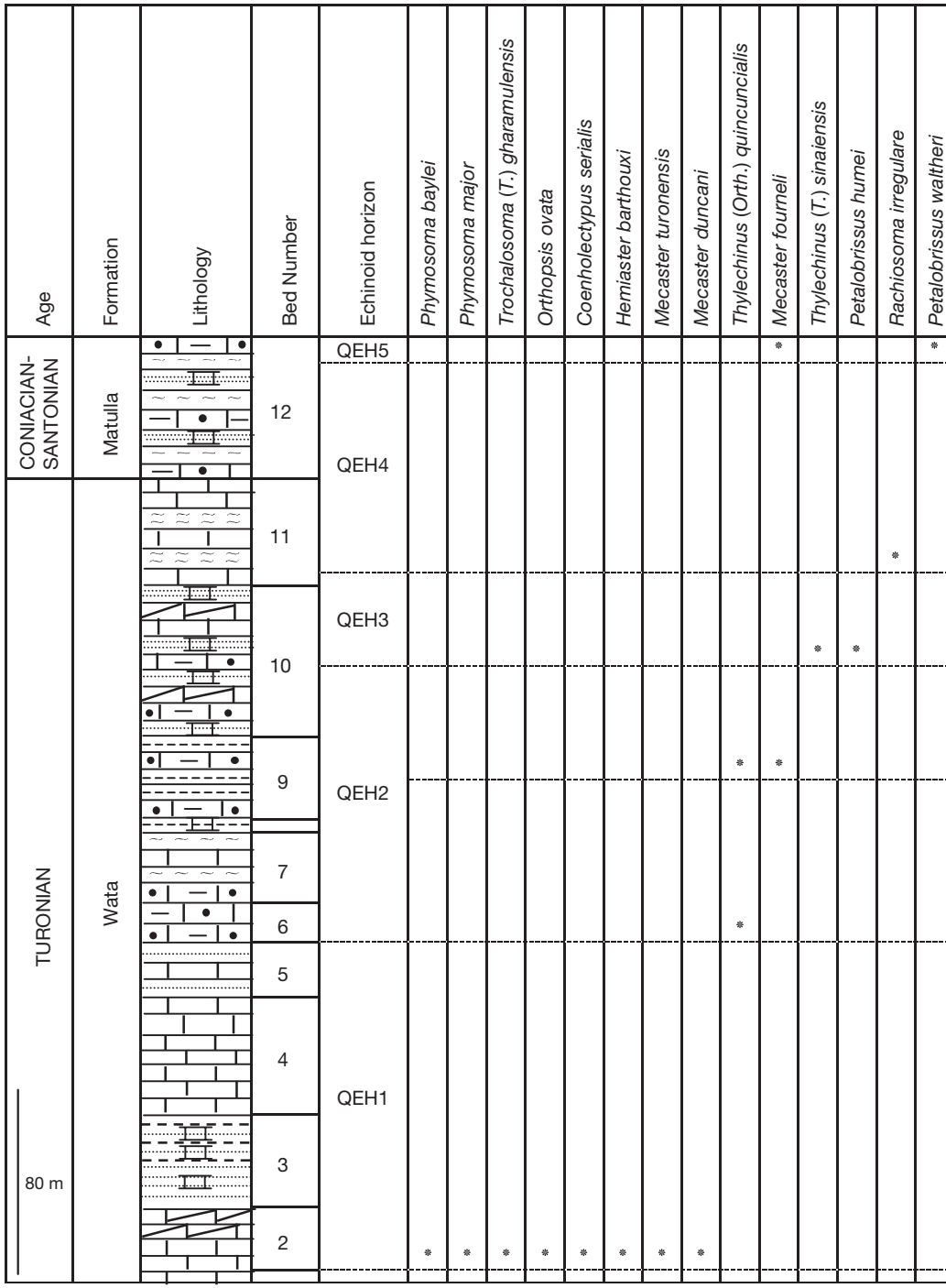


Fig 4. — Stratigraphic section of the Turonian-Santonian sequence in Wadi Abu Qaada (Wata and Matulla formations) showing the distribution of the echinoid species and echinoid horizons. Symbols of lithology: see Figure 3.

surface narrow. Interradial extrascrobicular surface wide and occupied by numerous horizontal series of granules separated by linear grooves. Radioles incomplete; shaft cylindrical, ornamented by axial rows of small nodes.

Remarks

This species is distinguished from *D. aegyptica* by the presence of sex rows of granules on interporiferous zone at ambitus, deeper areoles, wide extrascrobicular area, and by non-conjugate pores in the pore pair. It is distinguished from *D. crameri* by the difference in number of rows of granules in interporiferous zone (ten rows of granules at ambitus of *D. crameri*), round areoles, non-conjugate pores, and by the shape of radioles. Geys (1992) referred the present species to *Desoricidaris* (with conjugate pores) in spite of it has non-conjugate pores (according to Fourtau (1914), and the present material).

Infraclass ACROECHINOIDEA Smith, 1984
Plesion (Order) ORTHOPSIDA Mortensen, 1942
Family Orthopsidae Duncan, 1889
Genus *Orthopsis* Cotteau, 1864

Orthopsis miliaris (d'Archiac, 1835)
(Figs 5E; 6A, B)

Cidarites miliaris d'Archiac, 1835: 179, pl. 11, fig. 8.

Orthopsis miliaris – Smith & Bengtson 1991: 30, pl. 8B-F, text-fig. 23. — Néraudeau *et al.* 1995: 410, fig. 3f, g. — Smith 1995: 136, pl. 2, figs 4, 5; pl. 3, figs 1-9, 12-14. — Abdelhamid & El Qot 2001: 18, fig. 5K. — El Qot 2010: 266, pl. I, figs 2a-c, 4.

Material examined. — Two specimens from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE8-9, Abu Roash echinoid horizon 4 (REH4).

Description

Test diameter reaching 14.0-15.0 mm. Adapical surface dome-shaped (H/D = 0.50-0.51). Adoral surface concaved around peristome. Ambulacral area nearly one have the width of interambulacrum (Wa/Wi = 0.49-0.52). Major ambulacral plates are composed of triads of equal-sized simple plates (Fig. 6B). Interambulacral area with two columns of primary tubercles, besides two external and two internal columns of secondary tubercles (Fig. 6A). Both ambulacral and interambulacral tubercles are perforate and non-crenulated. Peristome deeply sunken (Dp/D = 0.37).

Orthopsis ovata (Coquand, 1862)
(Figs 5F; 6C, D)

Pseudodiadema ovatum Coquand, 1862: 256, pl. 27, figs 19-21.

Orthopsis ovata – Cotteau 1864: 564, pl. 1132, figs 1-6; 1869: 145, pl. 19, fig. 11. — Petitot 1959: 165.

Material examined. — Two specimens from the Turonian of Wadi Abu Qaada (Wata Formation), ASUAQE1-2, Wadi Abu Qaada echinoid horizon 1 (QEH1).

Description

Test moderate to large size (D = 21.8-43.7mm). Adapical surface conical- to dome-shaped. Adoral surface strongly depressed around peristome. Ambulacral areas narrow (Wa/Wi = 0.37-0.38). Peristome deeply sunken (Dp/D = 0.34).

Remarks

The genus *Orthopsis* has perforate and noncrenulated primary tubercles and this distinguishes it from *Pseudodiadema* Desor, 1855, *Diplopodia* M'Coy, 1848, and *Tetragramma* Agassiz, 1840 in which the primary tubercles are perforate and crenulated. This species

Fig. 5. — **A**, *Desoricidaris aegyptica* (Fourtau, 1914), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, interambulacral plates; **B**, **C**, *Desoricidaris crameri* (de Loriol, 1887), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, a spine and test fragment; **D**, *Cidaris schweinfurthi* (Gauthier, 1901), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH5, interambulacral plates; **E**, *Orthopsis miliaris* (d'Archiac, 1835), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, side view; **F**, *Orthopsis ovata* (Coquand, 1862), Wadi Abu Qaada, Turonian, Wata Formation, QEH1, side view; **G**, **H**, *Phymosoma abbatei* (Gauthier, 1898), Abu Roash, Turonian, rudist unit, REH1, adapical and side views; **I**, *Phymosoma baylei* (Cotteau, 1864), Wadi Abu Qaada, Turonian, Wata Formation, QEH1, side view; **J**, *Phymosoma beadnelli* (Gregory, 1906), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, ambulacral and interambulacral fragment; **K**, *Phymosoma major* (Coquand, 1862), Wadi Abu Qaada, Turonian, Wata Formation, QEH1, side view. Scale bars: A, D, E, 2.5 mm; B, C, G, H, 3.3 mm; F, 6.7 mm; I, K, 5 mm; J, 4 mm.

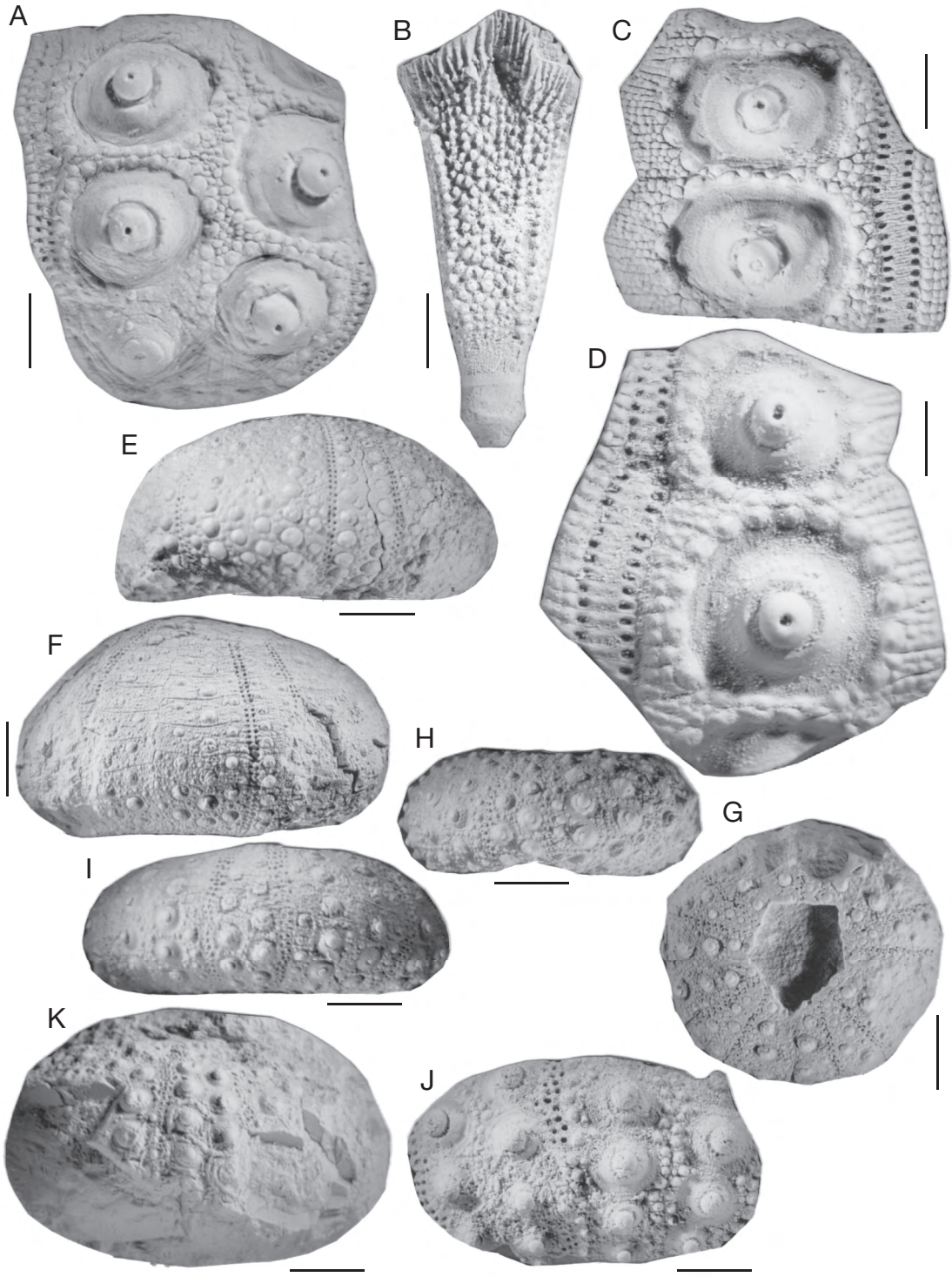

A
B
C
D
E
F
H
G
I
K
J

TABLE 1. — Measurements (in mm) of *Phymosoma abbatei* (Gauthier, 1898). Abbreviations: see Material and methods.

	D	H/D	Wa/Wi	Na	Ni	La/D	Dp/D
Range	9.5-20.0	0.32-0.52	0.62-0.72	7-10	7-10	0.37-0.42	0.41-0.60
Mean	14.0	0.41	0.66	8.5	8.5	0.39	0.49

is distinguished from *O. miliaris* in having a larger size (D = 21.8-43.7mm against 14.0-15.0 mm in *O. miliaris*), narrower ambulacra (Wa/Wi = 0.37-0.38 against 0.49-0.52 in *O. miliaris*), numerous and well developed tubercles in interambulacra (Fig. 6A, C). It is recorded from Algeria, Morocco, and Syria. It is recorded here from Egypt for the first time.

Order PHYMOSOMATOIDA
Mortensen, 1904
Family PHYMOSOMATIDAE Pomel, 1883
Genus *Phymosoma* Haime, 1853

Phymosoma abbatei (Gauthier, 1898)
(Figs 5G, H; 6E, F)

Cyphosoma abbatei Gauthier *in* Fourtau, 1898: 620, pl. 1, figs 2-6.

Phymosoma abbatei – Abdelhamid & El Qot 2001: 13, fig. 4J, K. — Abdallah *et al.* 2001: pl. 3, fig. 12. — El Qot 2006: 134, pl. 31, figs 1, 2, 4.

MATERIAL EXAMINED. — 31 measured specimens and numerous non-measured from the Turonian of Abu Roash (rudist unit), ASUARE10-40, Abu Roash echinoid horizon 1 (REH1).

MEASUREMENTS. — See Table 1.

DESCRIPTION
Test rounded, low. Adapical surface flattened to slightly convex. Adoral surface not sunken around peristome. Outline of apical system large, pentagonal and caducous (Fig. 5G). Ambulacral area wide, narrower adapically than near peristome. Poriferous zones undulate adapically, biserial near apical disc (uniserial in some specimens). Interporiferous zone with two columns of imperforate, crenulated primary tubercles as large as interambulacral tubercles at the ambitus and peristome, but tubercles very small and wide apart adapically (Fig. 6E, F).

REMARKS
Fourtau (1914) pointed out that the uniserial arrangement of the poriferous zones of the present species is confined to small individuals (diameter less than 16 mm). In the present material, it was found that the poriferous zones show variable arrangements, as in some specimens the biserial arrangement is conspicuous; in others, the biserial arrangement is confined to some ambulacral areas or even to some poriferous zones. It is worth mentioning that most of the large-sized specimens have biserial poriferous zones.

Phymosoma baylei
(Cotteau, 1864)
(Figs 5I; 6G; 7A, B)

Cyphosoma baylei Cotteau, 1864: 584, pl. 1138, figs 8-13; pl. 1139, figs 1-6.

Phymosoma baylei – Abdelhamid & El Qot 2001: 13, fig. 4L.

MATERIAL EXAMINED. — Two specimens: one from the Turonian (Wata Formation) of Wadi Dakhl, ASUDLE1, Wadi Dakhl echinoid horizon 1 (DEH1) and one from Wadi Abu Qaada, ASUAQE3, Wadi Abu Qaada echinoid horizon 1 (QEH1).

DESCRIPTION
Test diameter attaining 24.5-30.0 mm. Adoral surface flattened. Adapical surface convex (H/D = 0.39-0.43). Poriferous zones biserial and wide adapically. Major ambulacral plates trigeminate near peristome, polygeminate with five pore pairs arranged in arc at the ambitus (Fig. 7A), whereas near apical disc, each major ambulacral plate carries six pore pairs (Fig. 6G). Adradial extrascrobicular surface relatively wide and occupied by secondary tubercles and frequent granules (Fig. 7B).

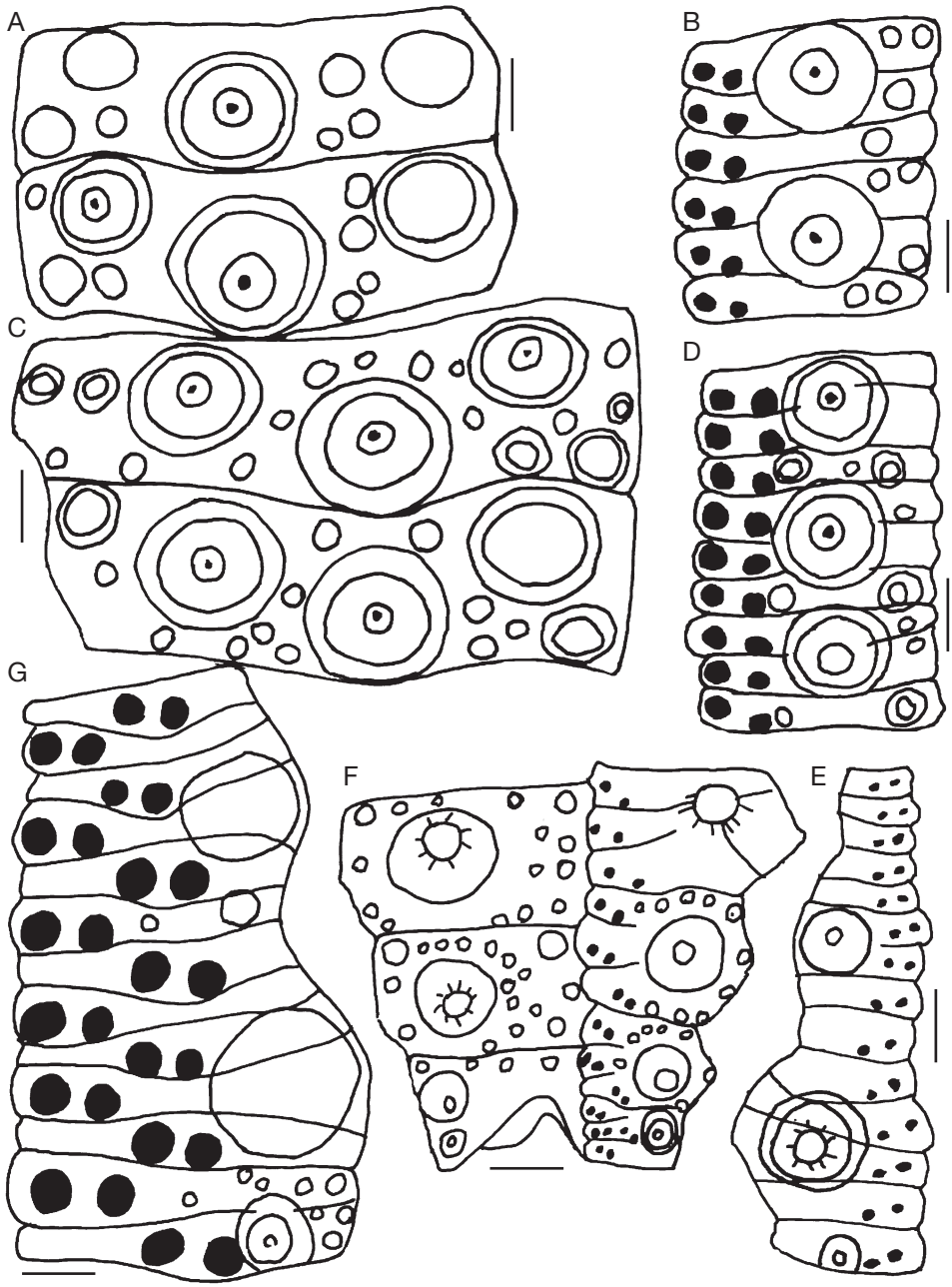


FIG. 6. — Camera lucida drawings: **A**, **B**, plating, tuberculation and poring of ambital interambulacral plates (**A**) and ambital ambulacral plates (**B**) in *Orthopsis miliaris* (d'Archiac, 1835) from the Coniacian-Santonian of Abu Roash; **C**, **D**, plating, tuberculation and poring of ambital interambulacral plates (**C**) and ambital ambulacral plates (**D**) in *Orthopsis ovata* (Coquand, 1862) from the Turonian of Wadi Abu Qaada; **E**, **F**, plating, tuberculation and poring in *Phymosoma abbatei* (Gauthier, 1898) from the rudist unit of Abu Roash; **E**, adapical half ambulacrum; **F**, adoral half interambulacrum and half ambulacrum; **G**, plating, tuberculation and poring of adapical half ambulacrum in *Phymosoma baylei* (Cotteau, 1864) from the Turonian of Wadi Abu Qaada. Scale bars: A, 0.4 mm; B, 0.3 mm; C, D, 1 mm; E, F, 0.8 mm; G, 0.4 mm.

Remarks

The present species (Fig. 6G) is distinguished from *P. abbatei* in having conspicuous and wide biserial poriferous zones in adapical surface, larger ambulacral tubercles in adapical surface, and more ambulacral and interambulacral tubercles per one column (Na = 12 vs 7-10; Ni = 11 vs 7-10). Devriès (1960) indicated that the poriferous zone of *P. baylei* is uniserial in specimens less than 15 mm diameter and that the biserial arrangement increases with the size of the individuals.

Phymosoma beadnelli (Gregory, 1906) (Figs 5J; 7C, D)

Cyphosoma beadnelli Gregory, 1906: 221, pl. 10, figs 6-8.

Cyphosoma abbatei mutatio *beadnelli* – Fourtau 1914: 29.

Phymosoma beadnelli – Devriès 1960: 133.

Material examined. — Many deformed tests and numerous test fragments from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE41-43, Abu Roash echinoid horizon 4 (REH4).

Description

Test with medium to large size. Ambulacral area wide (Wa/Wi = 0.79). Poriferous zone shows conspicuous biserial arrangement from the ambitus to the apex, wide near the apex where the two poriferous zones constitute 64 % of ambulacrum width. At the ambitus and adoral surface, ambulacral primary tubercles are confluent and as large as interambulacral tubercles but decrease in size near the apex.

Remarks

The present species is distinguished from *P. abbatei* in having confluent ambulacral and interambulacral tubercles, conspicuous biserial arrangement of poriferous zones above ambitus (Fig. 7C, D), and wider ambulacra (Wa/Wi = 0.79 vs 0.62-0.72). It is distinguished from *P. baylei* (Cotteau, 1864) in having wider ambulacra (Wa/Wi = 0.79 vs 0.63-0.73 in the latter species) and confluent ambulacral and interambulacral tubercles. Fourtau (1921) considered *P. beadnelli* as a mutation from *P. abbatei*, but it is believed that the above-mentioned differences between the two forms are sufficient to consider them separate species. Devriès (1960) pointed out that *P. beadnelli* resembles *P. coquandi* (Cotteau, 1864) but the latter species is distinguished in having wider extrascrobicular surface, nonconfluent areoles and abundant granules on interambulacra.

Phymosoma major (Coquand, 1862) (Fig. 5K)

Cyphosoma major Coquand, 1862: 256, pl. 27, figs 16-18. — Cotteau 1864: 596, pls 1143, 1144.

Phymosoma majus – Lambert 1937: 73, pl. 1, fig. 16. — Zaghbib-Turki 1975: 29, pl. 1, figs 13-15. — Néraudeau *et al.* 1993: 290, pl. 3, figs A-G.

Phymosoma major – El Qot 2006: 136, pl. 31, fig. 3; 2010: 270, pl. III, figs 8a, b, 9.

Material examined. — One specimen from the Turonian of Wadi Abu Qaada (Wata Formation), ASUAQE4, Wadi Abu Qaada echinoid horizon 1 (QEH1).

Description

Test large (D = 33.5 mm). Adapical surface fairly high (H/D = 0.50). Ambital ambulacral plates quadrigeminate. Poriferous zones conspicuously biserial above the ambitus. Interambulacral area with four columns of large, imperforate, crenulated primary tubercles.

Remarks

Bandel & Geys (1985) referred the present species (based on specimens with uniserial poriferous zone from the Coniacian of Jordan) to genus *Rachiosoma* Pomel, 1883. Abdelhamid & El Qot (2001) submitted arguments against referring of the present species to *Rachiosoma* Pomel, 1883. They erected a new species: *Rachiosoma geysi* Abdelhamid & El Qot, 2001 based on the Jordanian specimens and similar specimens from the Turonian of Gabal El-Minsherah, north Sinai. *Phymosoma major* is distinguished from *Phymosoma abbatei*, *Phymosoma baylei*, and *Phymosoma beadnelli* in having four columns of primary tubercles on each interambulacrum.

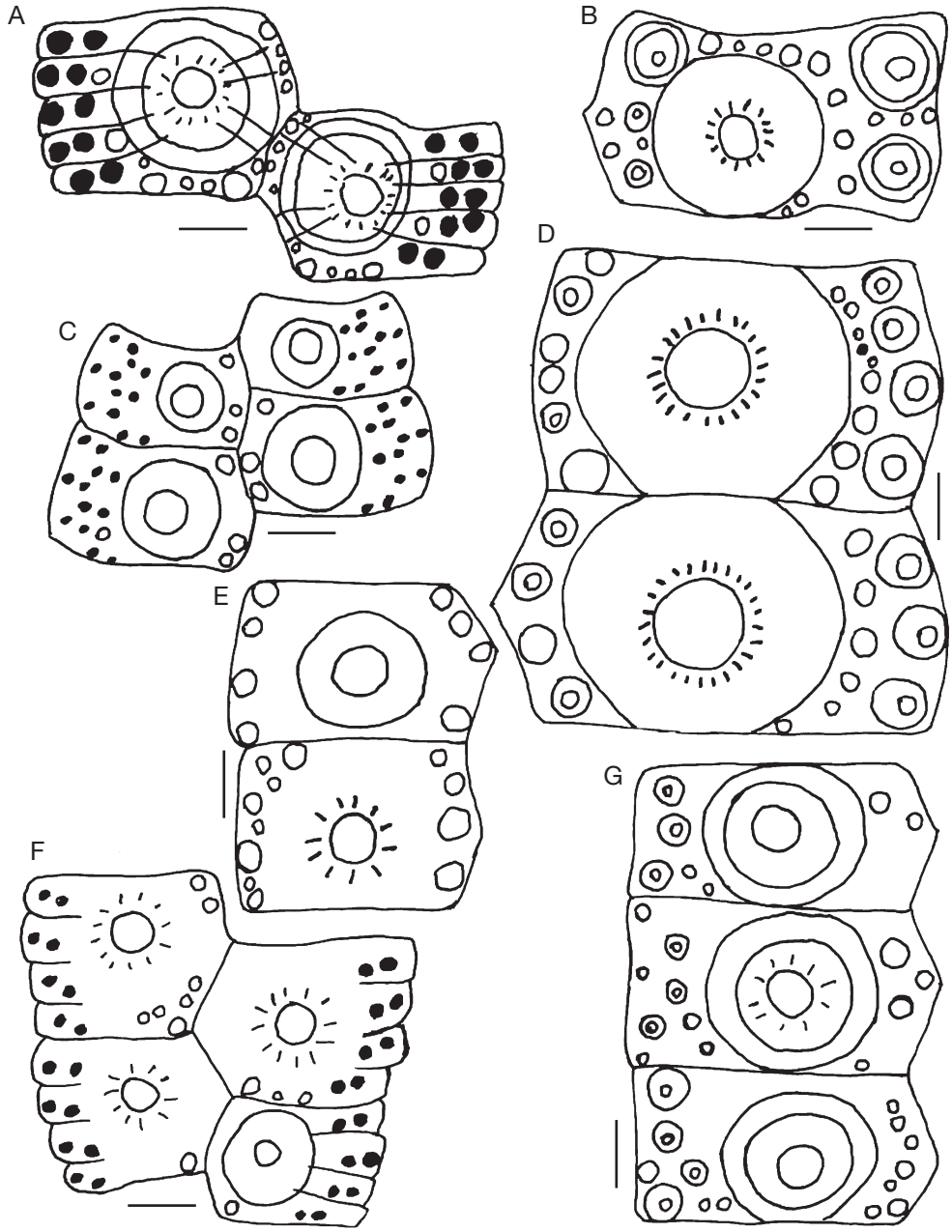


FIG. 7. — Camera lucida drawings: **A**, **B**, plating, tuberculation and poring in *Phymosoma baylei* (Cotteau, 1864) from the Turonian of Wadi Abu Qaada; **A**, ambital ambulacral plates; **B**, ambital interambulacral plate; **C**, **D**, plating, tuberculation and poring in *Phymosoma beadnelli* (Gregory, 1906) from the Coniacian-Santonian of Abu Roash; **C**, adapical ambulacral plates; **D**, ambital interambulacral plates; **E**, **F**, plating, tuberculation and poring in *Phymosoma thevestense* (Péron & Gauthier, 1879) from the Coniacian-Santonian of Abu Roash; **E**, ambital interambulacral plates; **F**, subambital ambulacral plates; **G**, plating and tuberculation of ambital interambulacral plates in *Rachiosoma irregulare* Fourtau, 1921 from the Turonian of Wadi Abu Qaada. Scale bars: A, 0.8 mm; B, 0.9 mm; C, D, 1 mm; E, F, 0.5 mm; G, 0.7 mm.

TABLE 2. — Measurements (in mm) of *Phymosoma roachensis* (Fourtau, 1914). Abbreviations: see Material and methods.

	D	H/D	Wa/Wi	Na	Ni	La/D	Dp/D
Range	6.7-9.1	0.32-0.42	0.54-0.77	8-9	7-9	0.49	0.47-0.56
Mean	7.8	0.37	0.65	8.5	8	0.49	0.51

TABLE 3. — Measurements (in mm) of *Phymosoma thevestense* (Péron & Gauthier, 1879).

	D	H/D	Wa/Wi	Na	Ni	La/D	Dp/D
Range	11.2-19.3	0.30-0.45	0.68-0.80	8-9	8-9	0.80	0.46-0.53
Mean	15.2	0.38	0.73	8.5	8.5	0.80	0.49

Phymosoma roachensis (Fourtau, 1914) (Fig. 8A, B)

Cyphosoma roachense Fourtau, 1914: 33, pl. 3, fig. 3.

Phymosoma roachensis – Abdelhamid 1997: 143, fig. 5 (4).

MATERIAL EXAMINED. — Six specimens from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE44-49, Abu Roash echinoid horizon 4 (REH4).

MEASUREMENTS. — See Table 2.

DESCRIPTION

Test very small, discoidal, low. Both adapical and adoral surfaces flattened. Outline of apical disc large, sub-round. Poriferous zones biserial near apical disc. Major ambulacral plates trigeminate near peristome, quadrigeminate at the ambitus and adapically. Interambulacral area with four columns of imperforate, crenulated primary tubercles. Peristome not sunken, large.

REMARKS

The present species is distinguished from the previously mentioned species of *Phymosoma*, in the present work, in having very small, discoidal and low test; flattened adapical and adoral surfaces, and not sunken peristome.

Phymosoma thevestense (Péron & Gauthier, 1879) (Figs 7E, F; 8C, D; 9A)

Cyphosoma thevestense Péron & Gauthier *in* Cotteau, Péron & Gauthier, 1879: 105, pl. 8, figs 5-8.

Phymosoma thevestense – Abdelhamid & El Qot 2001: 14, fig. 5A.

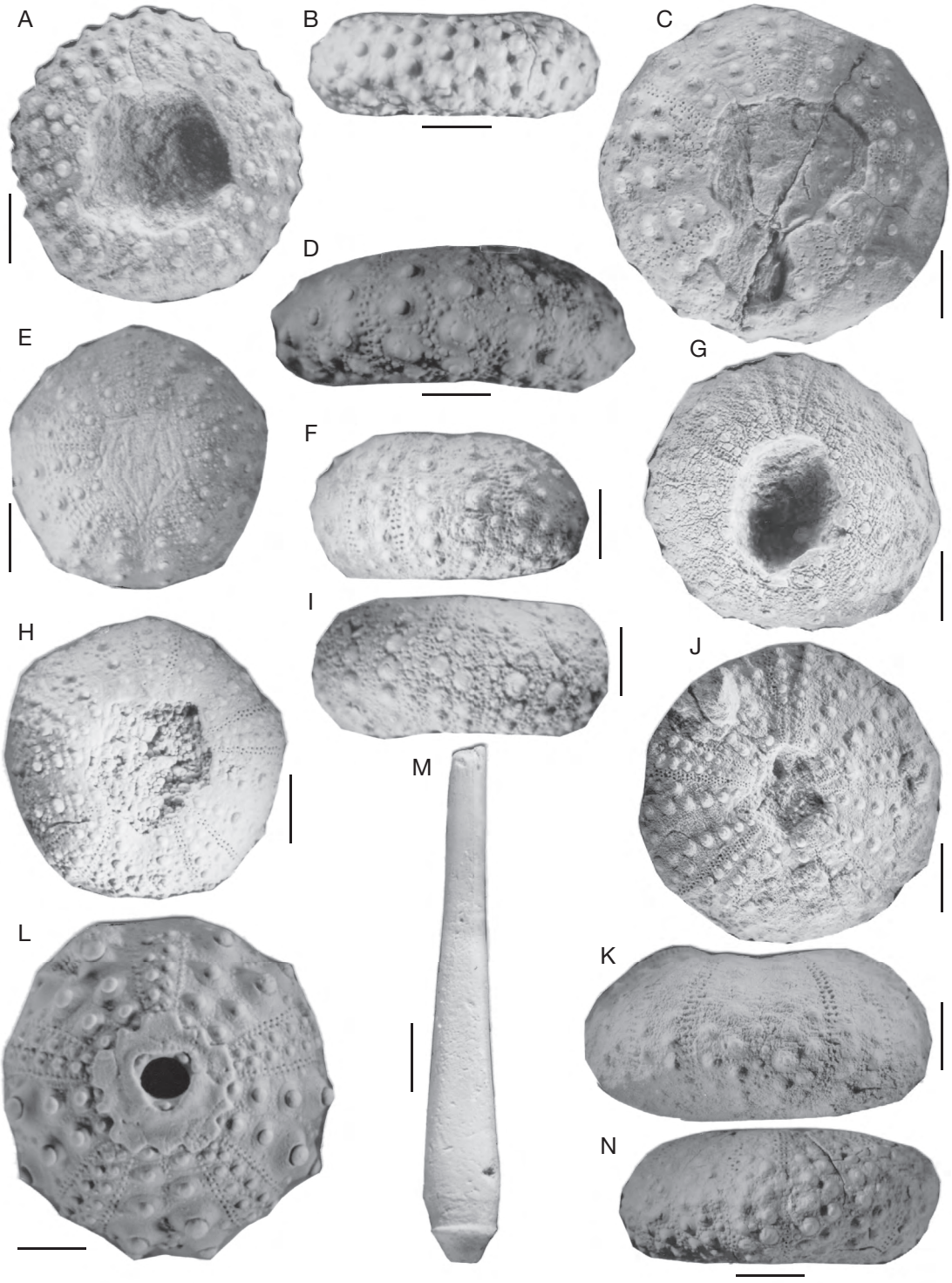
MATERIAL EXAMINED. — Six measured specimens and numerous non-measured ones from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE50-55, Abu Roash echinoid horizon 4 (REH4).

MEASUREMENTS. — See Table 3.

DESCRIPTION

Test low, discoidal (Fig. 8D). Adoral surface flattened, slightly depressed around peristome. Adapical surface flattened to feebly convex. Ambulacral area wide. Poriferous zones biserial near apical disc (Fig. 8C). Major ambulacral plates polygeminate with four to five pore pairs at the ambitus and adapically (Figs 7F; 9A), trigeminate near peristome.

FIG. 8. — **A**, **B**, *Phymosoma roachensis* (Fourtau, 1914), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, adapical and side views; **C**, **D**, *Phymosoma thevestense* (Péron & Gauthier, 1879), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, adapical and side views; **E**, **F**, *Rachiosoma irregulare* Fourtau, 1921, Wadi Abu Qaada, Turonian, Wata Formation, QEH4, adapical and side views; **G**, *Rachiosoma rectilineatum* (Péron & Gauthier, 1881), Wadi Dakhl, Coniacian-Santonian, Matulla Formation, DEH3, adapical view; **H**, **I**, *Thylechinus* (*T.*) *sinaiensis* n. sp., Wadi Abu Qaada, Turonian, Wata Formation, QEH3, (holotype) adapical and side views; **J**, **K**, *Thylechinus* (*O.*) *quincuncialis* Gregory, 1906, Wadi Abu Qaada, Turonian, Wata Formation, QEH2, adapical and side views; **L**, **M**, *Goniopygus innesi* Gauthier, 1901, Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, adapical view and a spine; **N**, *Trochalosoma* (*T.*) *gharamulensis* Abdelhamid & Azab, 2003, Wadi Abu Qada, Turonian, Wata Formation, QEH1. Scale bars: A, B, D, 2 mm; C, H. I, M, 3.3 mm; E, 4 mm; F, G, 5 mm; J, 10 mm; K, 6.7 mm; L, 2.5 mm; N, 5 mm.


A
B
C
D
E
F
G
H
I
J
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N

TABLE 4. — Measurements (in mm) of *Rachiosoma rectilineatum* (Péron & Gauthier, 1881). Abbreviations: see Material and methods.

	D	Wa/Wi	Na	Ni	La/D	Dp/D
Range	17.5-25.0	0.59-0.69	9-11	9-11	0.45	0.38-0.44
Mean	21.0	0.64	10	10	0.45	0.41

Interambulacral area with two columns of imperforate, crenulated primary tubercles. Two columns of granules occur around the interradial suture, and one column near the adradial suture (Fig. 7E).

REMARKS

The present species is distinguished from *Phymosoma major* and *Phymosoma roachensis* (Fourtau, 1914) in having two columns of primary tubercles on each interambulacrum. It is distinguished from *Phymosoma abbatei* in having conspicuous biserial poriferous zones adapically, larger apical disc (Ls/D = 0.80 against 0.37-0.42 in *Phymosoma abbatei*), wider ambulacra (Wa/Wi = 0.68-0.80 against 0.62-0.72 in *Phymosoma abbatei*) and in having narrower extrascrobicular surface. It is distinguished from *Phymosoma baylei* in having smaller test (D = 11.2-19.3 mm vs 24.5-30.0 mm in *Phymosoma baylei*), wider ambulacra (Wa/Wi = 0.68-0.80 vs 0.63-0.73 in *Phymosoma baylei*) and in having narrower extrascrobicular surface. In *Phymosoma beadnelli*, the poriferous zones show conspicuous biserial arrangement from the ambitus to the apex, wide near the apex, where the two poriferous zones constitute 64% of ambulacrum width, the primary tubercles are confluent at the ambitus and adoral surface, and this distinguished it from the present species. The present species is recorded from the Turonian of Algeria and Tunisia, but in Egypt it occurs in the Coniacian-Santonian.

Genus *Rachiosoma* Pomel, 1883

Rachiosoma irregulare Fourtau, 1921
(Figs 7G; 8E, F)

Rachiosoma irregulare Fourtau, 1921: 39, pl. 5, figs 3, 4. — Abdelhamid & El Qot 2001: 18, fig. 5D, E. — El Qot 2006: 137, pl. 31, figs 8, 10a, b.

MATERIAL EXAMINED. — Three specimens from the Turonian of Wadi Abu Qaada (Wata Formation), AS-UAQE5-7, Wadi Abu Qaada echinoid horizon 4 (QEH4).

DESCRIPTION

Test diameter attaining 15.5-24.6 mm. Adapical surface convex, high (H/D = 0.47-0.54). Outline of apical disc pentagonal, caducous (Fig. 8E) (La/D = 0.43-0.47). Ambulacral area wide (Wa/Wi = 0.62-0.75). Poriferous zones uniserial. Major ambulacral plates quadrigeminate, but they are trigeminate in three plates adjacent to peristome. Two columns of granules occur around the perradial suture. Interambulacral area with two columns of imperforate, crenulated, and nonconfluent primary tubercles. Adradial extrascrobicular surface wide and occupied by very small tubercles (Fig. 7G). Interradial extrascrobicular surface occupied by two columns of smaller granules.

REMARKS

This species is distinguished from *R. rectilineatum* (Péron & Gauthier, 1881) in having wider ambulacra at the apex, well developed ambulacral tubercles on adapical surface, relatively higher test (H/D = 0.47-0.54 against 0.38-0.49 in *R. rectilineatum*), and the mamelonated granules on the adradial extrascrobicular surface reach both the apical disc and peristome whereas in *R. rectilineatum* they are more developed but confined to the ambital area.

Rachiosoma rectilineatum
(Péron & Gauthier, 1881)
(Fig. 8G)

Cyphosoma rectilineatum Péron & Gauthier *in* Cotteau, Péron & Gauthier, 1881: 104, pl. 7, figs 1-4.

Rachiosoma rectilineatum – Geys 1992: 147, pl. 2, figs 8-9. — El Qot 2010: 272, pl. IV, figs 2a, b, 4, 5, text-fig. 5b.

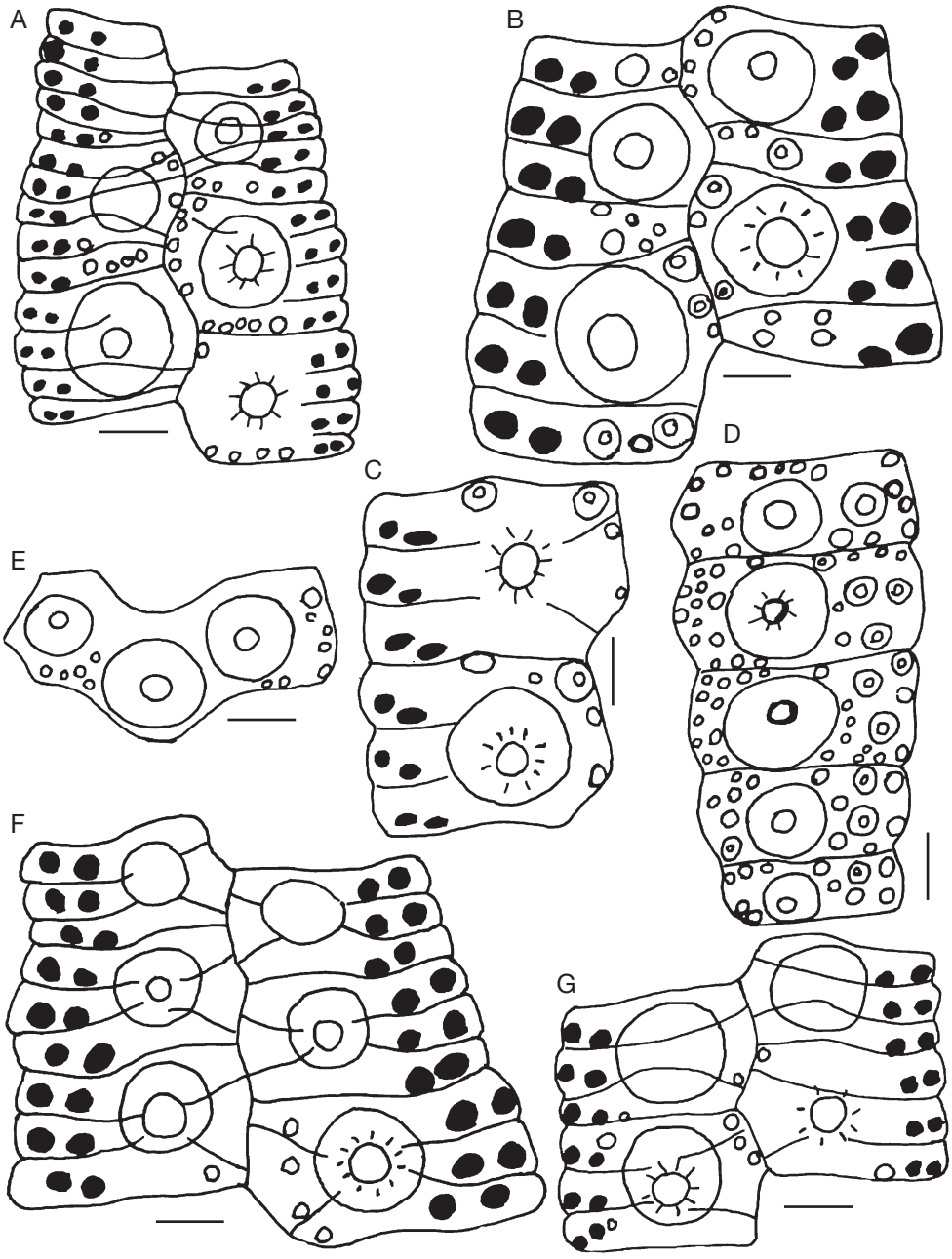

Fig. 9. — Camera lucida drawings: **A**, plating, tuberculation and poring of subambital ambulacrum in *Phymosoma thevestense* (Péron & Gauthier, 1879) from the Coniacian-Santonian of Abu Roash; **B**-**D**, plating, tuberculation and poring in *Thylechinus* (*T.*) *sinaiensis* n. sp. from the Turonian of Wadi Abu Qaada; **B**, adapical ambulacrum; **C**, ambital ambulacral plates; **D**, subambital interambulacral plates; **E**-**G**, plating, tuberculation and poring in *Thylechinus* (*O.*) *quincuncialis* Gregory, 1906 from the Turonian of Wadi Abu Qaada; **E**, ambital interambulacral plate; **F**, adapical ambulacrum; **G**, ambital ambulacrum. Scale bars: A, B, 0.5 mm; C, 0.4 mm; D, 0.8 mm; E, 2 mm; F, 0.9 mm; G, 1 mm.

TABLE 5. — Measurements (in mm) of *Thylechinus* (*Thylechinus*) *sinaiensis* n. sp. Abbreviations: see Material and methods.

	D	H/D	Wa/Wi	Na	Ni	La/D	Dp/D
Range	9.4-21.7	0.37-0.54	0.52-0.69	9-12	8-10	0.46	0.42-0.50
Mean	13.3	0.46	0.61	10.2	9	0.46	0.47

MATERIAL EXAMINED. — 13 measured specimens and many non-measured ones from the Coniacian-Santonian (Matulla Formation) of Wadi Dakhl, ASUDLE2-14, Wadi Dakhl echinoid horizon 3 (DEH3).

MEASUREMENTS. — See Table 4.

DESCRIPTION

Adapical surface convex. Adoral surface feebly depressed around peristome. Ambulacral areas relatively wide, narrowed near apical disc. Poriferous zones uniserial, straight. Major ambulacral plates quadrigeminate, but trigeminate on adoral surface. Interradial extrascrobicular surface narrow. Adradial extrascrobicular surface relatively wide and occupied by very small tubercles lying near adradial suture, beside numerous granules.

REMARKS

This species is known from the Santonian of Algeria, Egypt and Jordan. Geys (1992) recorded it from the basal part of the Turonian in Wadi Qena, Egypt.

Genus *Thylechinus* Pomel, 1883

Thylechinus (***Thylechinus***) ***sinaiensis*** n. sp. (Figs 8H, I; 9B-D; 10)

HOLOTYPE. — The specimen photographed in Figure 8H, I.

MATERIAL EXAMINED. — 12 specimens, ASUAQE8-19, deposited in Geology Department, Faculty of Science, Ain Shams University, Cairo.

TYPE LOCALITY. — Wadi Abu Qaada, Central Sinai, Egypt.

STRATIGRAPHIC HORIZON. — Turonian (Wata Formation), Wadi Abu Qaada echinoid horizon 3 (QEH3).

ETYMOLOGY. — Named after the region of Sinai from which the material has been collected.

DIAGNOSIS. — Test round to sub-pentagonal. Adapical surface convex and convexity increases as test size increases. Adoral surface flattened. Apical disc pentagonal, caducous (Fig. 8H). Ambulacral area wide (Fig. 10), flush but feebly swollen in large-sized individuals (Fig. 8H). Poriferous zone narrow, uniserial throughout; pore pairs arranged in triads in three plates adjacent to peristome. Interporiferous zone with two columns of imperforate, crenulated primary tubercles slightly less developed than interambulacral tubercles. On adoral and ambital areas, major ambulacral plates are composed of triads arranged in diadematoid manner (Fig. 9C), whereas adapically they are arranged in triads of simple plates (Fig. 9B). Interambulacra with two columns of imperforate, crenulated, nonconfluent tubercles. Adradial extrascrobicular surface wide and in each plate it is occupied by three mamelonated granules and many smaller granules. Interradial extrascrobicular surface relatively narrow, occupied by a lot of granules (Fig. 9D). Peristome round, large, flush and feebly sunken in large-sized individuals. Gill slits well developed.

MEASUREMENTS. — See Table 5.

DESCRIPTION

Poriferous zones uniserial throughout. Major ambulacral plates are composed of triads (Fig. 9B, C). Both ambulacral and interambulacral tubercles imperforate, crenulated, and nonconfluent. Adradial extrascrobicular surface wide, and occupied by three mamelonated granules, and many smaller granules on each plate (Fig. 9D).

REMARKS

The present species has uniserial poriferous zones throughout, trigeminate major ambulacral plates (Fig. 9B, C), both ambulacral and interambulacral areas with only two columns of imperforate, crenulated primary tubercles, and no large secondary tubercles. These characters refer the present species to the subgenus *Thylechinus* (*Thylechinus*). The present material is distinguished from *T.* (*T.*) *arabicus* (Fourtau, 1912) in having larger peristome (Dp/D = 0.30 in the latter species), wider

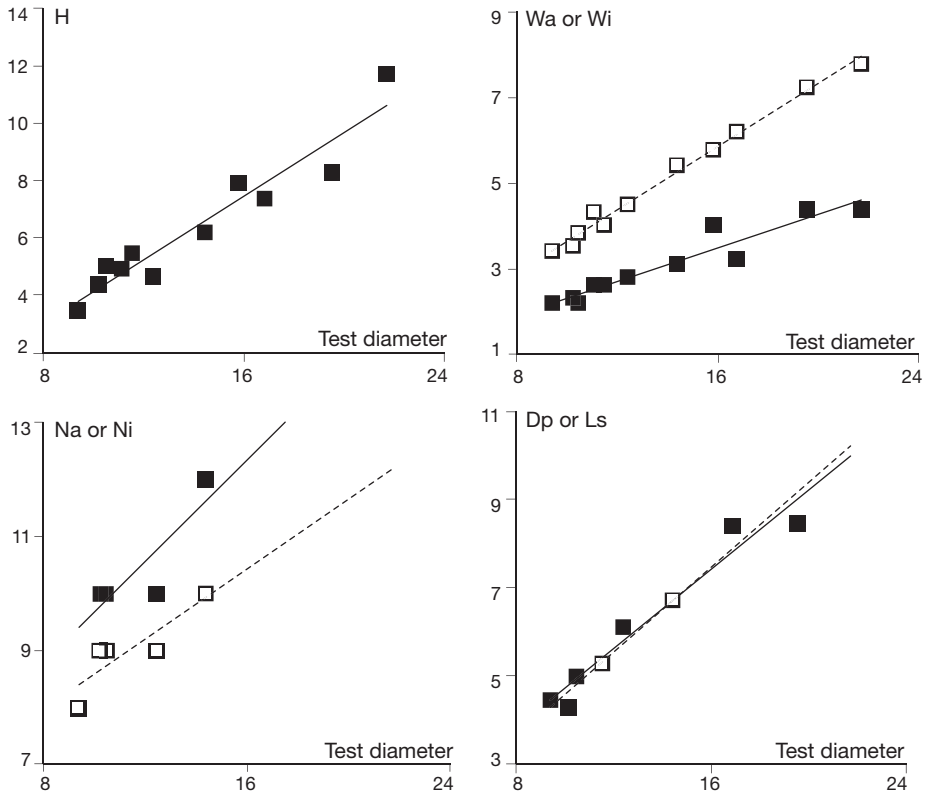

FIG. 10. — Biometric data on *Thylechinus* (*T.*) *sinaiensis* n. sp. showing the relation between: test diameter and test height (**H**); test diameter and both of width of ambulacrum (**Wa**, filled quadrangles, solid line) and width of interambulacrum (**Wi**, empty quadrangles, dashed line); test diameter and each of number ambulacral tubercles per row (**Na**, filled quadrangles, solid line) and number of interambulacral tubercles per row (**Ni**, empty quadrangles, dashed line); test diameter and each of diameter of peristome (**Dp**, filled quadrangles, solid line) and length of apical system (**Ls**, empty quadrangles, dashed line).

ambulacra (Wa/Wi = 0.50 in the latter species) and wider extrascrobicular surface occupied by a lot of well-developed granules. It is distinguished from *T* (*T.*) *ioudi* (Péron & Gauthier, 1881) from the Campanian of Algeria in having large, pentagonal apical disc (it is small, round in the latter species), adoral and ambital interambulacral tubercles separated by a horizontal series of granules (scrobicules are tangent in the latter species), and granules on adradial extrascrobicular surface are fairly more developed than those on interradial extrascrobicular surface (they are homogeneous in the latter species). It is distinguished from *T.* (*T.*) *said* (Péron & Gauthier, 1881) by its non-confluent interambulacral tubercles, larger apical disc (La/D = 0.34 in the latter species), larger peristome (Dp/D = 0.39 in the latter species), and in having relatively more flattened test (H/D = 0.46-0.63 in the latter species). *Thylechinus* (*T.*) *schlumbergeri* (Cotteau, 1864) from the Turonian of Batna and Martigues is distinguished from the present material by the abundance of granules on interambulacrals and separation of all its ambulacral tubercles by a double horizontal series of granules. *T.* (*T.*) *simplex* Thomas & Gauthier, 1889 is distinguished from the present material by its smaller peristome (Dp/D = 0.36-0.40 in *T.* (*T.*) *simplex*) and its ambulacral tubercles are smaller than interambulacral tubercles and strongly reduced in size adapically.

TABLE 6. — Measurements (in mm) of *Thylechinus* (*Orthechinus*) *quincuncialis* Gregory, 1906. Abbreviations: see Material and methods.

	D	H/D	Wa/Wi	Na	Ni	La/D	Dp/D
Range	10.8-48.5	0.32-0.52	0.49-0.71	11-16	8-14	0.28-0.36	0.34-0.42
Mean	28.5	0.43	0.61	13.5	11	0.32	0.38

Thylechinus (*Orthechinus*) *quincuncialis* Gregory, 1906 (Figs 8J, K; 9E-G)

Thylechinus quincuncialis Gregory, 1906: 222, pl. 11, fig. 8.

Thylechinus (*Orthechinus*) *quincuncialis* – Abdelhamid 1997: 143, fig. 5 (4).

MATERIAL EXAMINED. — 50 specimens from the Turonian of Wadi Abu Qaada (Wata Formation), AS-UAQE20-69, Wadi Abu Qaada echinoid horizon 2 (QEH2).

MEASUREMENTS. — See Table 6.

DESCRIPTION

Test size variable. Adapical surface slightly convex. Poriferous zones uniserial. Ambulacral tubercles are as large as interambulacral tubercles but rapidly reduced in size near apical disc. Major ambulacral plates are composed of triads arranged in diadematoid manner (Fig. 9F, G), whereas near apical disc, they are composed of triads of simple plates. Interambulacral area with two columns of imperforate, crenulated primary tubercles. In small- and medium-sized specimens extrascrobicular surface is occupied by large granules lying on the upper right and upper left of each ambital plate. As the size of test increases, there are two external columns of secondary tubercle are confined to the ambital area. In the large specimens (diameter more than 30 mm), there are two external and two internal columns of secondary tubercles; they are nearly as large as the primary tubercles (Fig. 9E). The adapical suture of interambulacral plates in small to medium-sized individuals is slightly concaved upwards. Maximum concavity is attained in specimens more than 30 mm diameter (Fig. 9E). Peristome faintly depressed.

REMARKS

This species is distinguished from *Thylechinus* (*Thylechinus*) *sinaiensis* n. sp. in having more than two columns of tubercles on each interambulacrum.

Family STOMECHINIDAE Pomel, 1883

Genus *Trochalosoma* Lambert, 1897

Trochalosoma (*Trochalosoma*) *gharamulensis* Abdelhamid & Azab, 2003 (Fig. 8N)

Trochalosoma (*Trochalosoma*) *gharamulensis* Abdelhamid & Azab, 2003: 860, pl. III, figs B-D. — El Qot 2006: 138, pl. 31, figs 11, 12.

MATERIAL EXAMINED. — Three specimens from the Turonian of Wadi Abu Qaada (Wata Formation), AS-UAQE70-72, Wadi Abu Qaada echinoid horizon 1 (QEH1).

DESCRIPTION

Outline pentagonal to round. Adapical surface flattened to feebly convex. Adoral surface not depressed around peristome. Ambulacral area wide, feebly swollen. Poriferous zones biserial and wide adapically constituting most of ambulacrum width near apical disc, narrow and uniserial at ambitus, wide and crowded near peristome forming oblique triads of pore pairs. Major ambulacral plates trigeminate near peristome, quadrigeminate at ambitus, polygeminate with five pore pairs near apical disc. Interambulacral area with two columns of imperforate, noncrenulated primary tubercles; beside two external columns of secondary, nonconfluent tubercles as large as the primary tubercles but don't persist until peristome and apical disc. Gill slits conspicuously developed.

TABLE 7. — Measurements (in mm) of *Goniopygus innesi* Gauthier, 1901. Abbreviations: see Material and methods.

	D	H/D	Wa/Wi	Na	Ni	La/D	Dp/D
Range	6.6-14.2	0.46-0.58	0.46-0.59	7-11	6-7	0.41-0.59	0.50-0.56
Mean	6.7	0.52	0.51	9	6.5	0.5	0.53

REMARKS

Abdelhamid & Azab (2003) erected this species from the Cenomanian of Gabal Gharamul, the Eastern Desert, Egypt. It is recorded here from the Turonian of Wadi Abu Qaada, west Sinai, Egypt.

Order ARBACIOIDA Gregory, 1900
Family ARBACIIDAE Gray, 1855
Genus *Goniopygus* Agassiz, 1838

Goniopygus innesi
Gauthier, 1901
(Fig. 8L, M)

Goniopygus innesi Gauthier *in* Fourtau, 1901: 60, pl. 1, figs 6-9. — Abdelhamid 1997: 146, fig. 5 (9). — El Qot 2006: 138, pl. 31, fig. 13; pl. 32, figs 1, 2a, b.

MATERIAL EXAMINED. — 16 specimens, numerous non-measured and frequent radioles from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE56-71, Abu Roash echinoid horizons 2 and 4 (REH2, REH4).

MEASUREMENTS. — See Table 7.

DESCRIPTION

Adapical surface dome-shaped, occasionally flattened. Apical disc large, raised around the periproct and at its periphery. The oculogenital plates and the sutures between them smooth (Fig. 8L). The inner edges of three of the genital plates carrying small granule on a semi-lunar depression. Ambulacral are wide at peristome. Poriferous zones slightly crowded near peristome. Ambulacral plates trigeminate. Interambulacral area with two columns of imperforate, noncrenulated, confluent primary tubercles. Peristome large, slightly sunken. Periproct sub-round. Radioles long; shaft solid, smooth, thick at the base, tapering top-wards (Fig. 8M), flattened; collar smooth.

Goniopygus sp.
(Fig. 11A)

MATERIAL EXAMINED. — One specimen from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE72, Abu Roash echinoid horizon 4 (REH4).

DESCRIPTION

Test very small (D = 7.5 mm), rounded. Adapical surface dome-shaped (H/D = 0.51). Adoral surface flattened. Apical disc large (La/D = 0.56); both ocular and genital plates ornamented by linear depressions around a point at the middle of each plate; at the middle of each suture and at the contact of every three sutures of the oculogenital plates, there is a small pit; on the inner edges of three plates of the genital plates, there are three granules, each one is surrounded by a shallow semi-lunar depression. Interporiferous zones with two rows of imperforate, non-crenulated, nonconfluent primary tubercles (Na = 8), at the ambitus they are slightly smaller and different from interambulacral tubercles, but near the apical disc they are distinctly smaller than interambulacral tubercles. Major ambulacral plates trigeminate. Interambulacral area with two columns of imperforate, noncrenulated, confluent primary tubercles (Ni = 6). Peristome fairly sunken (Dp/D = 0.52). Gill slits poorly developed.

REMARKS

This specimen is distinguished from *G. innesi*, *G. menardi* (Desmarest, 1825), *G. noguesi* Cotteau, 1863 and *G. major* Agassiz, 1838 by the presence of well-developed ambulacral tubercles on adoral surface and ambitus, linear depressions around a point at the middle of each ocular and genital plate, the presence of a small pit at the middle of each suture and at the contact of every three sutures of the oculogenital plates, and in having poorly developed gill slits.

TABLE 8. — Measurements (in mm) of *Coenholectypus roachensis* (Fourtau, 1914) n. stat. Abbreviations: see Material and methods.

	D	H/D	Wa/Wi	Dp/D
Range	8.0-16.5	0.50-0.64	0.47-0.67	0.38-0.46
Mean	11.3	0.57	0.57	0.42

Order HOLECTYPOIDA Duncan, 1889
Family HOLECTYPIDAE Lambert, 1883
Genus *Coenholectypus* Pomel, 1883

Coenholectypus roachensis
(Fourtau, 1914) n. stat.
(Figs 11B-D; 12)

Holectypus excisus race *roachensis* Fourtau, 1914: 44, pl. 3, fig. 7; 1921: 55.

Coenholectypus excisus roachensis – Abdelhamid 1997: 146, fig. 5 (10).

MATERIAL EXAMINED. — 12 specimens from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE73-84, Abu Roash echinoid horizons 4 and 5 (REH4, REH5).

MEASUREMENTS. — See Table 8.

DESCRIPTION
Outline sub-round to subpentagonal. Adapical surface high. Adoral surface concaved around peristome. Apical disc composed of five genital plates with five genital pores and five ocular plates with five ocular pores. Madreporite large swollen, extended to the other genital plates. Ambulacral area wide, feebly swollen. Peristome large, conspicuously sunken. Periproct large, oval, extending between peristome and mid-distance between apical disc and ambitus.

REMARKS
This subspecies is common in the Coniacian-Santonian of Egypt. Abdelhamid (1997) discussed the difference between *Coenholectypus excisus* (Desor, 1847) *sensu stricto* from the Cenomanian and *C. excisus roachensis* (Fourtau, 1914) from the Coniacian-Santonian. *Coenholectypus excisus roachensis* (Fourtau, 1914) is distinguished from *C. excisus* (Desor, 1847) in having wider ambulacra, slightly narrower interambulacra, and relatively higher test and wider peristome (Fig. 12). In the present work, the authors think that these differences elevate the rank of this subspecies to species level.

Coenholectypus serialis (Deshayes, 1847)
(Fig. 11E, F)

Holectypus serialis Deshayes *in* Agassiz & Desor, 1847: 88. — Desor 1855: 174, pl. 23, figs 7-9.

Coenholectypus serialis – Abdelhamid 1997: 146, fig. 5 (11).

MATERIAL EXAMINED. — Three specimens from the Turonian of Wadi Abu Qaada (Wata Formation), ASUAQE73-75, Wadi Abu Qaada echinoid horizon 1 (QEH 1).

DESCRIPTION
Test diameter attaining 15.7-24.2 mm. Outline rounded. Margins relatively thin. Adapical surface low (H/D = 0.39-0.46), dome-shaped. Adoral surface flattened, depressed around peristome. Ambulacral area represents 0.45-0.50 of the width of interambulacrum. Peristome sunken, narrow (Dp/D = 0.29). Periproct inframarginal, occupying the distance between peristome and posterior margin (Lk/D = 0.38), acute at its two extremities.

FIG. 11. — **A**, *Goniopygus* sp., Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, adapical view; **B**-**D**, *Coenholectypus roachensis* (Fourtau, 1914) n. stat., Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4 and REH5, adapical, adoral, and posterior views; **E**, **F**, *Coenholectypus serialis* (Deshayes, 1847), Wadi Abu Qaada, Turonian, QEH1, adapical and adoral views; **G**, **H**, *Catopygus gibbus* Thomas & Gauthier, 1889, Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH2, adoral and side views; **I**, *Petalobrissus djelfensis* (Thomas & Gauthier, 1889), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH5, adapical view; **J**, **K**, *Petalobrissus humei* (Fourtau, 1906) n. comb., Wadi Abu Qaada, Turonian, Wata Formation, QEH3, adapical and adoral views; **L**, **M**, *Petalobrissus waltheri* (Gauthier), Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH4, adapical and side views. Scale bars: A, 1.4 mm; B-D, G, H, L, M, 3.3 mm; E, F, J, K, 4 mm; I, 2.5 mm.

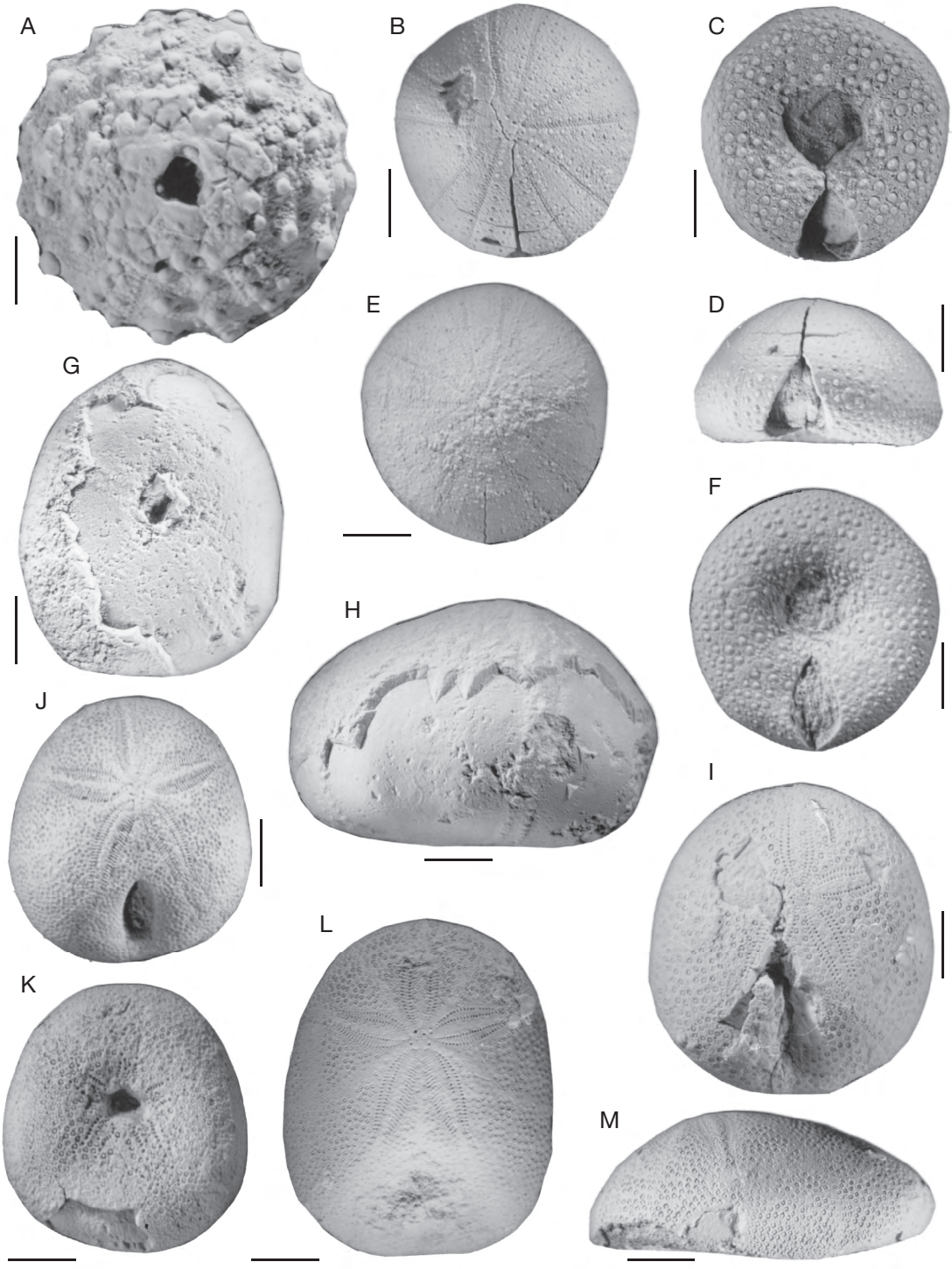
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TABLE 9. — Measurements (in mm) of *Petalobrissus djelfensis* (Thomas & Gauthier, 1889). Abbreviations: see Material and methods.

	L	W/L	H/L	LII/LI	NI	NII	NIII
Range	8.3-24.3	0.90-1.0	0.40-0.63	0.79-1.0	13-34	12-33	11-27
Mean	17.8	0.94	0.51	0.86	26.8	24.3	20.3

Order CASSIDULOIDA Claus, 1880
Family NUCLEOLITIDAE Agassiz & Desor, 1847
Genus *Catopygus* Agassiz, 1836

Catopygus gibbus Thomas & Gauthier, 1889
(Fig. 11G, H)

Catopygus gibbus Thomas & Gauthier *in* Gauthier, 1889: 47, pl. 3, figs 4-7. — Fourtau 1914: 57.

MATERIAL EXAMINED. — Five good specimens and many badly preserved other ones from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE85-89, Abu Roash echinoid horizon 2 (REH2).

DESCRIPTION
Test diameter attaining 11.7-20.0 mm. Outline wide at posterior (W/L = 0.80-0.88). Adapical surface convex, greatest height lies at the apical disc (H/L = 0.67-0.86). Adoral surface flattened. Posterior surface with low vertical truncation. Apical system anteriorly eccentric. Madreporite separates genital plates nos 1 and 4. Ambulacral areas petaloid, flush. Peristome slightly eccentric anteriorly. Periproct round, at the posterior truncation.

Family FAUJASIIDAE Lambert, 1905
Genus *Petalobrissus* Lambert, 1916

Petalobrissus djelfensis
(Thomas & Gauthier, 1889)
(Figs 11I; 13)

Echinobrissus djelfensis Thomas & Gauthier *in* Gauthier, 1889: 42, pl. 2, figs 30-32.

Petalobrissus djelfensis – Abdelhamid 1997: 148, fig. 6 (2).

MATERIAL EXAMINED. — Six specimens from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE90-95, Abu Roash echinoid horizon 5 (REH5) and seven specimens from the Coniacian-Santonian of Wadi Dakhl (Matulla Formation), ASUDLE15-21, Wadi Dakhl echinoid horizon 3 (DEH3).

MEASUREMENTS. — See Table 9.

DESCRIPTION
Test sub-rounded to oval. Maximum height lies at top of periproct. Adoral surface fairly concaved, depressed around peristome. Apical disc tetrabasal, anteriorly eccentric. Ambulacral areas petaloid. Anterior paired petals equal to or slightly shorter than the posterior paired petals, and slightly longer than the frontal petal. The two pores in each pore pair fused. All ambulacral plates beyond the petals are single-pored. Peristome pentagonal, feebly anteriorly eccentric, transverse. Bourrelets and phyllodes moderately developed. Periproct elongate, supramarginal.

REMARKS
The present species is distinguished from *P. waltheri* by its relatively larger test, more rounded outline (wider test), petal III are relatively shorter (Fig. 13), and by having less anteriorly eccentric peristome.

Petalobrissus humei (Fourtau, 1906) n. comb.
(Figs 11J, K; 14)

Echinobrissus humei Fourtau, 1906: 148, pl. 2, figs 5-10.

Nucleopygus humei – Lambert & Thiery 1921: 349.

MATERIAL EXAMINED. — 40 specimens from the Turonian of Wadi Abu Qaada (Wata Formation), ASUAQE76-115, Wadi Abu Qaada echinoid horizon 3 (QEH3).

MEASUREMENTS. — See Table 10.

DESCRIPTION
Apical disc slightly eccentric forwards. Ends of posterior petals lies at or slightly exceeds the

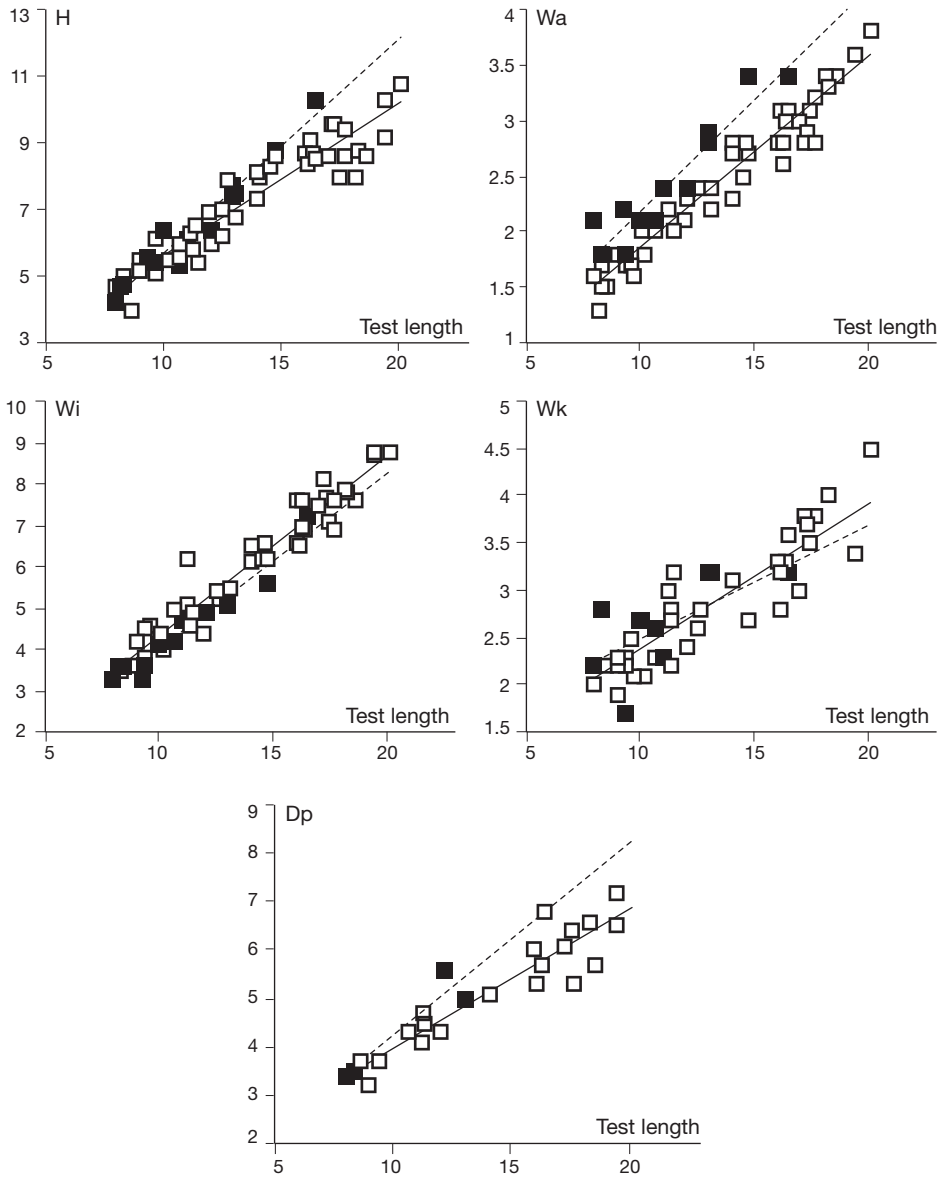

FIG. 12. — Comparison of *Coenholectypus roachensis* (Fourtau, 1914) n. stat. (filled quadrangles, dashed line) from the Coniacian-Santonian of Abu Roash and *Coenholectypus excisus* (Desor, 1847) (empty quadrangles, solid line) from the Cenomanian of Saint Paul, north Eastern Desert. The scatter plots show the relation between test length (**L**) and each of test height (**H**), width of ambulacrum (**Wa**), width of interambulacrum (**Wi**), width of periproct (**Wk**) and diameter of peristome (**Dp**).

adapical end of periproct. All ambulacral plates beyond petals single-pored; peristome faintly eccentric forwards.

REMARKS

This species is distinguished from *P. waltheri* in having small-sized test, petals II, III are relatively

TABLE 10. — Measurements (in mm) of *Petalobrissus humei* (Fourtau, 1906) n. comb. Abbreviations: see Material and methods.

	L	W/L	H/L	LII	LII/LI	NI	NII	NIII
Range	8.3-16.6	0.82-0.98	0.47-0.63	1.8-5.4	0.74-1.0	14-28	12-27	12-27
Mean	12.4	0.91	0.54	3.2	0.88	21.3	18.5	19.3

TABLE 11. — Measurements (in mm) of *Petalobrissus waltheri* (Gauthier, 1900). Abbreviations: see Material and methods.

	L	W/L	H/L	LI	LII/LI	LIII	NI	NII	NIII
Range	7.3-22.7	0.77-0.94	0.40-0.56	1.2-6.3	0.7-1.0	1.3-5.7	8-31	8-27	8-27
Mean	13.3	0.86	0.48	3.7	0.9	3.3	20.3	17.9	18.6

longer with larger number of pore pairs (Fig. 14), and relatively less eccentric apical disc and peristome. Abdelhamid (1997) discussed the difference between the genera *Petalobrissus*, *Nucleopygus* Agassiz, 1840, and *Echinobrissus* Gray, 1825 (= *Nucleolites* Lamarck, 1801). Due to the occurrence of a single pore in all ambulacral plates outside the petals, the present species refers to the genus *Petalobrissus*.

Petalobrissus waltheri (Gauthier, 1900) (Fig. 11L, M)

Echinobrissus waltheri Gauthier *in* Fourtau, 1900: 21, pl. 1, figs 8-10.

Petalobrissus waltheri – Abdelhamid 1997: 148, fig. 6 (3, 4). — Kora *et al.* 2002: pl. 4, fig. 11.

MATERIAL EXAMINED. — 40 specimens from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE96-135, Abu Roash echinoid horizons 2-5 (REH2-5), 16 from the Coniacian-Santonian in Wadi Dakhl (Matulla Formation), ASUDLE22-37, Wadi Dakhl echinoid horizon 2 (DEH2), and 28 from the same stage of Wadi Abu Qaada, ASUAQE116-143, Wadi Abu Qaada echinoid horizon 5 (QEH5).

MEASUREMENTS. — See Table 11.

DESCRIPTION

Test oval. Maximum width lies at end of the posterior paired petals. Anterior margin narrow. Posterior margin sub-round to straight. Adoral surface flattened, depressed around peristome. Apical disc tetrabasal. Ambulacral areas petaloid. Petals I, III, and V are relatively longer than petals II and IV. Pore pair conjugate, unequal, the outer slit-shaped, the inner round. All ambulacral plates beyond the petals are single-pored. Bourrelets occupy the vertical wall of peristome and part of interambulacra adjacent to peristome. Phyllodes moderately developed.

Order SPATANGOIDA Claus, 1876
Family TOXASTERIDAE Lambert, 1920
Genus *Toxaster* Agassiz, 1840

Toxaster dakhlensis n. sp. (Figs 15A-F; 16; 17A)

HOLOTYPE. — The specimen photographed in Figure 17A-C.

MATERIAL EXAMINED. — 15 specimens, ASUDLE38-52, deposited in Geology Department, Faculty of Science, Ain Shams University, Cairo.

TYPE LOCALITY. — Wadi Dakhl, north Eastern Desert, Egypt.

STRATIGRAPHIC HORIZON. — Turonian (Wata Formation), Wadi Dakhl echinoid horizon 1 (DEH1).

ETYMOLOGY. — Named after wadi dakhl, the locality from which material has been collected.

MEASUREMENTS. — See Table 12.

DIAGNOSIS. — Outline cordiform. Adapical surface convex, carinated behind the apical disc. Adoral surface swollen at the plastron. Apical disc semi-ethmolytic

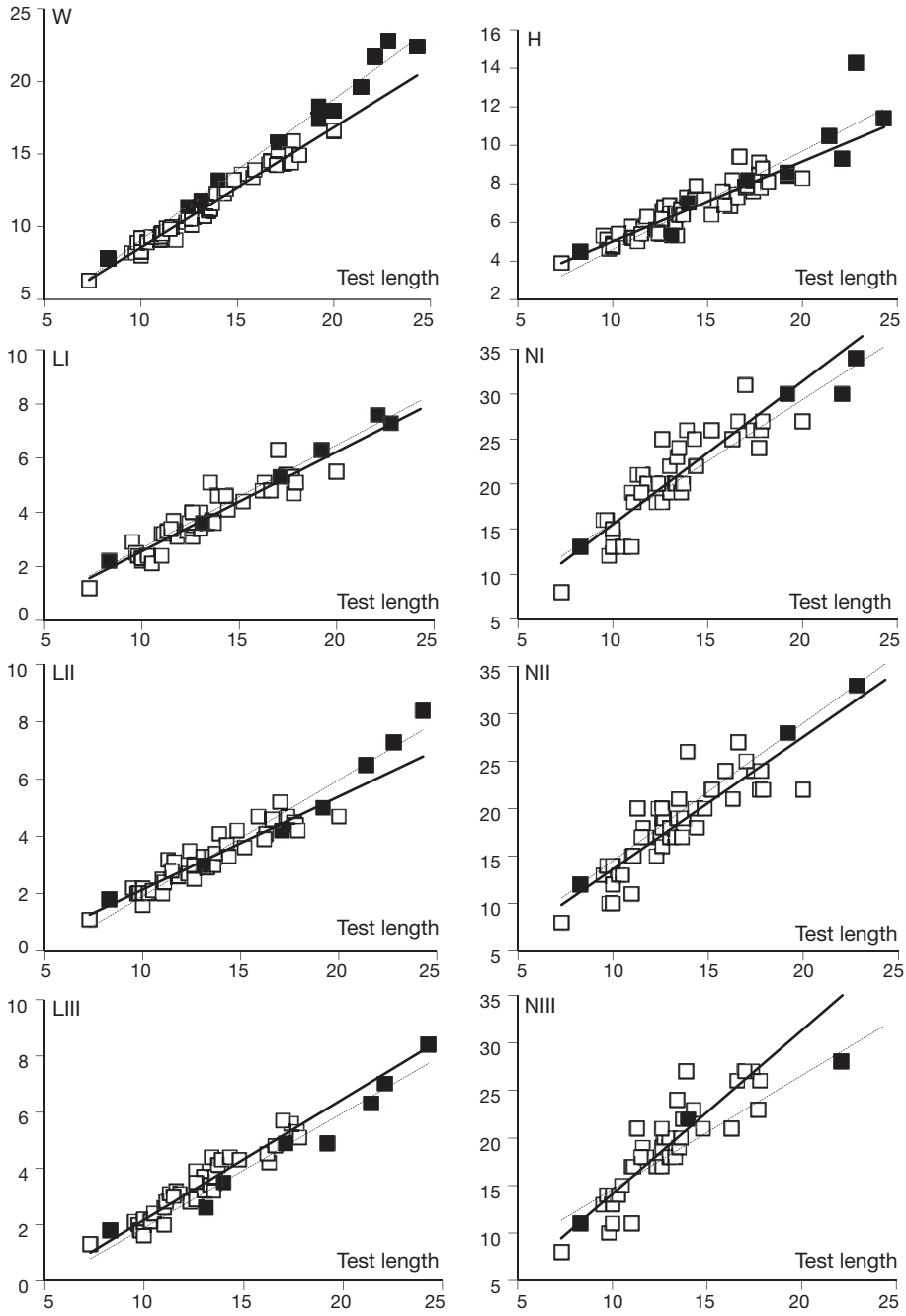

FIG. 13. — Comparison of *Petalobrissus djelfensis* (Thomas & Gauthier, 1889) from the Coniacian-Santonian of Abu Roash and Wadi Dakhl (filled quadrangles, dashed line) and *Petalobrissus waltheri* (Gauthier, 1900) from the Coniacian-Santonian of Abu Roash and Wadi Dakhl (empty quadrangles, solid line). The scatter plots show the relation between test length (**L**) and each of test width (**W**), test height (**H**), length of petal I or V (**LI**), number of pore pairs in petal I or V (**NI**), length of petal II or IV (**LII**), number of pore pairs in petal II or IV (**NII**), length of petal III (**LIII**), and number of pore pairs in petal III (**NIII**).

TABLE 12. — Measurements (in mm) of *Toxaster dakhlensis* n. sp. Abbreviations: see Material and methods.

	L	W/L	H/L	LII	LI/LII	NI	NII
Range	16.8-30.7	0.94-1.0	0.61-0.78	10.0-14.9	0.79-0.98	28-46	33-48
Mean	22.5	0.97	0.70	12.1	0.87	35.6	40.8

(madreporite separates genital plates 2 and 4) lying away from anterior margin by about 36-42% of the anterior–posterior distance. Frontal ambulacrum nonpetaloid, narrower than and as shallow as the paired petals, feebly notching the ambitus; poriferous zone narrow; pores oval; pore pair subequal, separated by a high ridge. Paired ambulacra petaloid, slightly depressed, wide, relatively closed distally; poriferous zones wide, equal; pores slit-shaped; pore pair equal, conjugate; pore pairs separated by a chain of fine granules; width of interporiferous zone nearly equal to or slightly less than width of one poriferous zone. Posterior paired petals slightly shorter than the anterior ones (Fig. 16). Angle between anterior paired petals = 125°; angle between posterior petals = 55-63°. Peristome pentagonal, labiates, and lying away from the anterior margin by 22-26% of the anterior-posterior distance. Periproct sub-round to oval, lying at the top of the posterior truncation.

DESCRIPTION

Outline cordiform; petals long, wide, slightly depressed; the frontal ambulacrum nonpetaloid. Fascioles absent. Apical disc semi-ethmolytic. Peristome pentagonal, labiates. Sternal plates fairly equal (Fig. 17A). Periproct sub-round to oval.

REMARKS

The present material is distinguished from the genus *Hemiaster* Agassiz & Desor, 1847 in having wide, long, and subequal petals, and by the absence of fascioles. The presence of asymmetric sternal plates, deep petals, and peripetalous and marginal fascioles distinguish *Polydesmaster* Lambert, 1920 from the present material. The presence of asymmetric sternal plates, deep petals, and peripetalous fascioles distinguishes *Jourdaniaster* Neumann, 1999 from the present material. The absence of fascioles, the shallow petals that not conspicuously closed distally, specially in the small individuals differentiate the present material from the genus *Mecaster* Pomel, 1883. The present specimens are similar to the genus *Toxaster* where they lack fascioles and have relatively shallow petals, relatively opened distally, but differ in having semi-ethmolytic apical disc, and subequal sternal plates. We think that this species represents a link between *Toxaster* and *Mecaster*.

The present specimens are distinguished from *Toxaster maurus* Lambert, 1931 from the Hauterivian of Morocco in having more rounded outline, smaller pores in the frontal ambulacrum, and more divergent anterior paired petals (Lambert 1931: 40, pl. 2, figs 13, 15). It is distinguished from *T. peroni* Lambert, 1920 in having more round outline, more divergent anterior paired petals, longer posterior paired petals, smaller pores in the frontal ambulacrum, and posterior interambulacrum carinated behind apical disc. It is distinguished from *T. obtusus* Lambert, 1931 in having more centric apical disc, longer and less divergent posterior petals, and non-flexuous anterior petals. It differs from *T. villei* Gauthier, 1875 in having longer posterior petals, more divergent anterior petals, smaller pores in the frontal ambulacrum, and more round test. It is differentiated also from *T. amplus* Desor, 1855 by the pre-mentioned diagnostic characters.

Family HEMIASTERIDAE Clark, 1917
Genus *Hemiaster* Agassiz & Desor, 1847

Hemiaster barthouxi Lambert, 1931
(Fig. 15G, H)

Hemiaster barthouxi Lambert, 1931: 196, pl. 5, figs 18, 19.

MATERIAL EXAMINED. — Five specimens from the Turonian of Wadi Abu Qaada (Wata Formation), ASUAQE144-148, Wadi Abu Qaada echinoid horizon 1 (QEH1).

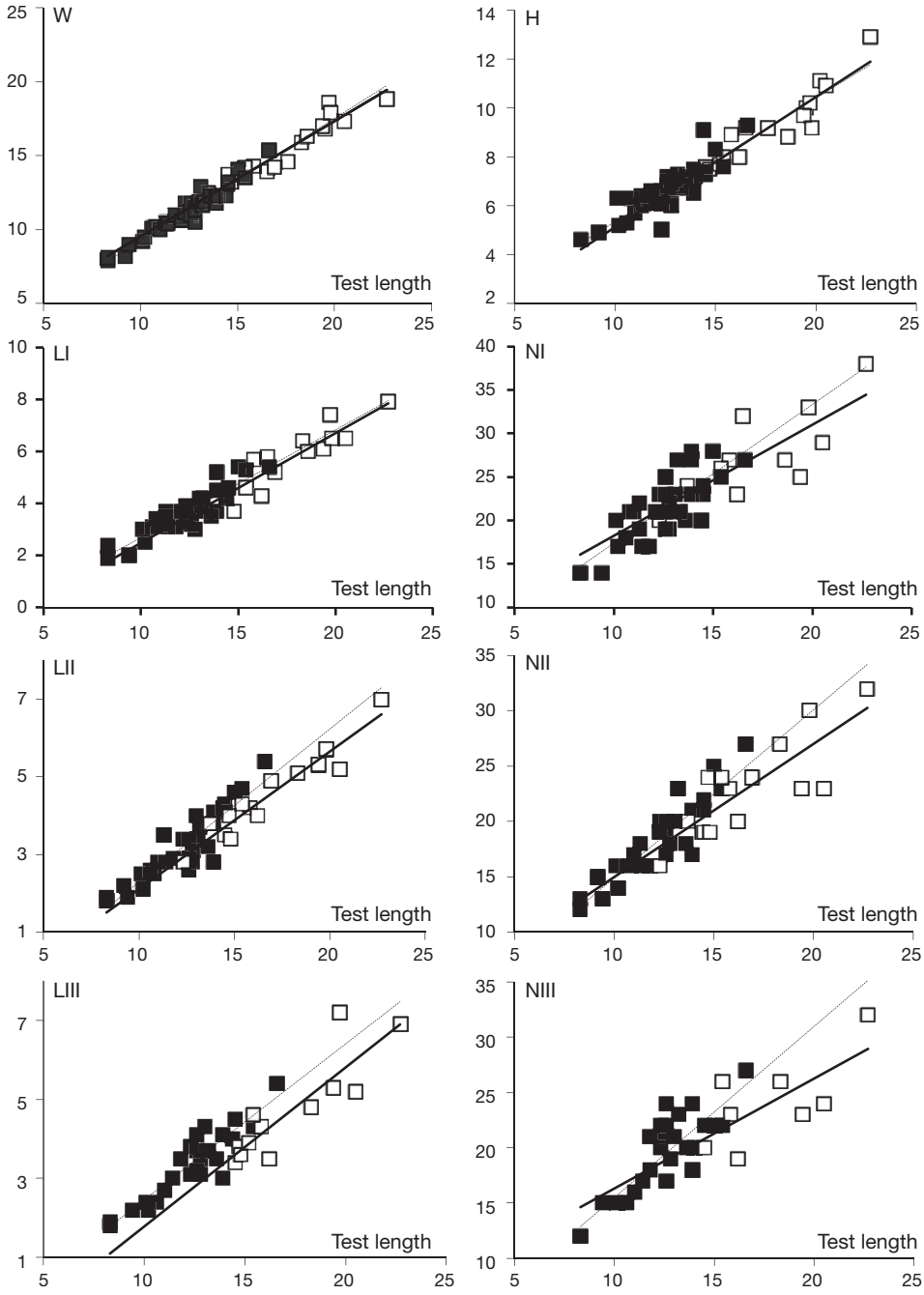

FIG. 14. — Comparison of *Petalobrissus humei* (Fourtau, 1906) n. comb. from the Turonian of Wadi Abu Qaada (filled quadrangles, dashed line) and *Petalobrissus waltheri* (Gauthier, 1900) from the Coniacian Santonian of Wadi Abu Qaada (empty quadrangles, solid line). The scatter plots show the relation between test length (**L**) and each of test width (**W**), test height (**H**), length of petal I or V (**LI**), number of pore pairs in petal I or V (**NI**), length of petal II or IV (**LII**), number of pore pairs in petal II or IV (**NII**), length of petal III (**LIII**) and number of pore pairs in petal III (**NIII**).

TABLE 13. — Measurements (in mm) of *Mecaster turonensis* (Fourtau, 1921). Abbreviations: see Material and methods.

	L	W/L	H/L	LII	LI/LII	NI	NII	NIII
Range	10.8-46.3	0.87-1.00	0.59-0.77	3.9-20.5	0.65-0.98	15-56	17-64	13-35
Mean	20.8	0.94	0.68	10.2	0.81	33	36.3	21

DESCRIPTION

Test length attaining 23.0-28.1 mm. Outline oval to sub-round, markedly wide at anterior (W/L = 0.91-1.0). Posterior margin straight. Adapical surface high, culminate behind the apical disc (H/L = 0.66-0.76). Adoral surface convex, swollen at the plastron. Posterior surface with oblique truncation. Apical disc centric, semi-ethmolytic. Frontal ambulacrum narrow and deep near apical disc, flush to very shallow at the ambitus. Paired ambulacra petaloid, relatively short and deep. Posterior paired petals shorter and less divergent than the posterior ones (LI/LII = 0.72-0.77, NI = 23-29, NII = 28-39). Fascioles are a narrow band of peripetalous parafasciole (*sensu* Néraudeau *et al.* 1998).

REMARKS

This species is characterized by its globular test with short petals and flush frontal ambulacrum at the ambitus. It is distinguished from *H. gauthieri* Péron, 1877 from the Turonian and Santonian of France and Spain in having relatively longer and deeper petals.

Genus *Mecaster* Pomel, 1883

Mecaster turonensis (Fourtau, 1921)
(Figs 15I-K; 17B, C)

Hemiaster heberti mutatio *turonensis* Fourtau, 1921: 89, pl. 11, figs 1-10.

Hemiaster heberti turonensis – Abdelhamid & El Qot 2001: 26, fig. 7G, H.

Hemiaster (*Mecaster*) *heberti* Coquand *turonensis* – El Qot 2006: 153, pl. 34, fig. 6a, b.

Mecaster turonensis – El Qot 2010: 282, pl. VI, figs 4a, b, 5, text-fig. 5f.

MATERIAL EXAMINED. — 130 specimens from the Turonian of Wadi Dakhl (Wata Formation), ASUDLE53-182, Wadi Dakhl echinoid horizon 1 (DEH1) and eight from the same stage of Wadi Abu Qaada, ASUAQE149-156, Wadi Abu Qaada echinoid horizon 1 (QEH1).

MEASUREMENTS. — See Table 13.

DESCRIPTION

Test size variable. Outline polygonal, slightly narrow at posterior. Maximum width lies to the anterior of apical disc. Posterior margin straight with feeble sulcus below periproct. Adoral surface convex, swollen at the plastron. Posterior surface with oblique truncation. Apical disc semi-ethmolytic, large, transverse, centric to slightly eccentric anteriorly. Frontal ambulacrum nonpetaloid, as deep as and slightly narrower than the paired petals, feebly notching the ambitus. Paired ambulacra petaloid, very wide, depressed, and long. Poriferous zones wide, equal. Pore pairs slit-shaped, equal, conjugate. Anterior paired petals long, reaching the ambitus. Posterior paired petals slightly shorter and less divergent than the anterior paired petals. Fascioles are composed of a narrow band of peripetalous parafasciole (*sensu* Néraudeau *et al.* 1998), slightly wider at the distal end of the paired petals.

FIG. 15. — **A**-**F**, *Toxaster dakhlensis* n. sp., Wadi Dakhl, Turonian, DEH1; **A**-**C**, adapical, adoral and side views (holotype); **D**-**F**, adapical, adoral and side views of a young specimen (paratype); **G**, **H**, *Hemiaster barthouxi* Lambert, 1931, Wadi Abu Qaada, Turonian, Wata Formation, QEH1, adapical and side views; **I**-**K**, *Mecaster turonensis* (Fourtau, 1921), Wadi Abu Qaada, Turonian, Wata Formation, QEH1, adapical, side and adoral views; **L**, **M**, *Mecaster fourneli* (Deshayes), Wadi Abu Qaada, Coniacian-Santonian, Matulla Formation, QEH5, adapical and side views; **N**, *Mecaster duncani* (Fourtau, 1906) n. comb., Wadi Dakhl, Turonian, Wata Formation, DEH1, adapical view; **O**, *Mecaster roachensis* (Gauthier, 1900) n. comb., Abu Roash, Coniacian-Santonian, Ostrea and Plicatula unit, REH1, adapical view. Scale bars: A-C, 10 mm; D-F, L, N-P, 6.7 mm; G-K, M, 5 mm.

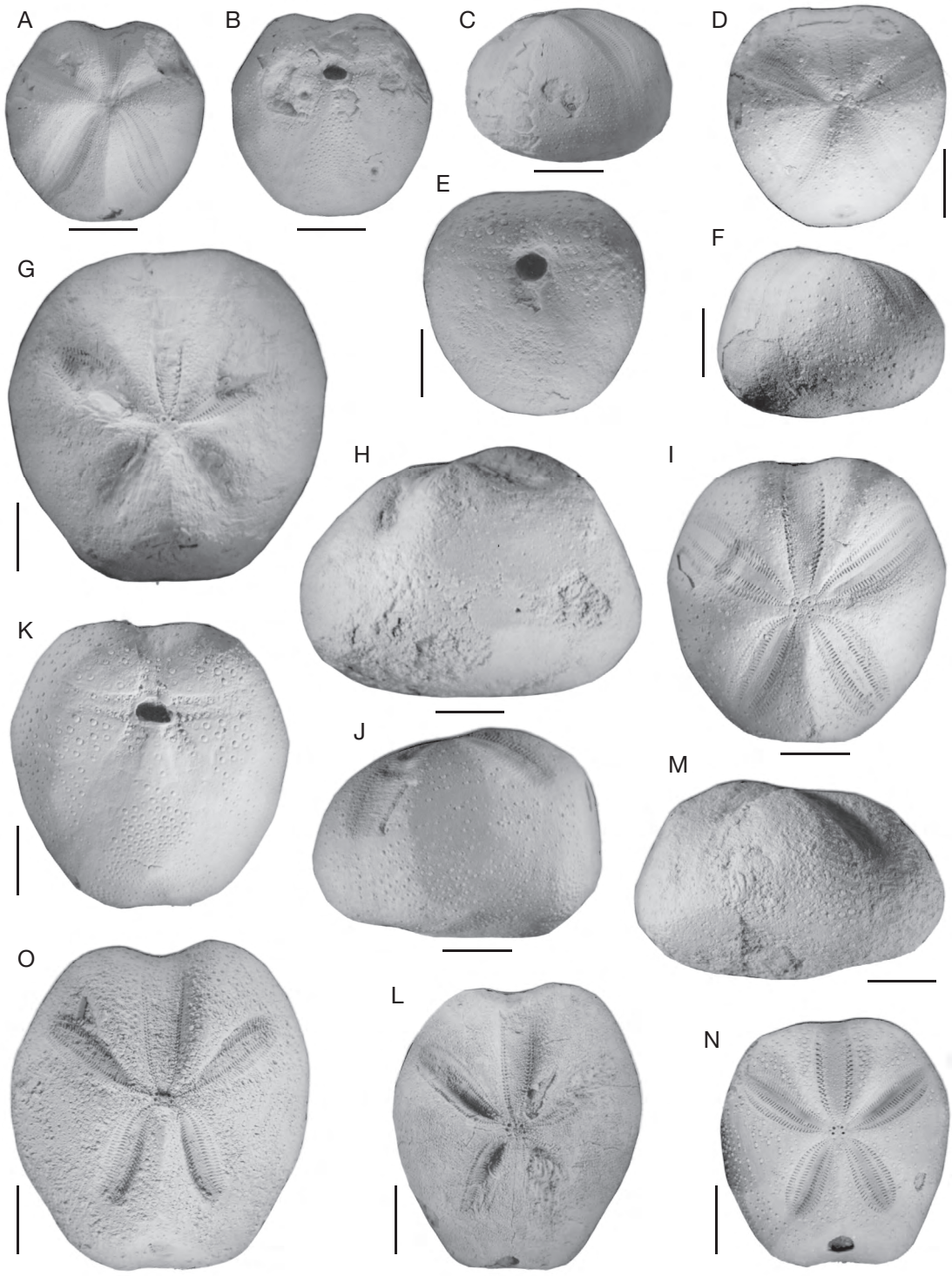
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TABLE 14. — Measurements (in mm) of *Mecaster fourneli* (Deshayes, 1847). Abbreviations: see Material and methods.

	L	W/L	H/L	LII	LI/LII	NI	NII
Range	12.2-44.4	0.86-1.00	0.59-0.80	4.7-18.6	0.60-0.93	21-40	26-50
Mean	24.1	0.93	0.70	9.9	0.76	27.4	36.3

TABLE 15. — Measurements (in mm) of *Mecaster duncani* (Fourtau, 1906) n. comb.

	L	W/L	H/L	LII	LI/LII	NI	NII	NIII
Range	12.8-34.2	0.85-0.97	0.57-0.71	5.2-15.1	0.72-0.98	20-41	26-44	15-26
Mean	20.4	0.91	0.63	8.7	0.85	28	33	20.3

REMARKS

The present species is distinguished from *Mecaster heberti* (Coquand, 1862) in having higher test, and wider and shallower paired petals. It is common in the basal part of the Turonian in many localities of Egypt (Fourtau 1921; El-Sheikh *et al.* 1998; Abdelhamid & El Qot 2001; Abdel-Gawad *et al.* 2004; El Qot 2006, 2010). Studying of the ocular and genital plates of the small-sized individuals of the present species revealed that individuals less than 11.3mm in length are juveniles and have no genital pores whereas individuals more than 14.2mm in length are adults and have well developed genital pores. Between these two test sizes, majority of individuals are having slightly distinguished genital pores; however there are many individuals still juveniles and have no genital pores at all; others have only three genital pores (genital pore no. 1 is absent); furthermore, there are individuals having only genital pore no. 4 is open. The juveniles are distinguished from the adults in having shallower ambulacra. The posterior surface is more oblique. The periproct is relatively larger and lies higher than in the adults. The posterior margin is straight in comparison to the concave margin of the adults. The plastronal area is flattened (swollen in the adults). The primary tubercles have a similar distribution as in the adults but they are more sparsely spaced. The two sub-anal sets of tubercles are less developed, widely spaced and slightly distinguished from the surrounding tubercles. The fascioles (parafascioles *sensu* Néraudeau *et al.* 1998) are weakly developed especially on the anterior half of test. These morphological variations might help in understanding of the ontogenetic changes of the present species.

Mecaster fourneli (Deshayes, 1847)
(Figs 15L, M; 17D, E)

Hemiaster fourneli Deshayes *in* Agassiz & Desor, 1847: 123. — Abdelhamid 1997: 154, fig. 7 (4). — Abdelhamid & El Qot 2001: 25, fig. 7C, D.

Periaster fourneli – Desor 1858: 383, pl. 42, fig. 5.

Hemiaster (*Mecaster*) *fourneli* – Abdel-Gawad *et al.* 2004: pl. 10, figs 12, 13. — El Qot 2006: 152, pl. 34, figs 2, 3. — Abdel-Gawad *et al.* 2007: pl. 6, figs 9, 10.

Mecaster fourneli – Smith & Bengston 1991: 61, pls 14A-M, 15A-L, 16E, F, figs 45K, L, 47, 48B, 50. — El Qot 2010: 280, pl. VI, figs 8, 9.

MATERIAL EXAMINED. — 16 measured specimens and numerous non measured from the Coniacian-Santonian of Abu Roash (Ostrea and Plicatula unit), ASUARE136-151, Abu Roash echinoid horizons 3-5 (REH3-5), four specimens and numerous non measured from the Coniacian-Santonian of Wadi Dakhl (Matulla Formation), ASUDLE183-186, Wadi Dakhl echinoid horizon 2 (DEH2), and one specimen from the Turonian (Wata Formation) of Wadi Abu Qaada, ASUAQE157, Wadi Abu Qaada echinoid horizon 2 (QEH2) and 12 from the Coniacian-Santonian (Matulla Formation), ASUAQE158-169, Wadi Abu Qaada echinoid horizon 5 (QEH5).

MEASUREMENTS. — See Table 14.

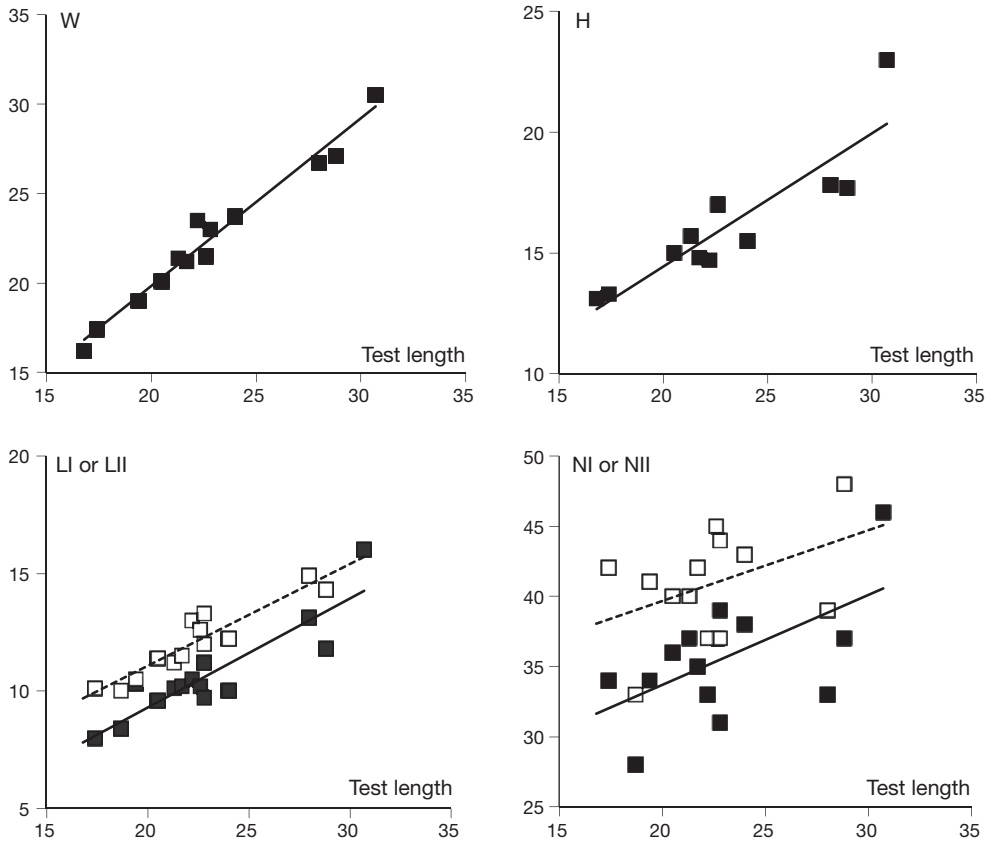

FIG. 16. — Biometric data on *Toxaster dakhlensis* n. sp., from the Turonian of Wadi Dakhl, showing the relation between test length (**L**) and each of test width (**W**); test height (**H**); length of petal I or V (**LI**), and number of pore pairs in petal I or V (**NI**; filled quadrangles, solid line); and length of petal II or IV (**LII**), and number of pore pairs in petal II or IV (**NII**; empty quadrangles, dashed line).

DESCRIPTION

Test size variable. Outline sub-hexagonal, and narrow at posterior. Anterior margin with conspicuous furrow. Apical disc semi-ethmolytic, transverse, centric to slightly eccentric backwards. Frontal ambulacrum nonpetaloid, wide, deep, and notching the ambitus until peristome. Pore pairs with small, oval, equal, nonconjugate, and oblique pores. Paired ambulacra petaloid, deep. Posterior paired petals shorter and less divergent than the anterior paired petals. Fascioles are composed of a wide band of peripetalous parafasciole (*sensu* Néraudeau *et al.* 1998).

Mecaster duncani (Fourtau, 1906) n. comb.
(Figs 15N; 17F)

Linthia duncani Fourtau, 1906: 162, pl. 3, figs 1-4.

Periaster duncani – Abdelhamid & El Qot 2001: 29, fig. 7N.

MATERIAL EXAMINED. — 29 specimens from the Turonian (Wata Formation) of Wadi Dakhl, ASUDLE187-215, Wadi Dakhl echinoid horizon 1 (DEH1) and 18 from the same stage of Wadi Abu Qaada, ASUAQE170-187, Wadi Abu Qaada echinoid horizon 1 (QEH1).

MEASUREMENTS. — See Table 15.

DESCRIPTION
Test polygonal. Maximum width lies slightly behind the distal ends of anterior paired petals. Apical disc semi-ethmolytic, transverse, centric to slightly eccentric anteriorly. Frontal ambulacrum nonpetaloid, and relatively deep. Paired ambulacra deep, wide, and petaloid. Peristome pentagonal, transverse, and labiates. There are two types of fascioles: a wide band of peripetalous ortho- to parafasciole (*sensu* Néraudeau *et al.* 1998) and a fine band of lateroanal parafasciole.

REMARKS
Many authors considered that the post-Cenomanian *Mecaster* Pomel, 1883 species can develop two fascioles (peripetalous and latero-anal) in fine grained sediments (Lambert 1921; Zaghbib-Turki 1989, 1990; Néraudeau 1994; Villier *et al.* 2004). Accordingly, many species previously referred to *Periaster* d'Orbigny, 1853 are attributed to *Mecaster* (bifasciata ecological varieties of the typical *Mecaster* species). The present species has long, sub-equal, moderately depressed paired petals. The apical disc is semi-ethmolytic (madreporite separates genital plates 1and 4). Fascioles are composed of a wide band of peripetalous ortho- to parafasciole *sensu* Néraudeau *et al.* (1998) and a narrow band of latero-anal parafasciole *sensu* Néraudeau *et al.* (1998; bifasciata stage). The labrum is triangular and long, and the sternal plates are approximately symmetric (Fig. 17F). These characters refer this species to genus *Mecaster*.

Mecaster roachensis (Gauthier, 1900) n. comb.
(Fig. 15O)

Periaster roachensis Gauthier *in* Fourtau, 1900: 24, pl. 1, figs 13-15. — Abdelhamid 1997: 156, fig. 7 (9, 10).

MATERIAL EXAMINED. — Two well preserved and numerous incomplete specimens from Abu Roash: Turonian (rudist unit), ASUARE152, Abu Roash echinoid horizon 1 (REH1) and the Coniacian-Santonian (Ostrea and Plicatula unit), ASUARE153, Abu Roash echinoid horizon 4 (REH4).

DESCRIPTION
Test size variable (L = 14.5-40.0 mm) but mostly has large size. Outline heat-shape (W/L = 0.91-0.95). Anterior margin with a marked sulcus. Adapical surface sloped forwards. Maximum height lies directly behind apical disc (H/L = 0.62-0.70). Posterior surface with oblique to nearly vertical truncation. Adoral surface swollen at the plastron. Sternal plates are approximately equal. Apical disc semi-ethmolytic, centric, and transverse. Frontal ambulacrum nonpetaloid (NIII = 40), deep, wider than the paired petals and conspicuously notching the ambitus until the peristome. Paired ambulacra petaloid, deep, and relatively narrow. Anterior paired petals long (LII = 7.8-13.9 mm, NII = 30-45). Posterior paired petals shorter (LI/LII = 0.80, NI = 30-45), narrower, and less divergent than the anterior paired petals.

REMARKS
This species has fairly long, slightly depressed paired petals. The posterior pair is relatively shallower and shorter than the anterior one. The apical disc is semi-ethmolytic (the madreporite separates the genital plates 1 and 4). Fascioles are a narrow band of peripetalous ortho- to parafasciole *sensu* Néraudeau *et al.* (1998) and a narrow band of latero-anal parafasciole (bifasciata stage). The labrum is triangular and long. The sternal plates are nearly symmetric. As discussed in the previous species, regards the relation between the two genera *Periaster*, d'Orbigny, 1853 and *Mecaster*, the characters of the present species attribute it to the genus *Mecaster*. *Mecaster roachensis* n. comb. is distinguished from *Mecaster fourneli* in having lateroanal parafascioles, maximum width lies at the mid distance between anterior and posterior of test, more centric apical disc, and wider frontal ambulacrum.

BIOSTRATIGRAPHIC AND BIOGEOGRAPHIC DISCUSSION

The biostratigraphic distribution of the echinoid species in the present study (Table 16) shows that 11 species are confined to the Turonian and 12 species are restricted to the Coniacian-Santonian. The range of five species exceeds the Turonian-Santonian.

The distribution of the echinoid species (Figs 2-4) shows that some local correlation occurs between

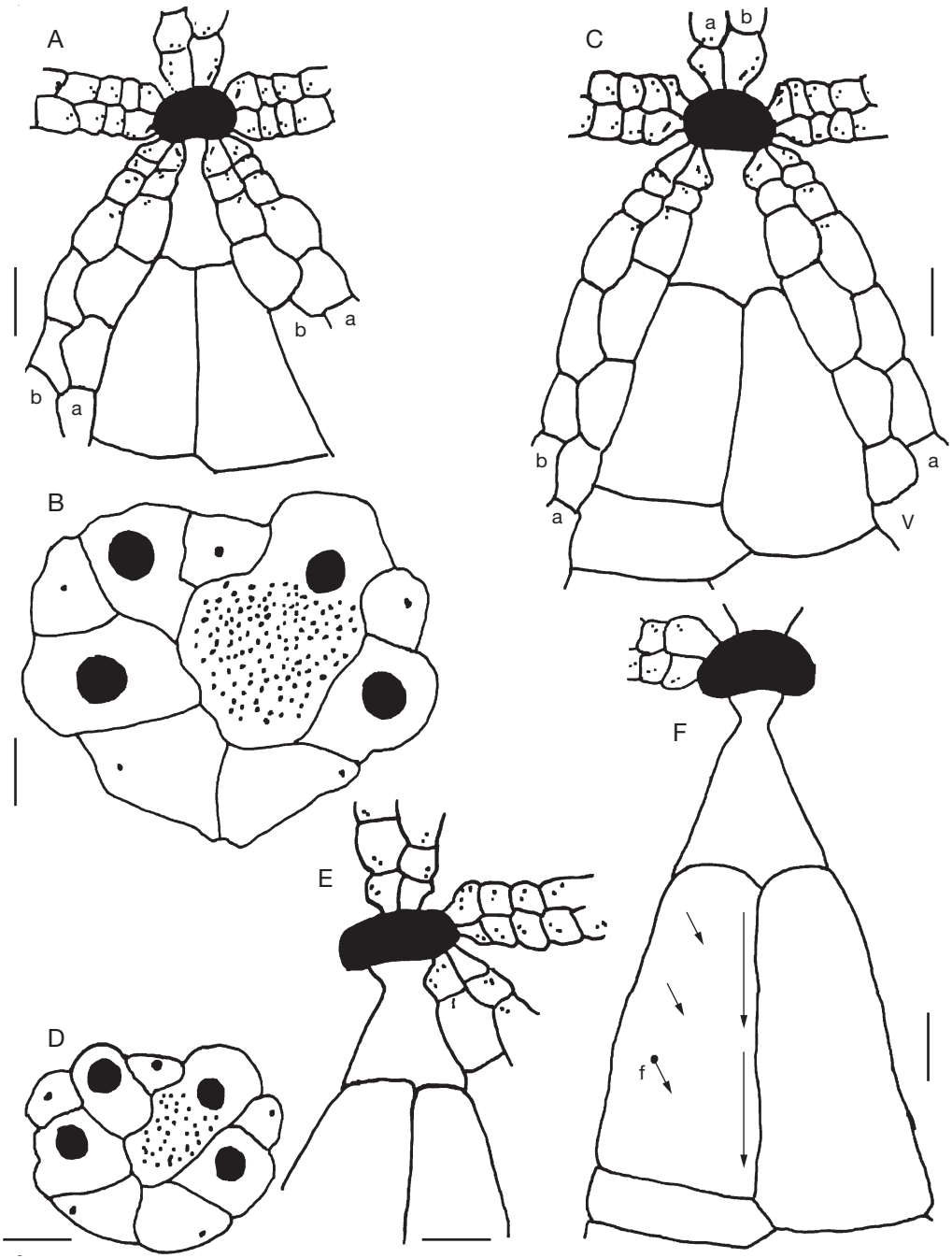

Fig. 17. — Camera lucida drawings: **A**, phyllode and plastron plating in *Toxaster dakhlensis* n. sp. from the Turonian of Wadi Dakhl; **B**, **C**, *Mecaster turonensis* (Fourtau, 1921) from the Turonian of Wadi Dakhl; **B**, apical disc; **C**, phyllode and plastron plating; **D**, **E**, *Mecaster fourneli* (Deshayes, 1847) from the Coniacian-Santonian of Wadi Abu Qaada; **D**, apical disc; **E**, phyllode and plastron plating; **F**, phyllode and plastron plating in *Mecaster duncani* (Fourtau, 1906) n. comb. from the Turonian of Wadi Abu Qaada. Abbreviations: **a**, first half of the ambulacrum; **b**, second half of the ambulacrum; **f**, direction of enlargement of the scrobicules on the sternal plates (indicated by the arrows); **V**, ambulacrum no. 5. Scale bars: A, C, 2 mm; B, 0.36 mm; D, 0.4 mm; E, 1.4 mm; F, 1.3 mm.

TABLE 16. — Stratigraphic distribution of the echinoid species studied in the present study. Abbreviations: **Cenom.**, Cenomanian; **Maast.**, Maastrichtian.

Species	Cenom.	Turonian	Coniacian -Santonian	Campanian	Maast.
Orthopsis miliaris (d'Archiac, 1835)	▲	▲	▲	▲	▲
Mecaster fourneli (Deshayes, 1847)		▲	▲	▲	
Desoricidaris aegyptica (Fourtau, 1914)			▲		
Desoricidaris crameri (de Loriol, 1887)			▲		
Cidaris schweinfurthi (Gauthier, 1901)			▲		
Phymosoma beadnelli (Gregory, 1906)			▲		
Phymosoma roachensis (Fourtau, 1914)			▲		
Phymosoma thevestense (Péron & Gauthier, 1879)		▲	▲		
Rachiosoma rectilineatum (Péron & Gauthier, 1881)			▲		
Goniopygus innesi Gauthier, 1901			▲		
Goniopygus sp.			▲		
Coenholectypus roachensis (Fourtau, 1914) n. stat.			▲		
Catopygus gibbus Thomas & Gauthier, 1889			▲		
Petalobrissus djelfensis (Thomas & Gauthier, 1889)			▲		
Petalobrissus waltheri (Gauthier, 1900)			▲		
Mecaster roachensis (Gauthier, 1900) n. comb.		▲	▲		
Phymosoma abbatei (Gauthier, 1898)		▲			
Phymosoma baylei (Cotteau, 1864)		▲			
Phymosoma major (Coquand, 1862)		▲			
Rachiosoma irregulare Fourtau, 1921		▲			
Thylechinus (*T.*) *sinaiensis* n. sp.		▲			
Orthopsis ovata (Coquand, 1862)		▲			
Coenholectypus serialis (Deshayes, 1847)		▲			
Petalobrissus humei (Fourtau, 1906) n. comb.		▲			
Toxaster dakhlensis n. sp.		▲			
Hemiaster barthouxi Lambert, 1931		▲			
Mecaster turonensis (Fourtau, 1921)		▲			
Thylechinus (*O.*) *quincuncialis* Gregory, 1906	▲	▲			
Trochalosoma (*T.*) *gharamulensis* Abdelhamid & Azab, 2003	▲	▲			
Mecaster duncani (Fourtau, 1906) n. comb.	▲	▲			

the echinoid horizons in the present studied sections and other echinoid and macrofossil horizons and assemblages in other parts of Egypt.

DISTRIBUTION OF ECHINOID HORIZONS IN ABU ROASH SECTION

Five echinoid horizons could be distinguished in the Turonian-Santonian section in Abu Roash, one in the Turonian and four in the Coniacian-Santonian (Fig. 2). From base to top, they are as follows:

1) Abu Roash echinoid horizon 1 (REH1): it occurs in the basal beds of the rudist unit (Turonian) and yields *Phymosoma abbatei* and *Mecaster roachensis* n. comb.;

2) Abu Roash echinoid horizon 2 (REH2): it occurs in the basal beds of the *Ostrea* and Plicatula unit (Coniacian-Santonian) and from which *Goniopygus innesi*, *Catopygus gibbus*, and *Petalobrissus waltheri* have been collected;

3) Abu Roash echinoid horizon 3 (REH3): it is rich in *Petalobrissus waltheri* and *Mecaster fourneli*;

4) Abu Roash echinoid horizon 4 (REH4): it is rich in echinoids and yields *Desoricidaris aegyptica*, *D. crameri*, *Orthopsis miliaris*, *Phymosoma beadnelli*, *Phymosoma roachensis*, *Goniopygus innesi*, *Goniopygus* sp., *Coenholectypus roachensis* n. stat., *Petalobrissus waltheri*, *Mecaster fourneli* and *Mecaster roachensis* n. comb.;

5) Abu Roash echinoid horizon 5 (REH5): it occurs in the uppermost beds of the Ostrea and Plicatula unit and yields *Desoricidaris crameri*, *Cidaris schweinfurthi*, *Coenholectypus roachensis* n. stat., *Petalobrissus djelfensis*, *P. waltheri* (Gauthier, 1900) and *Mecaster fourneli*.

TABLE 17. — Paleogeographic distribution of the echinoid species in the present study.

Species	Endemic	North Africa	Middle East	Europe	Brazil
Desoricidaris aegyptica (Fourtau, 1914)	▲				
Desoricidaris crameri (de Loriol, 1887)	▲				
Cidaris schweinfurthi (Gauthier, 1901)	▲				
Orthopsis miliaris (d'Archiac, 1835)		▲	▲	▲	▲
Orthopsis ovata (Coquand, 1862)		▲	▲		
Phymosoma abbatei (Gauthier, 1898)	▲				
Phymosoma baylei (Cotteau, 1864)		▲			
Phymosoma beadnelli (Gregory, 1906)	▲				
Phymosoma major (Coquand, 1862)		▲			
Phymosoma roachensis (Fourtau, 1914)	▲				
Phymosoma thevestense (Péron & Gauthier, 1879)		▲			
Rachiosoma irregulare Fourtau, 1921	▲				
Rachiosoma rectilineatum (Péron & Gauthier, 1881)		▲			
Thylechinus (*T.*) *sinaiensis* n. sp.	▲				
Thylechinus (*O.*) *quincuncialis* Gregory, 1906	▲				
Trochalosoma (*T.*) *gharamulensis* Abdelhamid & Azab, 2003	▲				
Goniopygus innesi Gauthier, 1901	▲				
Goniopygus sp.	▲				
Coenholectypus roachensis (Fourtau, 1914) n. stat.	▲				
Coenholectypus serialis (Deshayes, 1847)		▲	▲	▲	
Catopygus gibbus Thomas & Gauthier, 1889		▲			
Petalobrissus djelfensis (Thomas & Gauthier, 1889)		▲			
Petalobrissus humei (Fourtau, 1906) n. comb.	▲				
Petalobrissus waltheri (Gauthier, 1900)	▲				
Toxaster dakhlensis n. sp.	▲				
Hemiaster barthouxi Lambert, 1931	▲				
Mecaster turonensis (Fourtau, 1921)	▲				
Mecaster fourneli (Deshayes, 1847)		▲	▲		▲
Mecaster duncani (Fourtau, 1906) n. comb.	▲				
Mecaster roachensis (Gauthier, 1900) n. comb.	▲				

DISTRIBUTION OF ECHINOID HORIZONS IN WADI DAKHL SECTION

Three echinoids horizons could be recognized in the Turonian-Santonian sequence in Wadi Dakhl, one in the Turonian and two in the Coniacian-Santonian (Fig. 3). They are as follows from base to top:

1) Wadi Dakhl echinoid horizon 1 (DEH1): it occurs in the basal beds of the Wata Formation (Turonian) following a characteristic limestone bed very rich in large-sized cephalopods (ammonites). It yields *Phymosoma baylei*, *Toxaster dakhlensis* n. sp., *Mecaster turonensis* and *Mecaster duncani* n. comb.;

2) Wadi Dakhl echinoid horizon 2 (DEH2): it occurs in the basal beds of the Matulla Formation (Coniacian-Santonian) and from which *Petalobrissus waltheri* and *Mecaster fourneli* have been collected;

3) Wadi Dakhl echinoid horizon 3 (DEH3): it yields *Rachiosoma rectilineatum* and *Petalobrissus djelfensis*. It matches Abu Roash echinoid horizon 5 (REH5).

DISTRIBUTION OF ECHINOID HORIZONS IN WADI ABU QAADA SECTION

Five echinoid horizons are delineated in the Turonian-Santonian sequence in Wadi Abu Qaada, four in the Turonian and one in the Coniacian-Santonian (Fig. 4). From base to top they are as follows:

1) Wadi Abu Qaada echinoid horizon 1(QEH1): it occurs in the basal part of the Turonian sequence (Wata Formation) following a characteristic limestone bed very rich in large-sized cephalopods (ammonites). It yields *Orthopsis ovata*, *Phymosoma baylei*, *P. major* (Coquand, 1862), *Trochalosoma* (*T.*) *gharamulensis*, *Coenholectypus serialis*, *Hemi-*

TABLE 18. — Stratigraphic and paleogeographic distribution of the Cretaceous echinoids from Egypt.

		Geographic distribution of the echinoid species as percent to the total number of species			
Age	**Reference**	Endemic to Egypt	Common to North Africa	Common to Middle East	Common to Europe
Turonian-Santonian	Present work	66.7%	33.3%	13.3%	6.7%
	Abdelhamid & El Qot 2001	44%	39%	17%	17%
	Abdelhamid 1997	52%	38%	9.5%	14%
Cenomanian	Abdelhamid & Azab 2003	31%	60%	40%	37%
	Abdelhamid & El Qot 2001	34.5%	52%	48%	34%
Aptian-Albian	Abdelhamid & Azab 2003	43%	36%	36%	29%

aster barthouxi, *Mecaster turonensis*, and *Mecaster duncani* n. comb. *Mecaster turonensis* has a local biostratigraphic value where it appears in the basal beds of the Turonian (Wata Formation) overlying a bed containing large-sized cephalopods (ammonites). It is mostly associated with the echinoids *Phymosoma abbatei*, *P. baylei*, and *Mecaster duncani* n. comb. This horizon was recorded in Sinai such as Gabal Halal, Gabal Dhalfa, Gabal Libni (Fourtau 1921), Gabal El-Minsherah (*Phymosoma abbatei-Hemiaster heberti turonensis* horizon) and Gabal El-Hamra (*Hemiaster heberti turonensis* horizon and *Phymosoma abbatei* horizon) El-Sheikh *et al.* (1998), Abdelhamid & El Qot (2001), and the present work (QEH1 and DEH1). It correlates also with *Cyphosoma abbatei-Holectypus turonensis* zone in Awad & Issawi (1975). Abdel Gawad *et al.* (2004) and El Qot (2005) recorded this species in the Lower Turonian of Gabal Ekma (south Sinai), East Themed area (east Central Sinai), and Gabal Yelleg (north Sinai): *Hemiaster* (*Mecaster*) *heberti turonensis-Coenholectypus turonensis* Acme zone;

2) Wadi Abu Qaada echinoid horizon 2 (QEH2): it yields *Thylechinus* (*Orthechinus*) *quincuncialis* and *Mecaster fourneli*. It matches Sudr echinoid horizon 2 (SEH2) in Abdelhamid (1997);

3) Wadi Abu Qaada echinoid horizon 3 (QEH3): it yields *Thylechinus* (*T.*) *sinaiensis* n. sp. and *Petalobrissus humei* n. comb.;

4) Wadi Abu Qaada echinoid horizon 4 (QEH4): in which *Rachiosoma irregulare* occurs;

5) Wadi Abu Qaada echinoid horizon 5 (QEH5): it occurs in the upper beds of the Coniacian-Santonian sequence (Matulla Formation). It is rich in *Petalobrissus waltheri* and *Mecaster fourneli*. This horizon matches Wadi Dakhl echinoid horizon 2 (DEH2) and Abu Roash echinoid horizon 3 and 4 (REH3 and REH4) in the present work. It correlates to *Lopha dichotoma-Plicatula ferryi* zone in Awad & Issawi (1975), Kora & Hamama (1987), *Echinobrissus waltheri* zone in Zico *et al.* (1993), Sudr echinoid horizons 3 and 4 (SEH3 and SEH4) and Matulla echinoid horizons 1 and 2 (MEH1 and MEH2) in Abdelhamid (1997).

The biogeographic distribution of the Turonian-Santonian echinoids in the present study (Table 17) shows that most of the echinoid species in the present study are endemic (67% of species). Rest of species (33%) shows different affinities to the echinoid fauna of other Tethyan regions: 33% of species are common to North Africa, 13% to the Middle East and 7% to Western Europe.

The biogeographic distribution of the Cretaceous echinoids from Egypt (Table 18) indicates that endemism was high during the Aptian-Albian time (43% of species) whereas it was low during the Cenomanian (31-34.5 % of species) reflecting good biogeographic connections and a large spatial distribution of echinoids. The consequence is appearance of many cosmopolitan echinoid species and a biological affinity between the Tethyan echinoids and echinoids from the Arabian Gulf (Roman *et al.* 1989; Smith *et al.* 1990; and Néraudeau *et al.* 1995), Middle Asia (Caracurum; Stefanini 1928), West Africa (Lambert 1938 and Néraudeau 1991), and Brazil (Smith & Bengtson 1991). This is in

accordance with the global transgression of the Tethys during the Cenomanian Time (Awad & Fawzi 1956; Néraudeau 1991; Smith 1992; Néraudeau *et al.* 1995).

During the Turonian-Santonian time, endemism reappeared where 44 to 67% of the echinoid species are endemic. This is related to regression of the Tethys and predominance of localized environments. It was found also that the Cretaceous echinoids of Egypt (Table 18) show a close affinity to the echinoids of North Africa (33-60% of species). They resemble also echinoids from the Middle East (9.5-48% of species) and Western Europe (7-37% of species).

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