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REGULAR RESEARCH ARTICLE

A new species of *Hypselaster* (Echinoidea, Spatangoida) from the Middle Eocene Midawara Formation of the Eastern Desert, Egypt

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Abstract
The schizasterid echinoid genus *Hypselaster* Clark, 1917, is recorded for the first time from the Midawara Formation (Middle Eocene, Lutetian), which crops out east Maghagha area, east Nile Valley, Eastern Desert, Egypt. Except for *Hypselaster* sp. from the Upper Miocene (Messinian) of Morocco, no *Hypselaster* has been recorded in pan Africa. The material described in the present paper is considered to represent a new species (*Hypselaster strougoi* n. sp.) that is characterized by a medium, oval to subpentagonal test with distinct frontal sinus, a subcentral ethmolytic and wide apical disc (slightly behind the center of test) with two large and apart genital pores, an anteriorly excentric semilunal-shaped peristome, long, flexed and deeply sunken paired anterior petals, a longitudinally oval periproct in the topmost part of the oblique forwardly truncated posterior, and perforate, crenulated tubercles. Both peripetalous and incomplete latero-anal fascioles are present; the latero-anal fasciole is faint and incomplete laterally on the sides of the test.

Keywords Schizasteridae · Lutetian · Mokattamian · Maghagha area · New species

Introduction

In general, the genus *Hypselaster* Clark, 1917 is rare, despite the fact that it has a global fossil record. To date, five extinct species are distinguished, based on the material from Eocene to Miocene rocks of the Caribbean, England, Morocco and India. These include *H. obliquatus* (Sowerby, *in* Grant 1840) from the Eocene of India, *H. rajasthanensis* Srivastava and Kulshreshtha, 2009 from the Ypresian (Lower Eocene) of India, *H. branderianus* (Forbes, 1852) from the Bartonian (Middle Eocene) of England (see Lewis 1989), *H. perplexus* Arnold and Clark, 1927 from the Eocene of Jamaica and *Hypselaster* sp. of Lachkhem and Roman (1995) from the Upper Miocene of Morocco. In addition, there are nine extant species of the genus that inhabit the Caribbean Sea and the Indo-Pacific Ocean. These include *H. jukesii* (Gray, 1855) from Australia, *H. limicolus* (Agassiz, 1878) from the Gulf of Mexico, *H. rotundus* (Agassiz and Clark, 1907) and *H. fragilis* (Agassiz and Clark, 1907), both from Japan, *H. maximus* (Agassiz and Clark, 1907) from the Hawaiian Islands, *H. kempi* (Koehler, 1914) from the Indian Ocean, *H. brachypetalus* Clark, 1917 from the Caribbean, *H. dolosus* Clark, 1938 from Australia and *H. affinis* Mortensen, 1948 from the Philippines (Kroh and Smith 2010; Kroh 2015).

Stratigraphy

The sedimentary rocks exposed in the Maghagha area, east of the Nile Valley (Fig. 1), belong exclusively to the Middle Eocene (Lutetian and Bartonian). These rocks are highly fossiliferous, including foraminifera, ostracods, bryozoans, algae, echinoids, bivalves, gastropods, cephalopods, corals and crabs. Echinoids rank amongst the commoner macrofossils in the study area. Yet, there are only few papers that describe echinoids from the Maghagha area and the El Sheikh Fadl-Ras Gharib stretch; these include Strougo (1986), Azab (1992), Ali (2017) and Elattaar (2018).

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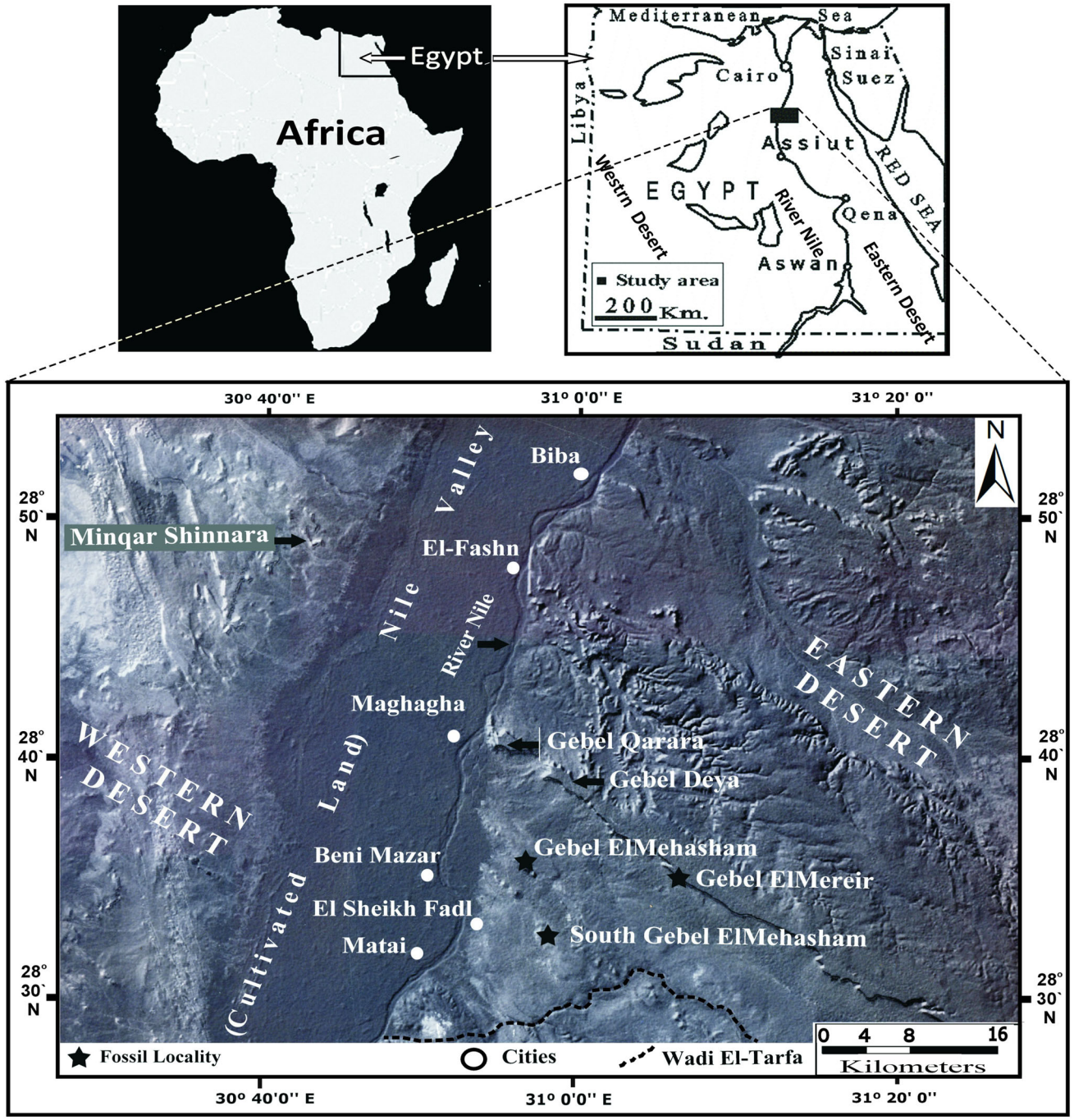

Fig. 1 Locality map of the study area, showing the areal distribution of the sections studied

Bishay (1961, 1966) subdivided the Eocene succession of the Maghagha area into three units, i.e., the Maghagha, Qarara and El Fashn formations, in ascending order. The gross lithological characters of all these units in the east of the Maghagha area extend to the southern part of the Fayum; these had earlier been named the Wadi Rayan Series by Beadnell (1905). Iskander (1943) was able to subdivide the Wadi Rayan Series into four units, from the base to the top: the Muweilih, Midawara, Sath El Hadid and El Gharaq formations. Lithostratigraphical units of the Fayum and Fayum-Nile Valley are similar to those exposed in the area east of the Nile Valley (Maghagha area), as indicated by Iskander (1943), Strougo (1986, 2002, 2008), Azab (1992), Elattaar and Seddik (2017) and Elattaar (2018). According to Strougo (2002), these four formations belong to the Mokattamian Stage, a local chronostratigraphical entity. By application of the priority rule, Iskander's nomenclature should be extended to include the

succession in the Maghagha area and that along the El Sheikh Fadl-Ras Gharib stretch, east of the Nile Valley.

The Middle Eocene succession of the Maghagha area comprises three formations, from the base to the top: the Muweilih, Midawara and Sath El Hadid formations (Figs. 2, 3). The echinoids of the present paper have been collected from the Midawara Formation at three main outcrops located east of the Nile Valley (Maghagha area, Eastern Desert), namely Gebel El Mehasham (co-ordinates: 28°30′03.1″N, 30°55′37.5″E), south Gebel El Mehasham (28°27′37.2″N, 30°57′56.0″E) and Gebel El Mereir (28°30′37.6″N, 31°04′26.3″E). The majority of this material came from a single sandstone bed in the Gebel El Mereir section (Figs. 1, 2, and arrowed in 3).

The basal part of the Midawara Formation constitutes the entire succession in the Gebel El Mehasham and south Gebel El Mehasham sections, whereas its upper part is exposed at Gebel El Mereir (Fig. 3). It typically starts with a thick unit of dark shale (forming the bulk of Gebel El Mehasham and south Gebel El Mehasham sections) and passes upwards into brown calcareous siltstones, sandstones and shale, with repetitive banks of *Nummulites*-rich rocks and shell beds. Elattaar (2018) recorded twenty-one echinoid species from this formation, three of which extend up into the upper unit, the Sath El Hadid Formation. Other associated fossils include nummulitid foraminifera, gastropods, bivalves, nautiloid cephalopods, crabs, corals and fish bones and teeth. Generally, this unit has been correlated with the Middle Eocene (Lutetian) and middle Mokattamian (MK4–MK5) (Strougo 1986, 2008; Strougo and Hottinger 1987; Boukhary et al. 1993; Strougo and Elattaar 2005; Elattaar and Seddik 2017; Elattaar 2018). The Sath El Hadid Formation represents the main (upper) part of the succession in the Gebel El Mereir section and it conformably overlies the Midawara Formation. The Muweilih Formation is not exposed in any of the sections studied; in general, it is barren of echinoids.

EPOCH	West Europe Divisions (STANDARD STAGE)	Local Chronostratig-raphic Units			Nile Valley and El Fayum Formation	
Late Eocene	Priabonian	Mokattamian	Upper	M K 12	Qasr El Sagha	
				M K 11		
				M K 10		
				M K 9		
			Middle	M K 8	Birket Qarun	
Middle Eocene	Bartonian			M K 7	ElGharaq	
				M K 6	Sath ElHadid	Present study
	Lutetian			M K 5	Midawara	
				M K 4		
			Lower	M K 3	Muweilih	
				M K 2		
				M K 1	Samalut	

Fig. 2 Subdivisions of the Mokattamian Stage and correlation with the standard stages (www.stratigraphy.org) (after Strougo 1985, 1986, 2008; Azab 1992) in the Nile Valley and the Fayum area, Egypt

Systematic palaeontology

(Following Kroh and Smith 2010)

Measurements These have been made by vernier caliper and are given in millimetres. All materials of the present paper are housed in the collections of the Museum of Geology Department, Faculty of Science, Sohag University (abbreviation: SUSGM). Prior to photography (digital camera), all specimens illustrated were coated with ammonium chloride.

Abbreviations *a* distance of apical disc from anterior margin, *Gebel* Mountain, *Gh* Gebel ElMehasham section, *SGh* South Gebel ElMehasham section, *Gr* Gebel ElMereir section, *H* test height, *L* test length, *Lpt* length of petals, *Npp* number of pore pairs in single poriferous zone, *W* test width, *Wadi* Valley, *I* petal I or V, *II* petal II or IV.

Family Schizasteridae Lambert, *in* Doncieux, 1905

Genus *Hypselaster* Clark, 1917

Type species. *Schizaster* (*Periaster*) *limicola* A. Agassiz, 1878, from the recent of the Gulf of Mexico.

***Hypselaster strougoi* Elattaar, n. sp.**

(Text-Fig. 4; Pl. 1)

Derivation of name In honour of Professor Amin Strougo (Geology Department, Faculty of Science, Ain Shams University, Egypt), in recognition of his knowledge in the fields of palaeontology and stratigraphy.

Diagnosis Test of medium size, oval to subpentagonal with a distinct anterior sinus; subcentral, ethmolytic apical disc, with two wide, circular genital pores, wider than long, lying in a shallow depressed area; anteriorly excentric, semi-lunate peristome; petals deeply depressed, petaloid and not reaching ambitus; anterior paired petals (II and IV) flexuous and longer than posterior ones; longitudinally oval periproct in uppermost part of slightly obliquely truncated posterior face.

Types The holotype (SUSGM 018-10-160) is from the Gebel El Mereir section, as is paratype 1 (SUSGM 018-10-163); paratype 2 (slightly deformed and compressed; SUSGM 018-10-164) is from the south Gebel El Mehasham section.

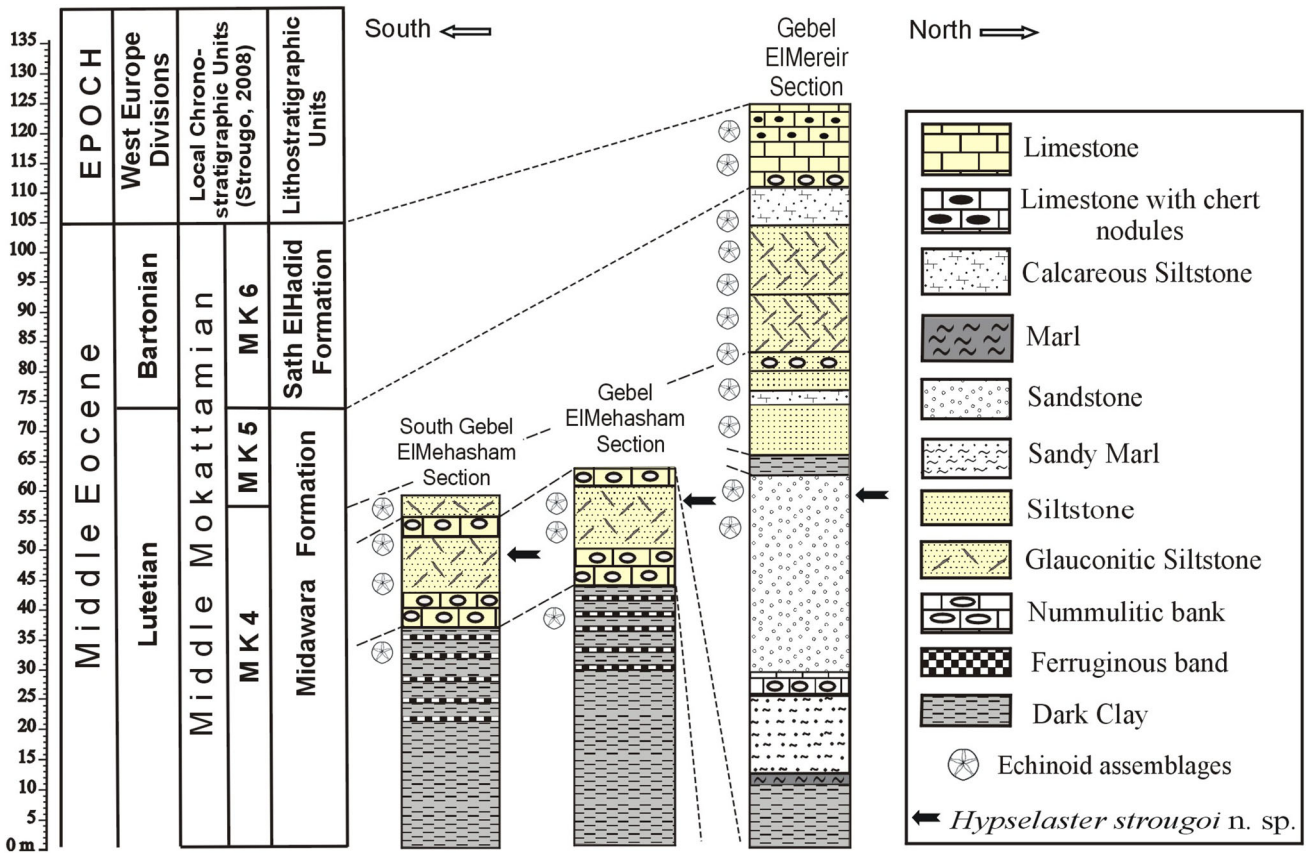

Fig. 3 Correlation chart of outcrops of the Midawara and Sath El Hadid formations in the area east of Maghagha, Eastern Desert, Egypt (Modified after Elattaar 2018, Fig. 3)

Additional material A single specimen from a calcareous siltstone bed in the Gebel El Mehasham section and all other material (50 specimens) from the Gebel El Mereir section; all from single sandstone bed of the Midawara Formation [Middle Eocene, Lutetian; middle Mokattamian Stage (MK4)]. Sixteen specimens of this lot were measured (see Table 1).

Description Test of medium size, broadly oval in outline, with slightly depressed anterior sinus; maximum width centrally; maximum height behind apical disc on keel of interambulacrum 5. Test longer than wide and wider than tall, with slightly obliquely truncated posterior face. Aboral surface with bulging interambulacral areas. Adoral surface swollen and regularly convex. Apical disc subcentral, large, wider than long, ethmolytic with two large, circular, genital pores (G1 and G4), in shallow depressed area (Fig. 4). Ambulacrum III nonpetaloid, wide, in deep groove, slightly broadening towards ambitus and extending to peristome. Pore pairs in part on sides of groove, arranged diagonally in single linear series with raised granule between each pore pair. Anterior and posterior paired petals petaloid, closed and depressed with conjugated, subpyriform to slit-like pore pairs; outer pore more elongated than inner one and not reaching down to ambitus; interporiferous zone half width of poriferous zone; I and V not flexuous, 0.62–0.71 length of anterior pair; II and IV flexuous, wider and longer than posterior ones. Peristome semi-lunate, wider than long and excentric anteriorly at about one quarter of test length. Periproct oval, elongated longitudinally, high on slightly obliquely truncated posterior face. Peripetalous fasciole wide, well-defined, deeply indented in interambulacra 1, 4 and 5, and passing close to extremities of petals, crossing ambulacrum III obliquely above ambitus. Latero-anal fasciole incomplete, very faint, absent laterally on one or both sides of test; in early ontogenetic stages, confined to below periproct, to grow progressively and become complete on one side of the test and absent on the other one in largest specimens. Perforate and crenulate tubercles; dense and fine on aboral surface and larger on adoral interambulacral areas, with asymmetrical areoles (Plate 1).

Discussion According to Fischer, *in* Moore (1966), the genus *Schizaster* is characterised by having a tall test, posterior petals that equal 0.3–0.5 the length of the anterior

Table 1 Measurements of sixteen specimens of *Hypselaster strougoi* Elattaar, n. sp

N = 16	*L*	*W*	*H*	*W/L*	*H/L*	Lpt					Npp					*A*	*A/L*	Locality and type
						I	II	I/II	I/*L*	II/*L*	I	II	I/II	I/*L*	II/*L*			
	14.1	13.3	10.3	0.94	0.73	3.1	5.0	0.62	0.22	0.35	14	19	0.74	0.99	1.35	7.9	0.56	Gh
	21.9	20.0	16.0	0.91	0.73	5.6	8.4	0.67	0.26	0.38	18	24	0.75	0.82	1.10	12.4	0.57	Gr
	22.4	21.0	14.8	0.94	0.66	6.1	8.8	0.69	0.27	0.39	18	23	0.78	0.80	1.03	12.5	0.56	Gr
	24.4	23.0		0.94		5.8	8.8	0.66	0.24	0.36	17	22	0.77	0.70	0.90	14.2	0.58	Gr
	25.9	25.0		0.97		6.8	9.6	0.71	0.26	0.37	17	22	0.77	0.66	0.85	14.7	0.57	Gr
	28.4	25.5	20.7	0.90	0.73	7.8	11.2	0.70	0.27	0.39	19	23	0.83	0.67	0.81	17.4	0.61	Gr
	28.6	27.6	19.3	0.97	0.67	7.8	11.2	0.70	0.27	0.39	19	25	0.76	0.66	0.87	16.1	0.56	Gr, Paratype1
	31.0	28.6	20.8	0.92	0.67	8.0	11.4	0.70	0.26	0.37	20	25	0.80	0.65	0.81	18.3	0.59	Gr
	31.2	29.5		0.95		8.1	11.4	0.71	0.26	0.37	20	24	0.83	0.64	0.77	18.4	0.59	SGh, Paratype2
	31.7	28.6	22.0	0.90	0.69	8.5	12.1	0.70	0.27	0.38	20	26	0.77	0.63	0.82	19.5	0.62	Gr
	34.3	31.0	22.7	0.90	0.66	8.9	12.5	0.71	0.26	0.36	21	26	0.81	0.61	0.76	21.2	0.62	Gr
	35.8	34.6		0.97		10.5	14.6	0.72	0.29	0.41	21	25	0.84	0.59	0.70	20.0	0.56	Gr
	35.9	33.6	24.4	0.94	0.68	10.2	14.6	0.70	0.28	0.41	19	24	0.79	0.53	0.67	21.6	0.60	Gr, Holotype
	36.5	34.5		0.95		10.4	14.5	0.72	0.28	0.40	20	25	0.80	0.55	0.68	20.9	0.57	Gr
	37.2	35.0	24.5	0.94	0.66	10.4	14.3	0.73	0.28	0.38	22	27	0.81	0.59	0.73	23.5	0.63	Gr
	38.0	35.3	27.0	0.93	0.71	11.3	15.7	0.72	0.30	0.41	19	23	0.83	0.50	0.61	23.4	0.62	Gr
Range	14.1–38.0	13.3–35.3	10.3–27.0	0.90–0.97	0.66–0.73	3.1–11.3	5.0–15.7	0.62–0.73	0.22–0.30	0.35–0.41	14–22	19.0–27.0	0.74–0.84	0.50–0.99	0.61–1.35	7.9–23.5	0.56–0.63	
Mean	29.8	27.9	20.2	0.93	0.69	8.1	11.5	0.70	0.27	0.38	19.0	23.9	0.79	0.66	0.84	17.6	0.59	

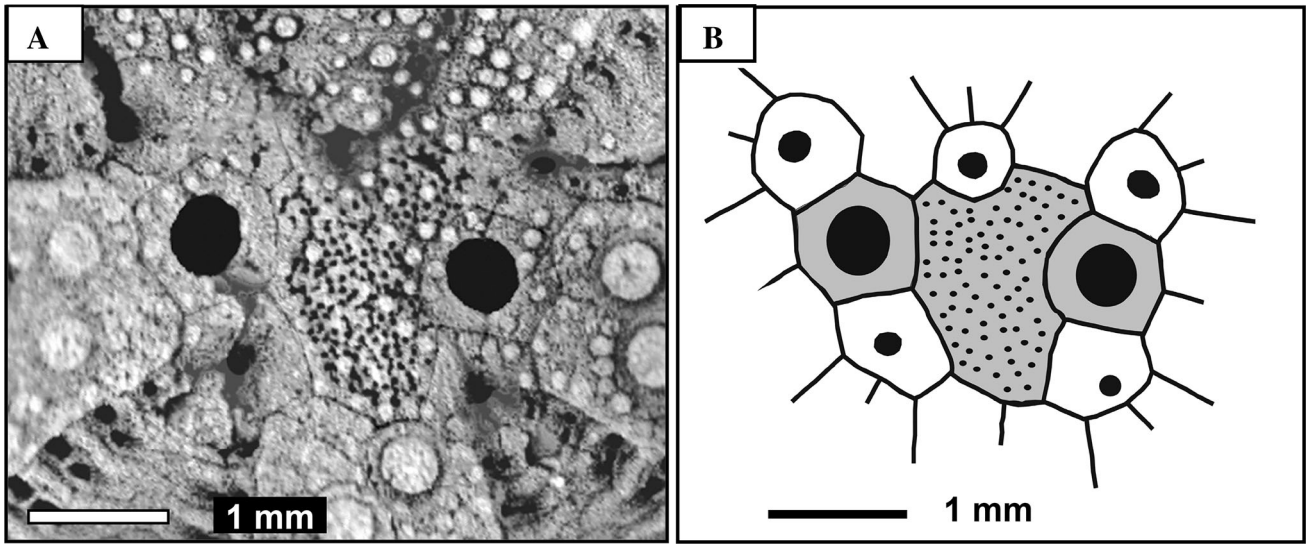

Fig. 4 Apical disc of *Hypselaster strougoi* n. sp., ethmolytic with two large, circular genital pores (G1 and G4). **a** apical disc of specimen SUSGM 018-10-164 (paratype 2; see Pl. 1, Fig. 5); **b** camera-lucida drawing of plating of A; ocular plates are white, genital plates light grey, with pores shown in black

pair and a posteriorly situated apical disc. In contrast, our species is characterised by having a low test, posterior petals that are 0.62–0.71 the length of the anterior pair and a subcentral apical disc, slightly behind the center of the test, at 0.56–0.61 of total test length from the anterior margin.

Hypselaster strougoi n. sp. differs from *H. rajasthanensis* Srivastava and Kulshreshtha, 2009 (p. 229, pl. 1, Figs. 1–8) in having a taller test, longer and wider petals, slit-like pore pairs (vs pyriform), more divergent anterior paired petals, a wider and deeper frontal groove (ambulacrum III), a wider apical disc, a greater distance between the two genital pores (G1 and G4) and a wider peipetalous fasciole. The new species can be differentiated from *H. perplexus* Arnold and Clark, 1927 (p. 56, pl. 11, Figs. 8–10) in having a lower test, with the tallest point lying posterior of the apical disc (vs test nearly of equal height anteriorly and posteriorly) and more deeply sunken and flexed petals that do not extend to the ambitus. It should be noted that Kier (1984, pp. 67–69, text-Fig. 75; pl. 34) and Donovan (1993, pp. 398, 399) considered *H. perplexus* to be a synonym of the Jamaican *Caribbaster loveni* (Cotteau, 1875).

Hypselaster strougoi n. sp. can be distinguished from *H. obliquatus* in lacking a central apical disc and circular test and by having relatively longer posterior petals, a deeper and wider anterior sinus, a wider apical disc, a wider anterior end of test and a narrower posterior one and a different shape of the latero-anal fasciole. The new species differs from *H. branderianus* (see Lewis 1989, p. 19, text-Figs. 4–6; pl. 3, Figs. 3, 4a, b, 5; pl. 4, Figs. 1a, b, 2–4; pl. 5, Fig. 1) in having longer and wider paired petals (in particular I and V), a deeper ambulacrum III and narrower fascioles, and from *Hypselaster* sp. of Lachkhem and Roman (1995, p. 259, pl. 3, Fig. 7) in possessing more divergent, longer and wider paired petals, especially I and V.

A comparison with recent congeners shows the new species to differ from *H. affinis* Mortensen, 1948 (p. 121) in having a wider and lower test (*W*/*L* = 0.83, *H*/*L* = 0.79 in *H. affinis*), longer posterior petals compared to anterior ones (Lpt I/II = 0.62–0.71 in the new species, rather than, 'less than half the length of the anterior ones' in *H. affinis*) and flexuous anterior paired petals (vs straight). *Hypselaster strougoi* n. sp. differs from *H. maximus* (Agassiz and Clark, 1907) (p. 259) (see also Clark 1917, p. 186, pl. 154, Fig. 18) in having a smaller test and in lacking a bare zone connecting the upper end of the periproct with the peripetalous fasciole, and from *H. limicolus* (Agassiz, 1878) (p. 193, pl. 3, Figs. 1–4) (see also Clark 1917, p. 187) in having the tallest point of the test posteriorly of the apical disc (vs test height nearly equal anteriorly and posteriorly), a longer and lower test and longer posterior petals in comparison to anterior ones.

The new species differs from *H. rotundus* (Agassiz and Clark, 1907) (p. 138; see also Clark 1917, p. 187, pl. 146, Figs. 9–10; pl. 148, Figs. 1–2; pl. 154, Figs. 11–14) in having a lower and narrower test and longer posterior petals relative to the anterior ones. It differs from *H. fragilis* (Agassiz and Clark, 1907) (p. 138; see also Clark 1917, p. 189, pl. 148, Figs. 5–8) in having a lower test, longer posterior paired petals relative to anterior ones and an apical disc with two large gonopores that lies more

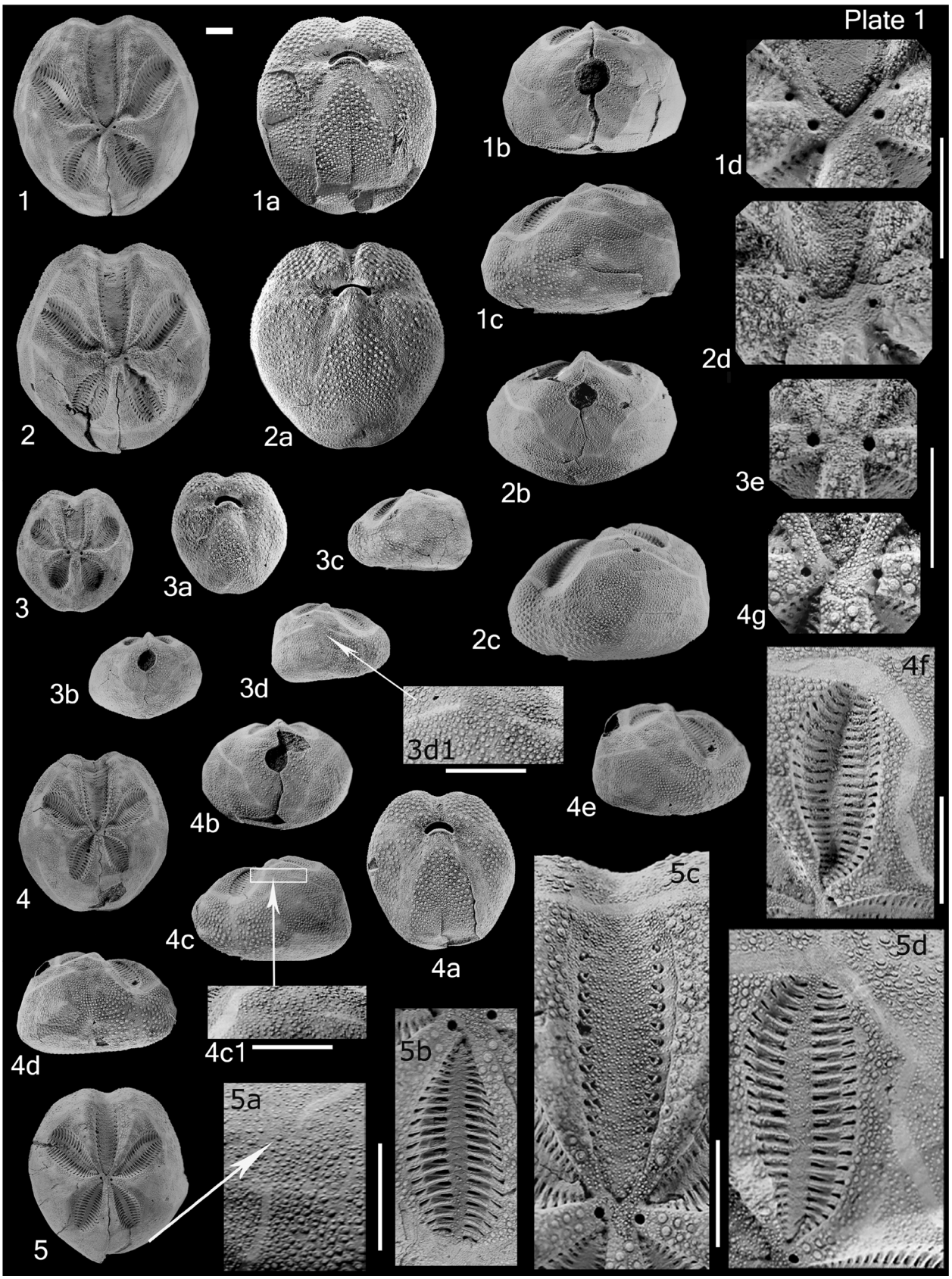
Plate 1
1
1a
1b
1c
1d
2
2a
2b
2c
2d
3
3a
3b
3c
3d
3d1
3e
4
4a
4b
4c
4c1
4d
4e
4f
4g
5
5a
5b
5c
5d

◀**Plate 1** *Hypselaster strougoi* n. sp.; **1–1d** SUSGM 018-10-160 (holotype), aboral, oral, posterior, left lateral views and closeup of apical disc, respectively, showing complete latero-anal fasciole on this side of the test; the other side is eroded. **2–2d** SUSGM 018-10-161, aboral, oral, posterior, left lateral views and closeup of apical disc, respectively, showing complete latero-anal fasciole on this side of the test; the other side is eroded. **3–3e** SUSGM 018-10-162, aboral, oral, posterior, left lateral, right lateral views, closeup of interambulacrum 1 of 3d and closeup of apical disc, respectively; (**3c, 3d, 3d1** showing incomplete latero-anal fasciole on two sides of the test). **4–4g** SUSGM 018-10-163 (paratype 1); **4–4e** aboral, oral, posterior, left lateral, closeup of interambulacrum 1 of 4c, right lateral and tilted right lateral views, respectively; (**4c, 4c1** showing incomplete latero-anal fasciole on this side of the test), (**4d, 4e** showing complete latero-anal fasciole on this side of the test); **4f** closeup of petal II and peripetalous fasciole on interambulacrum 1; **4g** closeup of apical disc of 4. **5–5d** SUSGM 018-10-164 (paratype 2), aboral view, closeup of right lateral side of posterior end with incomplete latero-anal fasciole, closeup of petal V, closeup of ambulacrum III and apical disc and closeup of petal II and peripetalous fasciole on interambulacrum 1, respectively. Scale bars equal 5 mm

posteriorly (vs centrally or slightly anteriorly) and from *H. kempi* (Koehler, 1914) (p. 162, pl. 8, Figs. 1–3, 5, 7–8, 16; pl. 19, Figs. 1–13) (see also Clark 1917, p. 190) in having a smaller peristome, a wider periproct, longer posterior petals relative to anterior ones and a wider and deeper ambulacrum III.

The new Egyptian species can be differentiated from *H. jukesii* (Gray, 1855) (p. 61, pl. 3, Fig. 4) in having a narrower anterior end of test, a more anteriorly situated peristome and with maximum test width lying centrally (vs anteriorly). It differs from *H. dolosus* Clark, 1938 (p. 430, pl. 28, Figs. 4–7) in having a lower test, a narrower periproct, a narrower anterior groove (ambulacrum III), longer and wider paired petals and more divergent anterior paired ones. Finally, *H. strougoi* n. sp. differs from *H. brachypetalus* Clark, 1917 (p. 191, pl. 148, Figs. 3–4; pl. 154, Figs. 1–3) in having a wider test, longer and wider paired petals, more divergent paired petals, longer posterior paired petals relative to the anterior ones, a deeper and narrower anterior sinus (ambulacrum III) and with the maximum test width lying centrally (vs anteriorly).

Occurrence and stratigraphical age This is the first record of a representative of the genus *Hypselaster* from Egypt, with material from the Midawara Formation (Middle Eocene, Lutetian; middle Mokattamian, MK4) at three outcrops, viz. Gebel El Mehasham, south Gebel El Mehasham and Gebel ElMereir (Figs. 1, 2, 3).

Geographical distribution of Hypselaster Stratigraphically, this genus ranges from the Eocene to the present day (Kroh and Smith 2010; Kroh 2015), with six species of Eocene to Miocene age from the Caribbean, England, Morocco, Egypt and India and nine extant congeners from the Caribbean and Indo-Pacific Ocean.

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