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TAXONOMY AND PALEOBIOGEOGRAPHY OF LATE BATHONIAN BRACHIOPODS FROM GEBEL ENGABASHI, NORTHERN SINAI

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ABSTRACT—A brachiopod fauna of late Bathonian age recovered from the Kehailia Formation from Gebel Engabashi in northern Sinai consists of six species (two rhynchonellids and four terebratulids) referred to six genera, of which one genus and two species are new: *Globirhynchia sphaerica* (Cooper, 1989) new combination, *Daghanirhynchia angulocostata* Cooper, 1989, *Ectyphoria sinaiensis* new species, *Cooperithyris circularis* new genus and species, and new material: *Avonothyris* species A, and *Ptyctothyris* species A. The brachiopods described herein comprise a fauna located at the northern part of the Indo–African Faunal Realm within the Jurassic Ethiopian Province. They extend the geographic distribution of those taxa that show great affinity with the Jurassic brachiopod fauna of Saudi Arabia described by Cooper (1989). Differentiation of the endemic faunas that is so characteristic of many of these Ethiopian Province faunas is becoming more well-defined.

INTRODUCTION

THE INVERTEBRATE faunas of Sinai have been studied by numerous workers over the past century. Douvillé (1916) dealt with the brachiopod, molluscan and echinoderm faunas, Cossman (in Douvillé, 1925) and Hirsch (1979) worked on the bivalves and gastropods, whereas Arkell (1952) and Parnes (1974) dealt with the ammonites. Brachiopods were studied more specifically by Farag (1957, 1959) and Farag and Gatinaud (1960a, 1960b). Farag compiled a faunal list taken from the studies of Douvillé (1916) and Arkell (1952); this is expanded upon here. In more recent studies Feldman (1987), Feldman and Owen (1988, 1993), Feldman et al. (1991, 2009), Hegab (1988, 1989, 1991a, 1991b, 1991c, 1992, 1993, 1995, 2003, 2004), and Hegab and Aly (2004) reviewed the brachiopods of northern Sinai, revised the taxonomy and discussed their paleobiogeography.

Stratigraphic, structural and mapping studies were completed by Range (1920), Moon and Sadek (1921), Hoppe (1922), Farag (1959), Al Far (1966), and Goldberg et al. (1971). Hirsch et al. (1994, 1998) presented biostratigraphic and tectonic data on northern Sinai taken, in part, from the northern Sinai Hallal borehole as well as outcrop analysis. The present paper dealing with brachiopods of the Kehailia Formation continues a long-term effort on the part of paleontologists to complete a taxonomic revision of the brachiopod faunas of the Jurassic Ethiopian Faunal Province (Feldman et al., 2001). Completion of this project will allow us to further gain insight into the paleoecology of the various marine communities (e.g., Feldman and Brett, 1998; Wilson et al., 2008) and construct a biostratigraphic framework for the Jurassic of the Middle East.

GEOLOGIC SETTING, BIOSTRATIGRAPHY AND PALEOECOLOGY

The outcrop area lies within Gebel El-Maghara, a Pliensbachian–Oxfordian sedimentary sequence approximately 2000 m thick. Paleobiogeographically this is at the junction of the Indo–African and Tethyan faunal realms in the Sinai Peninsula (Feldman et al., 1991). The rocks generally form two anticlines, the Shushet el Maghara and Homayir that are asymmetric with steep to overturned flanks, bordered by longitudinal thrust faults that lie parallel to the NE–SW trend of the fault axes (Picard and Hirsch, 1987). The stratigraphy used in this paper is based on field observations by Hegab and Feldman in addition to the work of Al Far (1966), Goldberg et al. (1971) and Picard and Hirsch (1987). In the Bathonian sequence the Kehailia–Arroussiah formations consist of shales and oolitic carbonates in the lower part with occasional sandstone interbeds. Above this lie carbonates and some shales but little sandstone, above which are shales with some thin oolitic-oncolitic limestone beds with thin sandstone interbeds. Goldberg et al. (1971; subunit 67) recognized stromatoporoids indicating proximity to the Callovian–Oxfordian facies that typifies this group. For additional detailed stratigraphic information, including columnar sections of Gebel El-Maghara and Gebel Engabashi, see Feldman et al. (1991) and Hirsch et al. (1998).

Gebel Engabashi is located within the breached anticline of Gebel El-Maghara, northern Sinai, and is characterized by numerous outcrops of Bathonian and Callovian age (see Fig. 1 for location of Gebel Engabashi; GPS coordinates: N 30°41′25″; E 33°25′07″). During the early Bathonian there was a substantial regression in the area, evidenced by paralic coals in the Safa Formation. Hegab (1991c) discussed the paleoenvironmental conditions prevailing during the deposition of the Safa Formation which he subdivided into two phases. The lower two thirds of a thick alternating shale and sandstone sequence are unfossiliferous and are characterized by primary sedimentary structures such as cross-stratification and plant remains of continental, probably fluviatile origin. These sediments, usually ferruginous, are characteristically brown or red due to a regressive phase resulting in rivers and streams depositing terrigenous, iron oxide–rich sediments. The upper third of the Safa Formation is characterized by shallow marine facies, consisting of marly and oolitic limestones and calcareous shales that signify the beginning of a transgressive phase. The shore line of this transgression is marked by coralline limestone with coral heads. The faunal assemblage typical of these sediments (brachiopods, mollusks, corals, and rare echinoderms) supports a shallow marine depositional environment (Hegab, 1991c).

The middle and late Bathonian strata are suggestive of a period of renewed transgression as indicated by shaly-calcareous shelf-platform sediments of the Kehailia Formation

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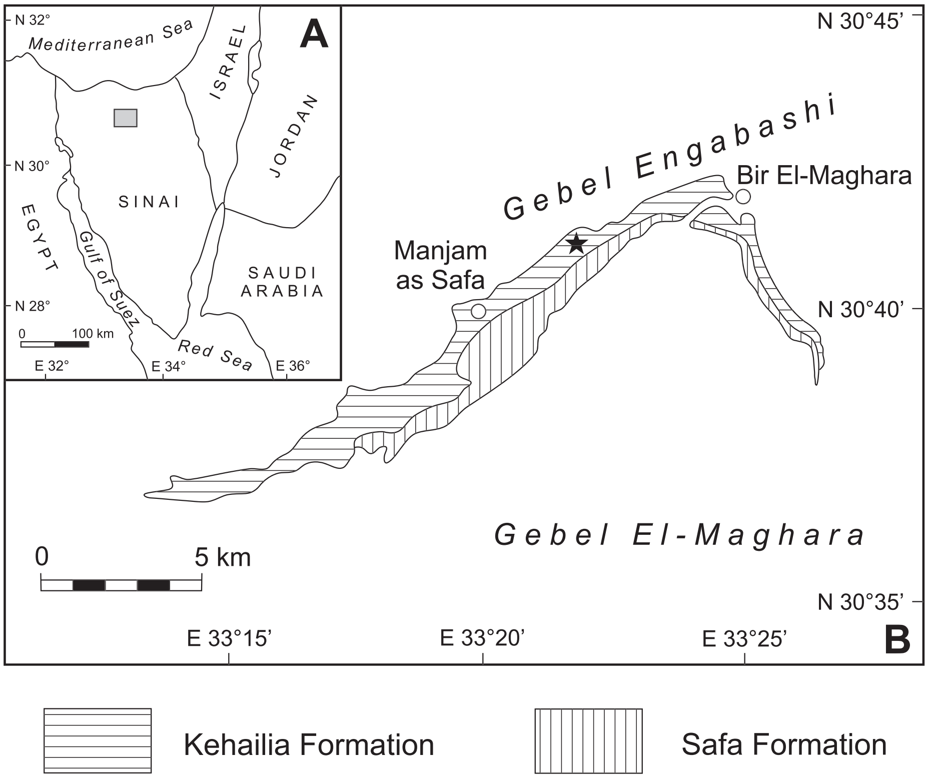

FIGURE 1—*A*, geographic location of study area is indicated by rectangle; *B*, distribution of the Bathonian sediments of the Safa and Kehailia formations of breached anticline of Gebel El-Maghara, northern Sinai, modified from Al Far (1966). The collecting locality is indicated by star.

(Picard and Hirsch, 1987; Hirsch and Picard, 1988; Fig. 2). Mesozoic biostratigraphy is largely based on ammonites but few ammonites were found in these sediments so brachiopods may be the key to biostratigraphic interpretation in the region. The late Bathonian–early Callovian transition remains unclear and the alleged lowstand followed by an overall transgression (Haq et al., 1988), probably occurs much lower in the sequence (Hirsch et al., 1998).

The sediments from which the fauna described herein was collected consist of ochre colored wackestones with scattered patches of packstones and sporadically dispersed ferruginous grains. From correlative strata in other regions within Gebel El-Maghara which is approximately 30 km in length and 12 km in width, (see Goldberg et al., 1971 for the stratigraphy), in a calcareous and sandy series of beds, we recognize two bivalve and gastropod assemblages. The first is dominated by *Nuculana decorata* with abundant *Paleonucula tenuistriata*, *P. variabilis*, *Astarte pisiformis*, *Discohelix elegantula*, *Procerithium bouchardi*, *Exelissa solitudinis*, *Dicroloma armata*, and *D. tumida* (Hirsch, 1979). The second assemblage is dominated by *Eligmus asiaticus–Africogryphaea costellata* and is common in marly and calcareous strata with *Bucardiomya lirata*, a burrowing suspension feeder (Hirsch, 1979). This interval contains the ammonite *Bullatimorphites bullatus,* which is a Tethyan early Callovian marker, the genus *Bullatimorphites* appearing in the late Bathonian. In addition to the brachiopods, faunal constituents include: minute benthic foraminifers (lagenids and trocholinids), bivalves, gastropods and microgastropods. A foraminifer species, found in the lower part of the overlying limestones of the Gebel Arroussiah Formation, was first identified as *Meyendorffina bathonica* (in Goldberg, et al., 1971). This well-known marker of the late Bathonian in western Europe, renamed as *Orbitammina bathonica* (in Picard and Hirsch, 1987) and *Satorina apuliensis* (in Hirsch and Picard, 1988), is now considered to be a flat, new species, of *Kilianina* (in Hirsch et al., 1998) that is indicative of an early Callovian age and characterizes the southern Tethyan Realm. As no further ammonites were found preserved with the fauna, a late Bathonian age is supported by the presence of two rhynchonellid species, *Globirhynchia sphaerica* Cooper, 1989 and *Daghanirhynchia angulocostata* Cooper, 1989, also known from the Bathonian of Saudi Arabia (Cooper, 1989) as well as the late Bathonian–Callovian genus *Ectyphoria* Cooper, 1989. We feel that based on the micro- and magafauna as well as the sediments, it can be inferred that sedimentary environment was mid-neritic.

PALEOBIOGEOGRAPHY

The Ethiopian Province is defined geographically by a Gondwanian shelf crescent from east to north Africa including Somalia, Kenya, Tanzania, Saudi Arabia, the Levant, Egypt, and the Maghreb (the western region of north Africa including Algeria, Tunisia, Libya, Morocco, Mauritania and the western Sahara) (Hirsch et al., 1998; Fig. 3). The Ethiopian Province has been recognized from the Early Jurassic until the mid and possibly end of the Cretaceous Period by the presence of endemic taxa at the species, genus and family level. These endemics (e.g., *Somalirhynchia africana*, *Daghanirhynchia daghaniensis*, *Somalithyris bihendulensis, Striithyris somaliensis*, *Bihenithyris barringtoni, B. weiri*) have been noted, especially in the brachiopods, by Weir (1925) and Muir-Wood (1935). Arkell (1952, 1956) recognized endemic faunas in the ammonoid Cephalopoda and Kitchin (1912) in the trigoniacean and crassatellacean bivalves. A clearer picture of the endemism so characteristic of many of these faunas is becoming more well-defined.

This paper is a continuation of a long-term project undertaken by several workers in northern Sinai (Feldman

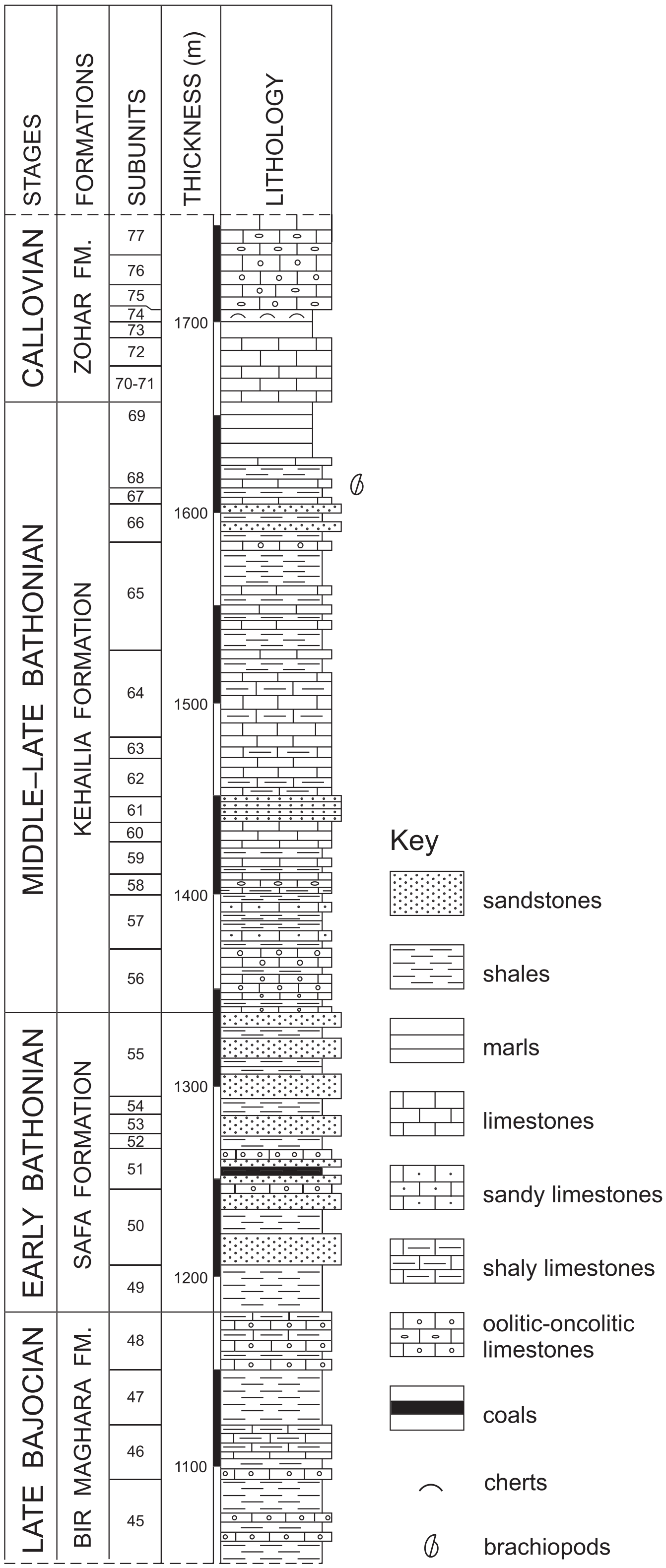

FIGURE 2—Stratigraphic composite column of breached anticline of Gebel El-Maghara, northern Sinai, showing lithology and brachiopod-yielding beds. Modified from Picard and Hirsch (1987), Feldman et al. (1991), and Hirsch et al. (1998).

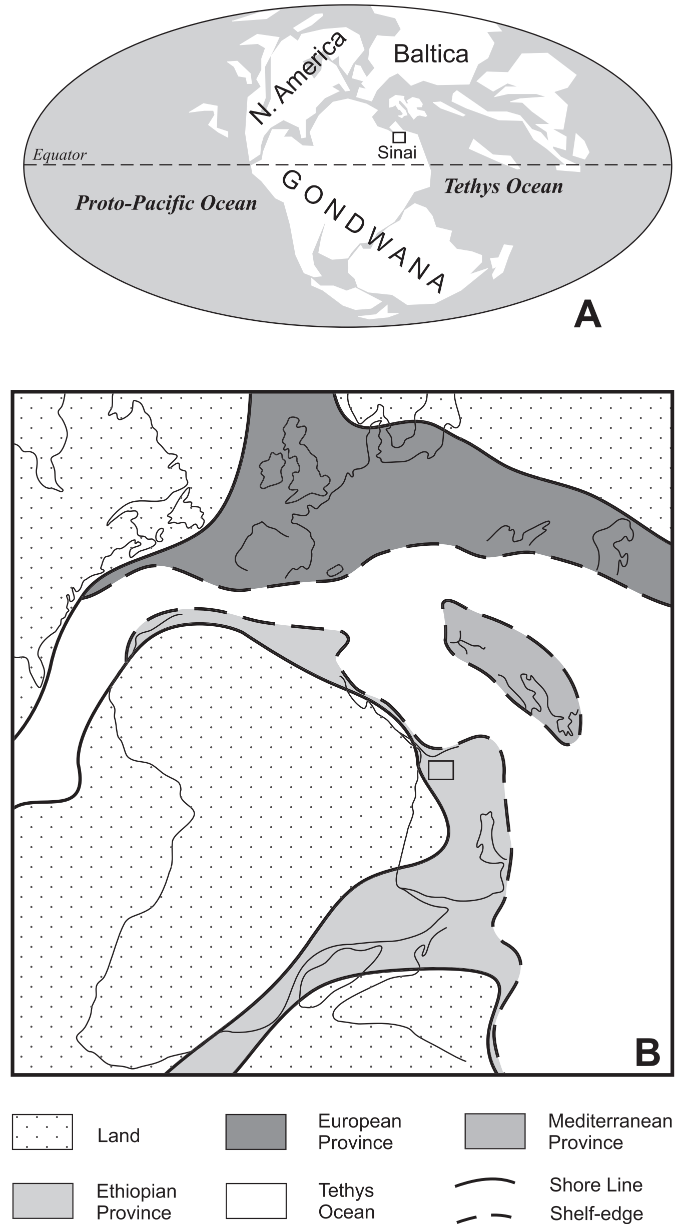

FIGURE 3—*A*, global paleogeographic map for the Middle Jurassic modified from Scotese (2004); *B*, paleogeographic map of the Ethiopian Province (Bathonian) modified from Dewey et al. (1973), Hallam (1975) and Vörös (1984). Study area is indicated by rectangle.

1986, 1987; Feldman and Owen 1988, 1993; Feldman et al., 1982, 1991) and Israel (Feldman et al., 2001), to taxonomically study and revise the brachiopod faunas. These revisions will help establish the history of brachiopod species and their evolution within the Ethiopian Province. We expect that the data compiled as a result of these studies will enable us to interpret the biogeographic history of the Ethiopian Province as well as gain insight into the structure and paleoecology of its marine communities (see, for example, Feldman and Brett, 1998). We are presently studying a zeillerid fauna from Gebel El-Maghara, northern Sinai and southern Israel, as well as rhynchonellids and terebratulids from Jordan. Upon completion of these taxonomic studies we will have completed our project of revising the brachiopods of the Ethiopian Province that will allow us to define faunal- and province-realm boundaries with greater accuracy.

MATERIAL AND METHODS

The material studied was collected in 1999 by Hegab from Gebel Engabashi, a section with the breached anticline of

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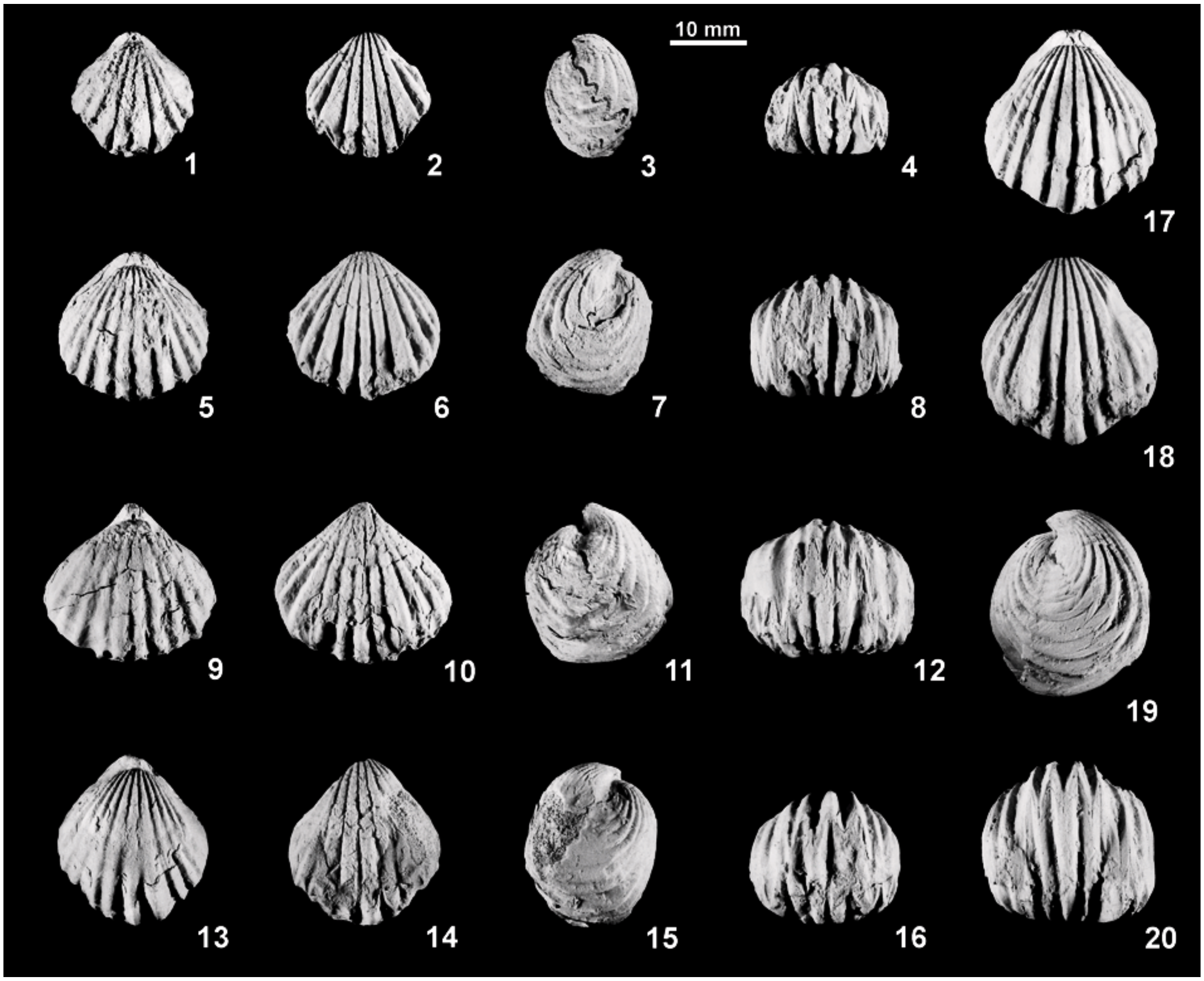

FIGURE 4—*Globirhynchia sphaerica* (Cooper, 1989) new combination, late Bathonian, Gebel Engabashi, northern Sinai. *1–4*, RGF VR 74/1, dorsal, ventral, lateral, and anterior views; *5–8*, RGF VR 74/2, dorsal, ventral, lateral, and anterior views; *9–12*, RGF VR 74/3, dorsal, ventral, lateral, and anterior views; *13–16*, RGF VR 74/4, dorsal, ventral, lateral, and anterior views of sectioned specimen; *17–20*, RGF VR 74/5, dorsal, ventral, lateral, and anterior views.

Gebel El-Maghara in northern Sinai. The collection consists of 28 brachiopod specimens (seven rhynchonellids and 21 terebratulids). The shells are relatively well preserved; all specimens are articulated. The specimens chosen for transverse serial sectioning were calcined and then embedded in plaster. As a result of burning, the internal elements become white and distinct from the sediment and secondary mineralization. Specimens were serially sectioned at a distance of 0.1 or 0.2 mm using a grinding apparatus (Cutrock, London). The sections were drawn using a binocular microscope (Carl Zeiss, Jena) on which was mounted a camera lucida. For every rhynchonellid specimen sectioned we drew approximately 30 sections and for the terebratulids about 70 sections from which the most important are presented. Serial sections are drawn with the ventral valve oriented uppermost (see Motchurova-Dekova et al., 2008). The photographed specimens were coated with ammonium chloride. One of the authors (HRF) had the opportunity to study Cooper's (1989) collections of Saudi Arabian specimens housed in the United States National Museum, Smithsonian Institution (USNM) and Feldman's (1991) collection from northern Sinai, housed in the American Museum of Natural History (AMNH) and the Natural History Museum (NHM) in London and compared them with the present collection. The studied brachiopod specimens are housed in the collection at the Department of Paleontology, the Faculty of Mining and Geology, the University of Belgrade, Serbia (RGF VR).

For the classification of the Rhynchonellida we refer to the Treatise on Invertebrate Paleontology, Vol. 4 (Savage et al., 2002), whereas for the Terebratulida we follow the taxonomy in Vol. 5 (Lee et al., 2006). For the supraordinal classification of the Brachiopoda, the classification given by Williams et al. (1996) is herein followed.

SYSTEMATIC PALEONTOLOGY

Phylum BRACHIOPODA Duméril, 1806
Subphylum RHYNCHONELLIFORMEA Williams, Carlson, Brunton, Holmer, and Popov, 1996
Class RHYNCHONELLATA Williams, Carlson, Brunton, Holmer, and Popov, 1996
Order RHYNCHONELLIDA Kuhn, 1949
Superfamily HEMITHIRIDOIDEA Rzhonsnitskaia, 1956
Family CYCLOTHIRIDIDAE Makridin, 1955
Subfamily CYCLOTHYRIDINAE Makridin, 1955
Genus GLOBIRHYNCHIA Buckman, 1918

Type species.—*Rhynchonella subobsoleta* Davidson, 1852, p. 91, pl. 17, fig. 14.

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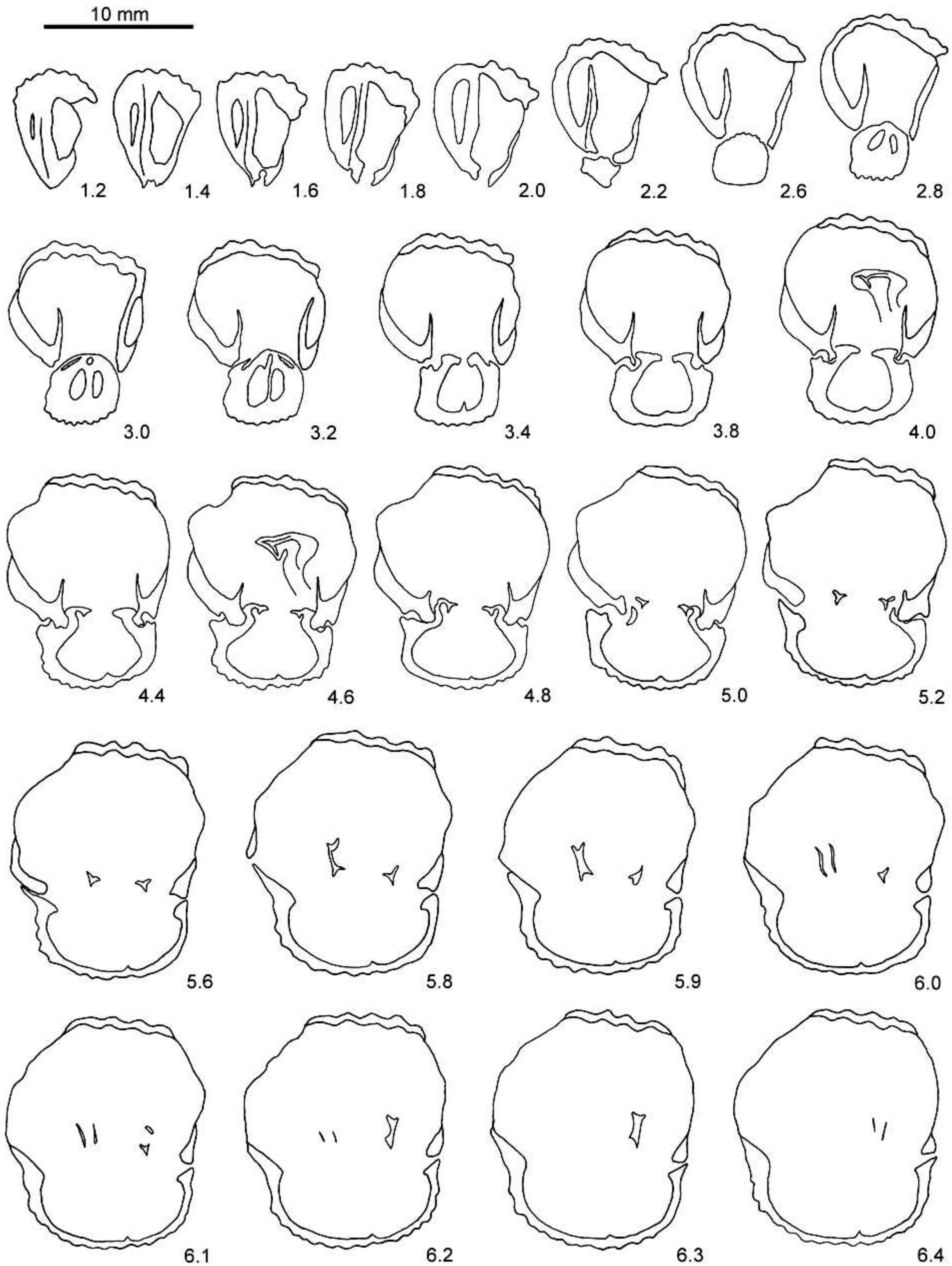

FIGURE 5—Transverse serial sections of *Globirhynchia sphaerica* (Cooper, 1989) new combination, late Bathonian, Gebel Engabashi, northern Sinai. Original dimensions of the specimen (in mm): L=23.4; W=20.6; T=18.1. Numbers refer to distance in mm from the ventral apex; RGF VR 74/4.

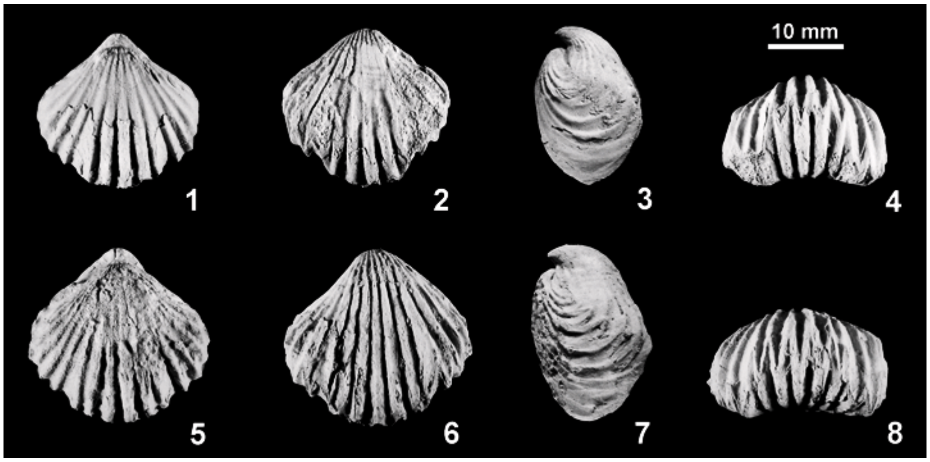

FIGURE 6—*Daghanirhynchia angulocostata* Cooper, 1989, late Bathonian, Gebel Engabashi, northern Sinai. *1–4*, RGF VR 74/6, dorsal, ventral, lateral, and anterior views; *5–8*, RGF VR 74/7, dorsal, ventral, lateral, and anterior views of sectioned specimen.

GLOBIRHYNCHIA SPHAERICA (Cooper, 1989) new combination
Figures 4, 5

Gibbihynchia sphaerica COOPER, 1989, p. 37, pl. 10, figs. 18–30.

Material.—Five specimens, RGF VR 74/1 to RGF VR 74/5.

Description.—External characters: medium sized (see Appendix), roundly triangular to oval in outline, strongly dorsibiconvex, subspherical, typically length greater than width, rarely equal, or width greater then length, maximum width and thickness at midlength, subquadrate in anterior profile, lateral and anterior margins rounded; shell thickened markedly along margins; squama and glotta well expressed; planarea extensive, flat; beak very small, pointed, erect to slightly incurved, foramen hypothyrid, beak ridges indistinct; interarea poorly developed; anterior commissure uniplicate, high, with parallel sides; fold slightly developed, beginning at posterior third, becoming more elevated anteriorly; shallow ventral median sulcus extends from the umbonal region, widening anteriorly; shell surface covered with coarse subangular costae, on each valve numbering 11 to 12 in juvenile and 17 to 18 in adult, four costae on fold and three in sulcus; costae originating in beak region and dorsal umbo, becoming much stronger anteriorly. Internal characters: pedicle collar present; deltidial plates disjunct, relatively thick; dental plates very slightly ventrally divergent, disappearing before full development of hinge teeth; lateral cavities narrow and short; teeth massive, globular, with strong lateral denticula; crural bases crescentic, concave laterally, project above and below the level of the hinge plates, clearly separated from it; hinge plates slender and relatively narrow, ventrally convex and dorsally inclined; euseptoidum reduced to a low ridge; crura canaliform, curving ventrally, with widened and thickened distal ends (similar in appearance to a diabolo), anteriorly splitting into two approximately parallel, non-discrete plates that represent an expression of the gutter-like shape of the crura, terminating at a distance of 0.22 dorsal valve length from dorsal umbo.

Discussion.—Based on external morphology, Cooper (1989), without investigation of interior characters, attributed his new species described herein to *Gibbirhynchia*. Present serial sections through a specimen of *G. sphaerica* show clearly dorsoventrally widened distal ends of crura which are accompanied by distal splitting of the crura into two approximately parallel, non-discrete plates as noted above. This feature among the Mesozoic rhynchonellids has been reported so far only in a few genera of the superfamily Hemithiridoidea: in the Early Jurassic *Squamirhynchia* Buckman, 1918, the Middle Jurassic *Globirhynchia* Buckman, 1918, and *Moquellina* Ching, Sun, and Ye in Ching et al., 1979, the Middle Jurassic to Early Cretaceous *Septaliphoria* Leidhold, 1921, the Early to Late Cretaceous *Cyclothyris* M'Coy, 1844, and the Late Cretaceous *Almerarhynchia* Calzada Badía, 1974 (see Shi and Grant, 1993; Radulović et al., 2007). Cooper (1989) based his assignment of his species to *Globirhynchia* on the type of crura. *Globirhynchia* has canaliform crura whereas the crura in *Gibbirhynchia* are raduliform. On the other hand, *Gibbirhynchia* is Early Jurassic, whereas *Globirhynchia* is Middle Jurassic in age.

Cooper (1989) erected eight species of the genus *Gibbirhynchia* from the Jurassic of Saudi Arabia. He stated that although conforming to the characters outlined for the genus in exterior details, these specimens differ to some extent from the genus in interior details and among themselves. Thus, generic attribution of those species to *Gibbirhynchia* makes Cooper's species identifications questionable. Manceñido et al. (in Savage et al., 2002, p. 1354) stated in the diagnosis of *Gibbirhynchia* that "Middle Jurassic (Bajocian–Bathonian) records of Arabia as in Cooper (1989) are probably referable to *Nastosia* Cooper, 1989." Externally, upper Bajocian *Nastosia* is very close to *Globirhynchia* but internally it is quite different; it possesses a thin septalium, long and nearly parallel, closely positioned dental plates, long and high septum, and raduliform crura.

As stated by Cooper (1989) the present species is very close to early Bathonian *Gibbirhynchia costata* Cooper (1989, p. 35, pl. 9, figs. 17–23). *Globirhynchia sphaerica* differs in having a much more spherical shape, coarser and crowded costae, and a wider beak.

The specimens from northern Sinai figured herein are larger than those of Saudi Arabia figured originally by Cooper (1989) and they match the external characters described by that author.

Occurrence.—Bathonian (middle Dhruma Formation, *Micromphalites* Zone) of Saudi Arabia and late Bathonian of Gebel Engabashi within the breached anticline of Gebel El-Maghara, northern Sinai (N 30°41′25″; E 33°25′07″).

Family TETRARHYNCHIIDAE Ager, 1965
Subfamily TETRARHYNCHIINAE Ager, 1965
Genus DAGHANIRHYNCHIA Muir-Wood, 1935

Type species.—*Daghanirhynchia daghanensis* MUIR-WOOD, 1935, p. 82, pl. 8, fig. 5.

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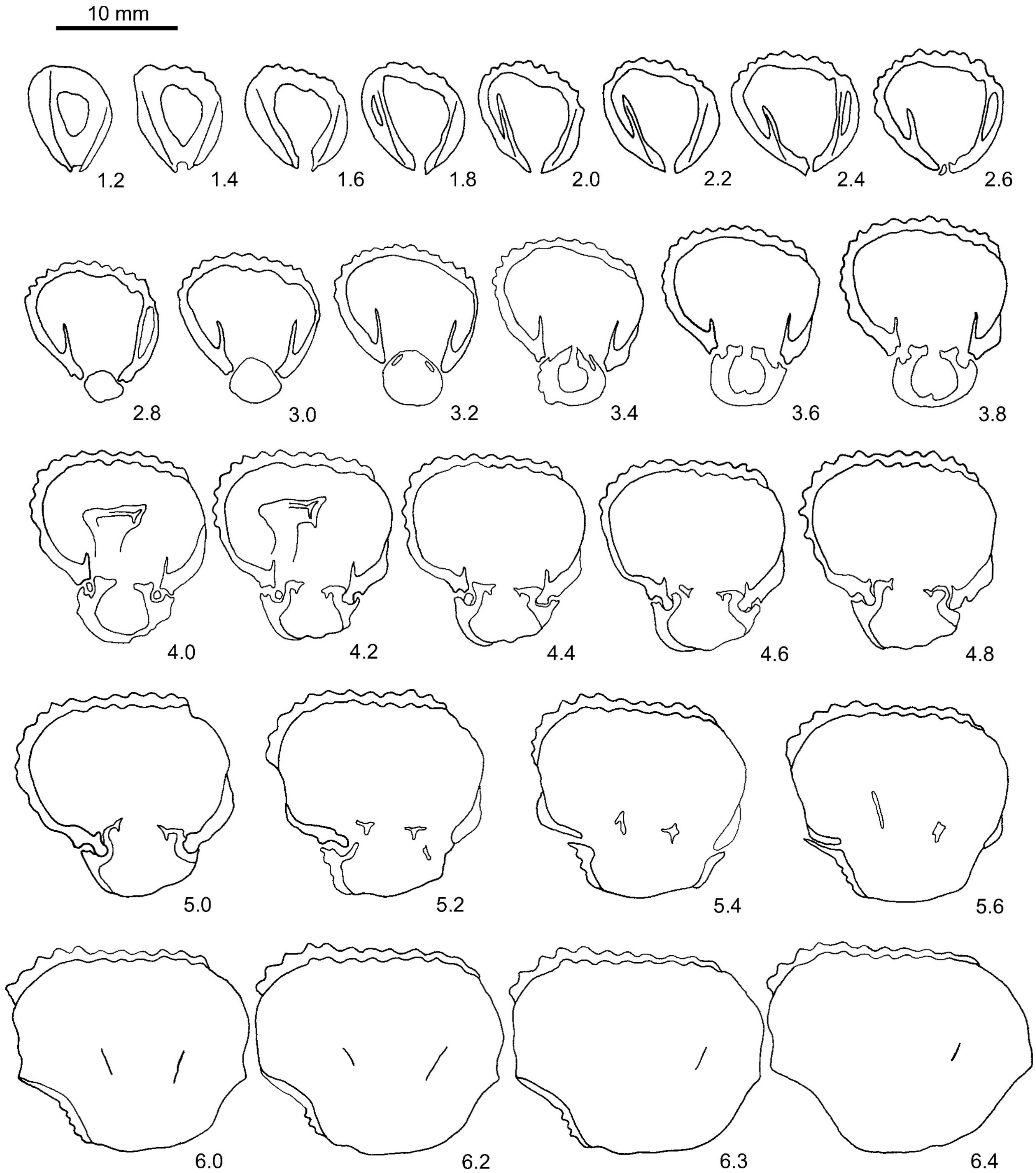

FIGURE 7—Transverse serial sections of *Daghanirhynchia angulocostata* Cooper, 1989, late Bathonian, Gebel Engabashi, northern Sinai. Original dimensions of the specimen (in mm): L=23.9; W=24.8; T=14.6. Numbers refer to distance in mm from the ventral apex; RGF VR 74/7.

DAGHANIRHYNCHIA ANGULOCOSTATA Cooper, 1989
Figures 6, 7

Daghanirhynchia angulocostata COOPER, 1989, p. 26, pl. 6, figs. 1–19; pl. 7, figs. 44–53; pl. 11, figs. 16–21; text-figs. 13, 14; Hegab and Aly, 2004, p. 192, pl. 4, figs. 1–4.

Material.—Two specimens, RGF VR 74/6 and 74/7.

Description.—External characters: medium sized (see Appendix), transversely oval in outline, dorsibiconvex, maximum convexity and thickening slightly posterior to midlength; deltidial plates disjunct; beak delicate, sharply pointed, slightly incurved to erect, foramen small, hypothyrid; beak ridges short, poorly developed; planarea present; squama and glotta developed; interarea small, concave; fold originating slightly

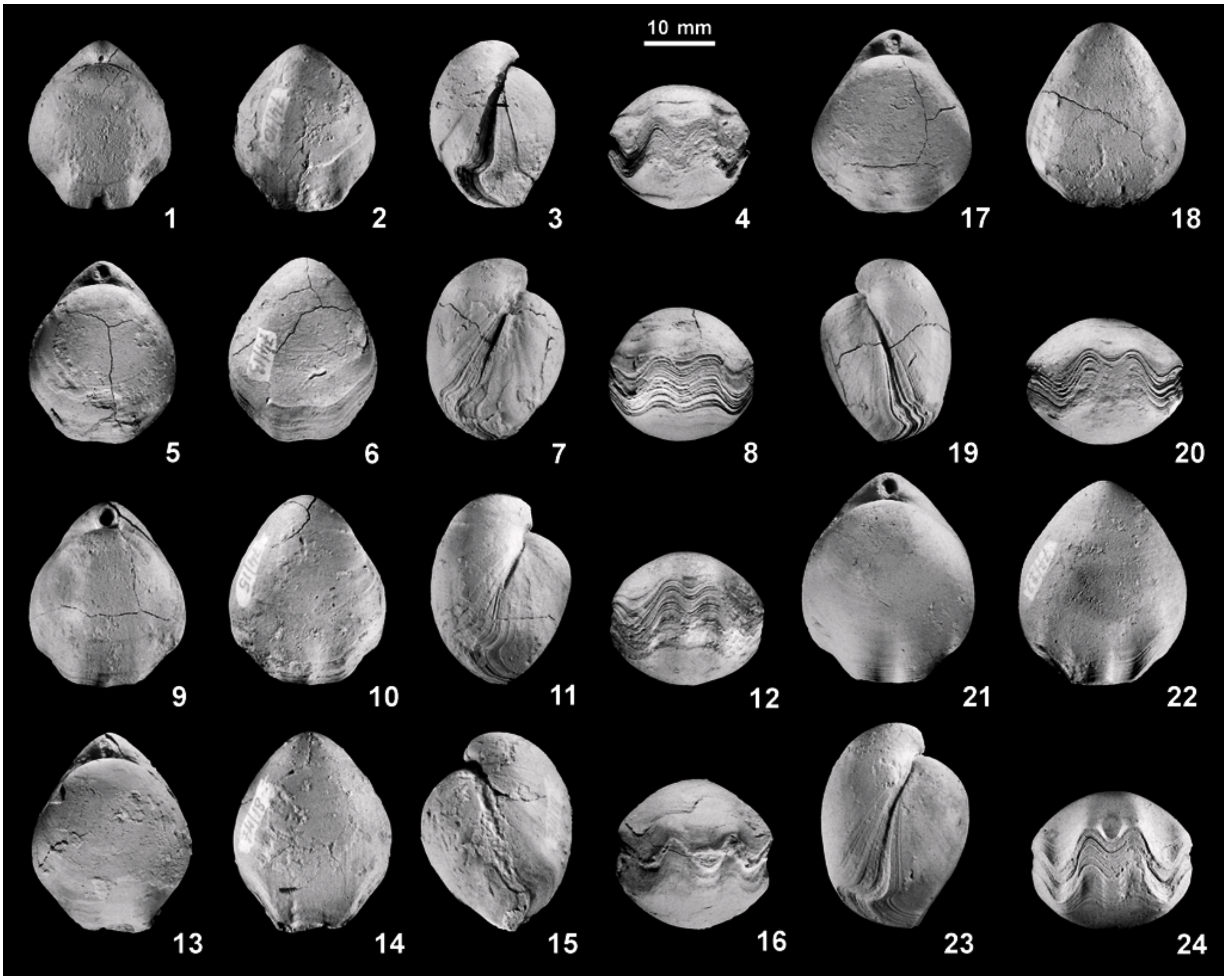

FIGURE 8—*Ectyphoria sinaiensis* new species, late Bathonian, Gebel Engabashi, northern Sinai. *1–4*, paratype, RGF VR 74/10, dorsal, ventral, lateral, and anterior views; *5–8*, paratype, RGF VR 74/13, dorsal, ventral, lateral, and anterior views; *9–12,* paratype, RGF VR 74/14, dorsal, ventral, lateral, and anterior views; *13–16*, paratype, RGF VR 74/15, dorsal, ventral, lateral, and anterior views of sectioned specimen; *17–20*, paratype, RGF VR 74/18, dorsal, ventral, lateral, and anterior views; *21–24*, holotype, RGF VR 74/22, dorsal, ventral, lateral, and anterior views.

posteriorly to midlength, elevating and widening anteriorly; sulcus originating slightly posterior to midlength, broad and relatively deep; anterior commissure trapezoidal; each valve ornamented with 19–21 coarse, subangular costae, five to six on fold and four to five in sulcus. Internal characters: dental plates subparallel, very short, lateral cavities small and narrow; teeth strong, globular, with lateral denticula; hinge plates narrow and slender, at beginning horizontal, anteriorly becoming slightly dorsally inclined; euseptoidum reduced to a small ridge; crural bases small, crescent-like, concave laterally, project not only in the dorsal valve, but also project above the level of the hinge plates toward the ventral valve; crura raduliform, curved toward ventral valve, anteriorly widened, straight and divergent, finish at 0.18 of dorsal valve length.

Discussion.—These shells are quite similar to those described by Cooper (1989) in general characters except that the Sinai specimens are not as widely triangular as Cooper's but this could be due to variation. They do compare favorably with some of his other illustrations (pl. 7, figs. 44–53). This species differs from *Daghanirhynchia daghaniensis* (Muir-Wood, 1935, pl. 8, fig. 5a–5c) from the Callovian of Somalia in having a much wider shell. It differs from *Daghanirhynchia magharaensis* Hegab, 2004 and *D. sadeki* Hegab, 2004 from Bathonian of northern Sinai, in having a transversely oval outline and in a larger number of costae.

Occurrence.—Bathonian (Dhruma Formation, *Thambites*, *Tulites*, *Micromphalites*, and *Dhrumaites* zones) of Saudi Arabia, Egypt (the Gulf of Suez) and late Bathonian of Gebel Engabashi within the breached anticline of Gebel El-Maghara, northern Sinai (N 30°41′25″; E 33°25′07″).

Order TEREBRATULIDA Waagen, 1883
Suborder TEREBRATULIDINA Waagen, 1883
Superfamily LOBOIDOTHYRIDOIDEA Makridin, 1964
Family LOBOIDOTHYRIDIDAE Makridin, 1964
Subfamily LOBOIDOTHYRIDINAE Makridin, 1964
Genus ECTYPHORIA Cooper, 1989

Type species.—*Ectyphoria inflata* COOPER, 1989, p. 80, pl. 20, figs. 14–19, 27–29.

ECTYPHORIA SINAIENSIS new species
Figures 8, 9

Diagnosis.—Medium sized *Ectyphoria*, no dorsal umbonal sulcus, margins thickened, slight folding evident, pedicle collar

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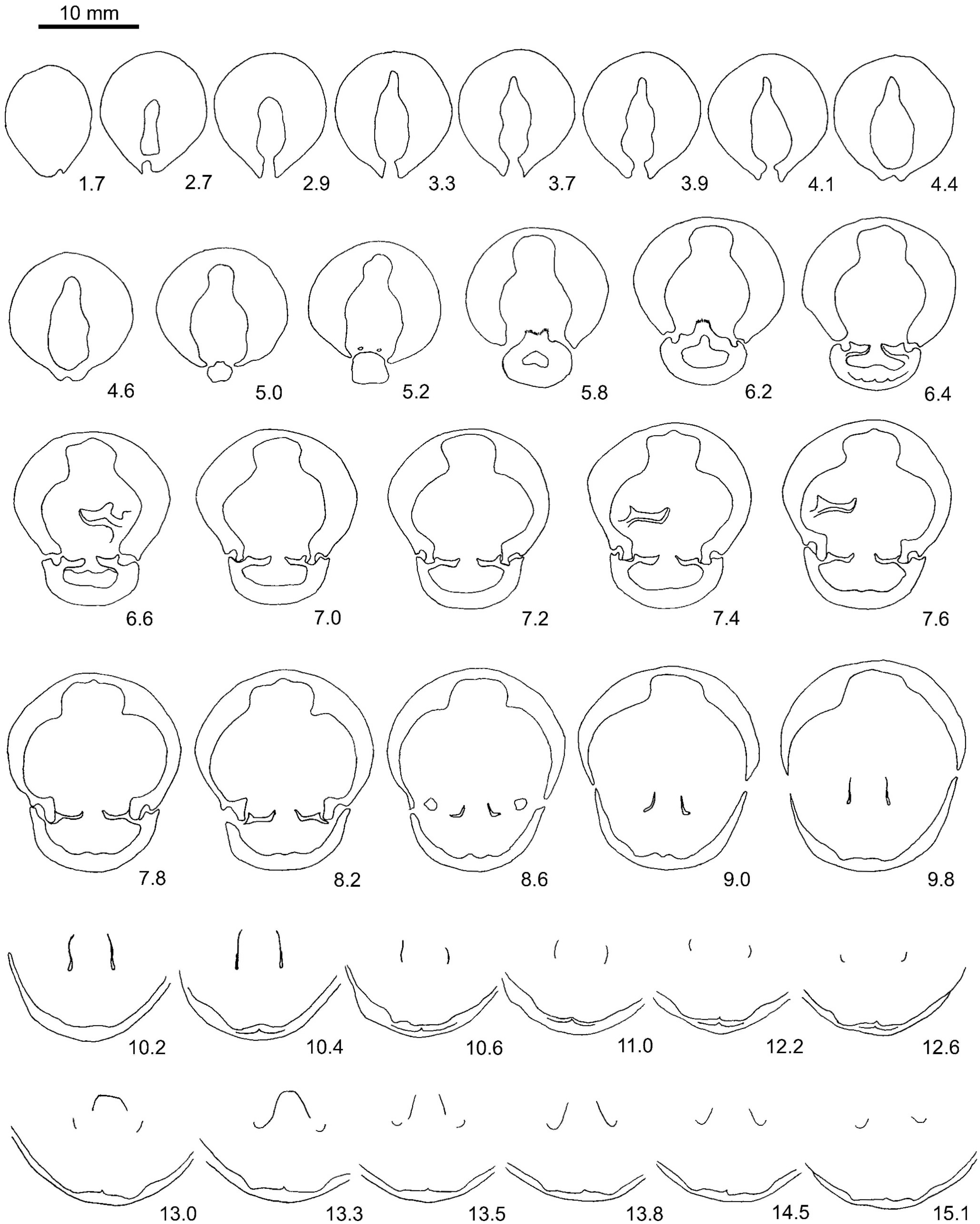

FIGURE 9—Transverse serial sections of *Ectyphoria sinaiensis* new species, late Bathonian, Gebel Engabashi, northern Sinai. Original dimensions of the specimen (in mm): L=28.4; W=22.8; T=22.0. Numbers refer to distance in mm from the ventral apex; paratype, RGF VR 74/18.

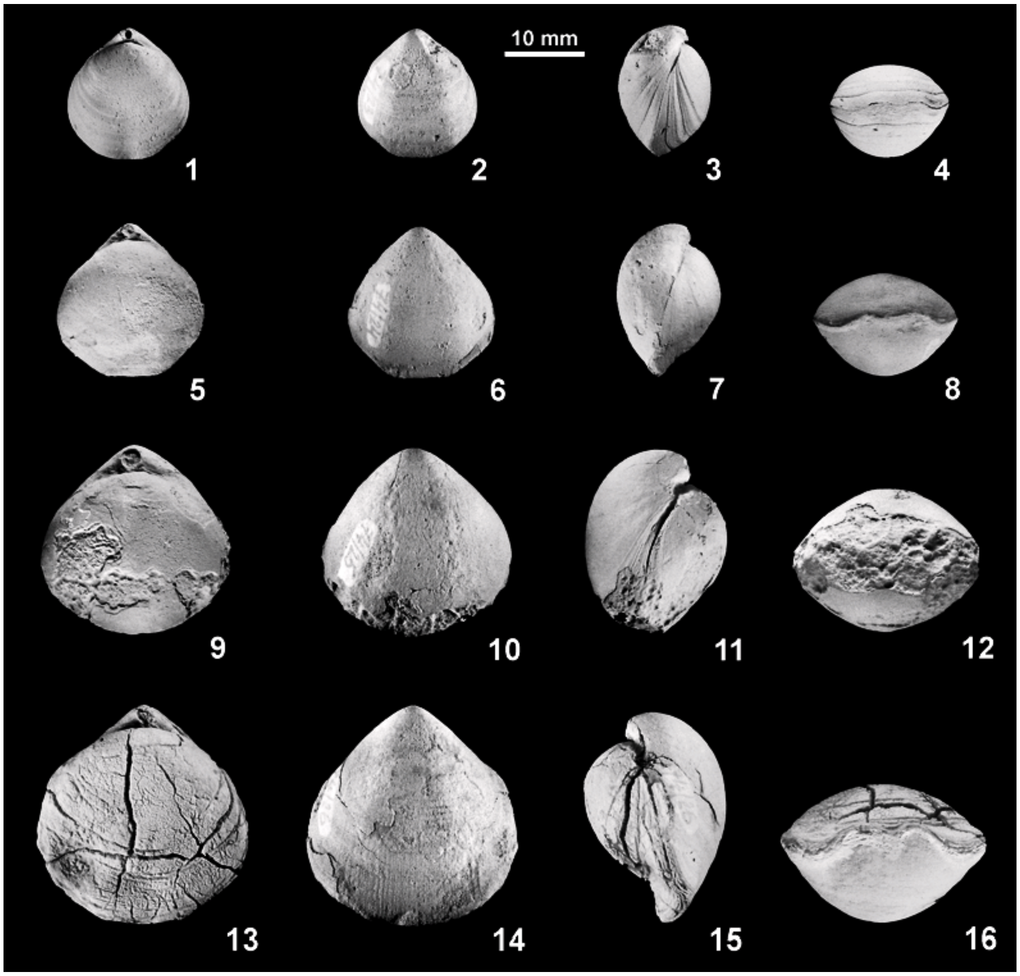

FIGURE *10*—*Cooperithyris circularis* new genus and species. *1–4*, paratype RGF VR 74/23, dorsal, ventral, lateral, and anterior views; *5–8*, paratype, RGF VR 74/24, dorsal, ventral, lateral, and anterior views; *9–12*, paratype, RGF VR 74/25, dorsal, ventral, lateral, and anterior views of sectioned specimen; *13–16*, holotype, RGF VR 74/26, dorsal, ventral, lateral, and anterior views.

developed, cardinal process bilobed, dorsal umbonal cavity present, hinge plates subhorizontal, attached dorsally to small crural bases, euseptoidum reduced, transverse band highly arched, loop long 0.44 of dorsal valve length, terminal points long.

Description.—External characters: shells medium sized (see Appendix), elongate-oval to rounded-pentagonal in outline, always longer than wide, strongly and nearly equally biconvex, maximum width slightly anterior to midlength, maximum thickness at midlength; no dorsal umbonal sulcus observed; beak carinate, erect, in close contact with dorsal umbo overlapping and obscuring symphytium, foramen moderate in size, labiate, permesothyrid, beak ridges indistinct; fold and sulcus slightly developed on anterior quarter of shell; lateral commissure straight, anterior commissure slightly bisulcate; numerous growth lines concentrated toward anterior and lateral margins; marginal thickening develops in the adult stage. Internal characters: slender pedicle collar noted in ventral valve; symphytium narrow, relatively thick; cardinal process bilobed; teeth quadrate, nearly vertically inserted in relatively small sockets, with well-developed denticula; dorsal umbonal cavity developed. Hinge plates nearly horizontal; low crural bases; outer socket ridges much stronger than inner ones; crural processes high, subparallel, ventrally tapering; euseptoidum reduced to a low ridge; loop long 0.44 of dorsal valve length, transverse band wide, highly arched with long terminal points.

Etymology.—After the Sinai Peninsula from where the shells were collected.

Types.—Holotype RGF VR 74/22, paratypes RGF VR 74/8 to RGF VR 74/21; a total of 15 specimens available.

Occurrence.—Late Bathonian of Gebel Engabashi within the breached anticline of Gebel El-Maghara, northern Sinai (N 30°41′25″; E 33°25′07″).

Discussion.—Referring to the external characters, such as elongate-oval to rounded-pentagonal outline, the strongly inflated valves, the shape of beak and biplicate anterior commissure, the new species is very similar to the type species, *Ectyphoria inflata* Cooper, 1989 (p. 80, pl. 20, figs. 14–19, 27–29) from the late Bathonian (Dhruma Formation, *Dhrumaites* Zone) of Saudi Arabia. The main external difference between the new species and *E. inflata* is the presence of a dorsal umbonal sulcus in the latter. The internal characters presented in Figure 9 are comparable with those for the genus given in Cooper's serial sections (1989, fig. 36) in which the transverse band and terminal points are missing.

Genus COOPERITHYRIS new genus

Type species.—*Cooperithyris circularis* new species.

Included species.—*Sphaeroidothyris weiri* Hegab, 1992.

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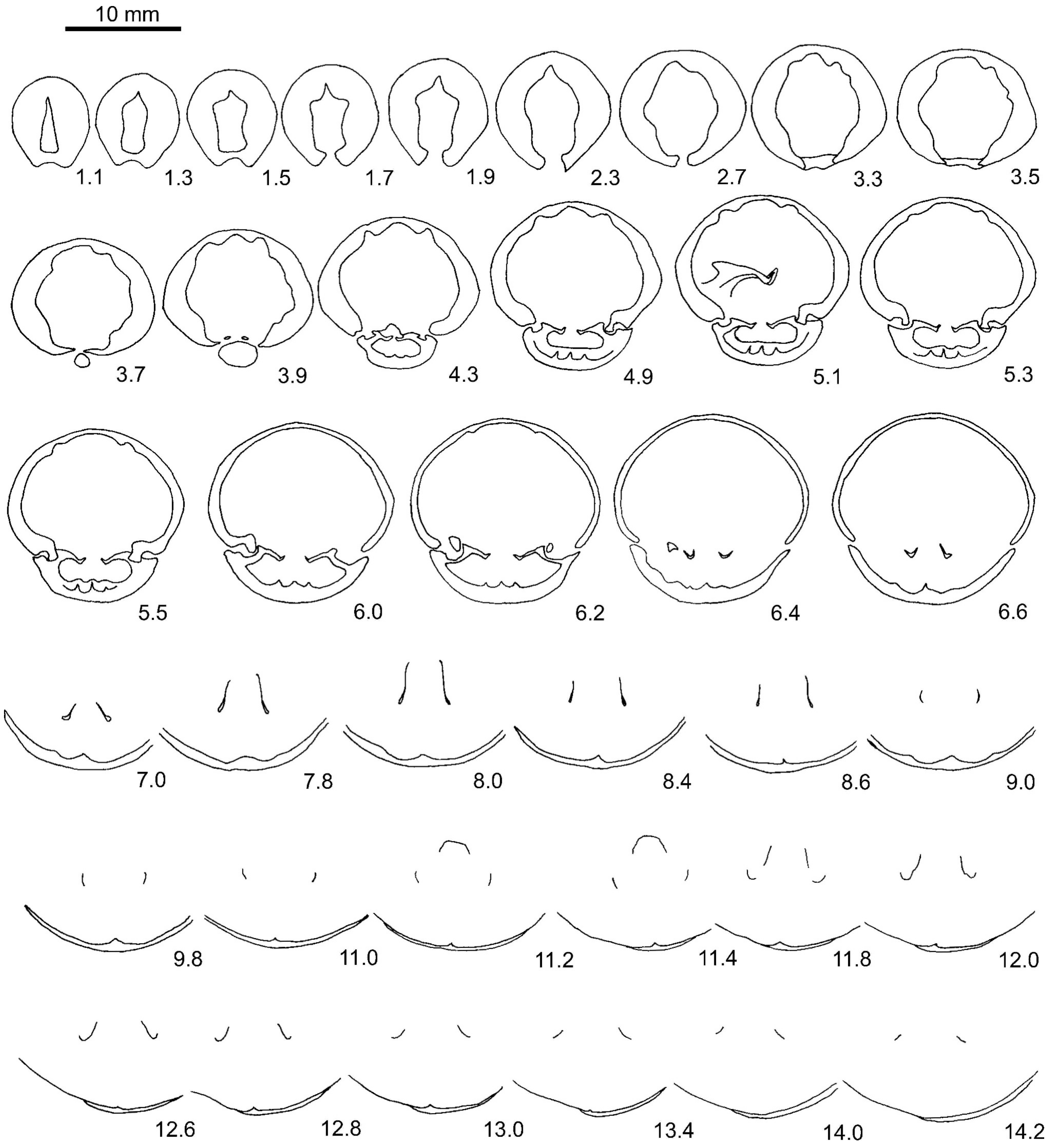

FIGURE *11*—Transverse serial sections of *Cooperithyris circularis* new genus and species, late Bathonian, Gebel Engabashi, northern Sinai. Original dimensions of the specimen (in mm): L=28.4; W=22.8; T=22.0. Numbers refer to distance in mm from the ventral apex; paratype, RGF VR 74/25.

Etymology.—Name in honor of the late G. Arthur Cooper.

Diagnosis.—As for species.

Discussion.—Based on external morphology, particularly circular outline, short beak, and folding of the shell which is never well developed, the new genus, can be compared only with *Somalithyris* Muir-Wood, 1935, from the Oxfordian–Kimmeridgian of Somalia and Saudi Arabia. It differs externally in having a more circular outline and much less developed folding which is confined toward the anterior commissure. The internal structures of these two genera are different, with the new genus having a less developed cardinal process, smaller crural bases, subquadrate teeth with a sharper angle of insertion and longer loop. It is interesting to note that in *Cooperithyris* and *Somalithyris* (see Muir-Wood, 1936, fig. 10), and also in some Jurassic genera such are *Sphaeroidothyris* Buckman, 1918 (see Muir-Wood, 1936, fig. 10), *Ptyctothyris* Buckman, 1918 (see Muir-Wood, 1935, fig. 20), *Avonothyris* Buckman, 1918 (see Muir-Wood, 1965, fig. 637, 2a–n), *Epithyris* Phillips, 1841 (see Muir-Wood, 1965, fig. 641, 2a–j), *Tubithyris* Buckman, 1918 (see

FIGURE 12—*Avonothyris* species A, late Bathonian, Gebel Engabashi, northern Sinai. *1–4*, RGF VR 74/27, dorsal, ventral, lateral, and anterior views.

Radulović, 1993, p. 156, fig. 4), and *Holcotchithyris* Hegab, 1995 (fig. 3) the euseptoidum is bounded by two parallel ridges. This character should not be a criterion for determining the genus or even the species.

Occurrence.—Late Bathonian of Gebel Engabashi within the breached anticline of Gebel El-Maghara, northern Sinai (N 30°41′25″; E 33°25′07″).

COOPERITHYRIS CIRCULARIS new species
Figures 10, 11

Diagnosis.—Medium size, circular to elongate oval, moderately equibiconvex, sulciplicate; beak short, small, erect, foramen large, slightly labiate, permesothyrid; folding confined near anterior commissure; symphytium partly visible; cardinal process bilobed; crural bases small; hinge plates thin and wide, dorsally inclined; loop 0.48 of dorsal valve length, transverse band broad, highly arched, terminal points moderately long.

Description.—External characters: medium sized (see Appendix), circular in outline, slightly longer than wide, maximum width and thickness at midlength or slightly anterior; beak short, small, erect, in close contact with dorsal umbo, partially concealing symphytium, foramen permesothyrid, relatively large, circular, slightly labiate, pinhole size in juveniles, beak ridges indistinct; lateral commissure nearly straight, anterior commissure gently sulciplicate; folding of the shell weak, confined to near anterior commissure; surface marked by well-developed growth lines. Internal characters: low pedicle collar present; symphytium thick; cardinal process bilobed; teeth quadrate, with well-developed lateral denticula; hinge plates thin and wide, dorsally inclined; crural bases very small, project toward ventral valve, crural processes are high and slender, slightly ventrally convergent; euseptoidum strong, paralleled by two ridges; loop thin, extending 0.48 of dorsal valve length, transverse band broad and high arched, terminal points moderately long.

Etymology.—Latin *circularis*, circular, refers to the outline of the shell.

Types.—Holotype RGF VR 74/26; paratypes RGF VR 74/23 to RGF VR 74/25; a total of 4 specimens available.

Occurrence.—Late Bathonian of Gebel Engabashi within the breached anticline of Gebel El-Maghara, northern Sinai (N 30°41′25″; E 33°25′07″).

Discussion.—Based on the circular outline, the shape of the beak, and sulciplicate anterior commissure the new species can only be compared with some representatives of the genus *Somalithyris* described by Cooper (1989) from the Jurassic of Saudi Arabia, namely, *Somalithyris subcircularis* Cooper, 1989 (p. 89, pl. 29, figs. 8–14) and *Somalithyris rotundata* Cooper 1989 (p. 89, pl. 29, figs. 5–17) from the Kimmeridgian (Hanifa Formation). The new species differs in having more inflated valves, a more circular outline and less pronounced folding. Another form from Saudi Arabia which is similar in general aspect to the present species is the late Bajocian–early Bathonian *Sphaeroidothyris arabica* Cooper, 1989 (p. 90, pl. 29, figs. 26–34). It is distinguished by its smaller size, less inflated valves and rectimarginate anterior commissure.

From Gebel El–Maghara in northern Sinai Hegab (1992) introduced two late Callovian species: *Sphaeroidothyris weiri* (p. 40, pl. 1, figs. 12–19) and *Sphaeroidothyris magharaensis* (p. 41, pl. 1, figs. 20–22). *Sphaeroidothyris magharaensis* is considered to be a juvenile form of *S. wieri* and therefore a synonym of the latter. The interior of these fits well with those of described species.

Genus AVONOTHYRIS Buckman, 1918

Type species.—*Avonothyris plicatina* BUCKMAN, 1918, p. 102, pl. 21, fig. 9.

AVONOTHYRIS species A
Figure 12

Avonothyris? species COOPER, 1989, p. 75, pl. 23, figs. 1–3.

Material.—One specimen with damaged beak, RGF VR 74/27.

Description.—External characters: large size (see Appendix), elongate oval in outline, equibiconvex, lateral margins slightly rounded, maximum width and thickness at midlength; beak massive, wide, erect, beak ridges short and rounded; lateral commissure gently ventrally arched in the posterior two-thirds and sharply curved ventrally at anterior, anterior commissure strongly bisulcate; a shallow sulcus originates about midlength on dorsal valve, deepens anteriorly, bordered by rounded and parallel carinae. Ventral valve with median flattened and wide fold originating one-third the distance from the beak, separated by shorter and narrower sulci; fine growth lines, much more numerous and crowded anteriorly, and ornament fine radiating capillae (about two to three capillae per mm near the anterior margin). Internal characters: due to the paucity of material no serial sections could be prepared and internal morphology was not studied.

Discussion.—The described species show external similarities, such as outline, inflation of the valves, and especially the large size, with some species of *Avonothyris*, namely, *A. corpulenta* Buckman, 1918 and *A. variabilis* Feldman et al., 1991. In contrast to the specimen figured here, *A. corpulenta*, from the Bathonian of southern England, has a narrower beak, more widely triangular shell and slightly wider fold with convergent carinae. *A. variabilis* from the late Callovian of northern Sinai has a more subpentagonal outline and convergent and rounded carinae on the dorsal fold.

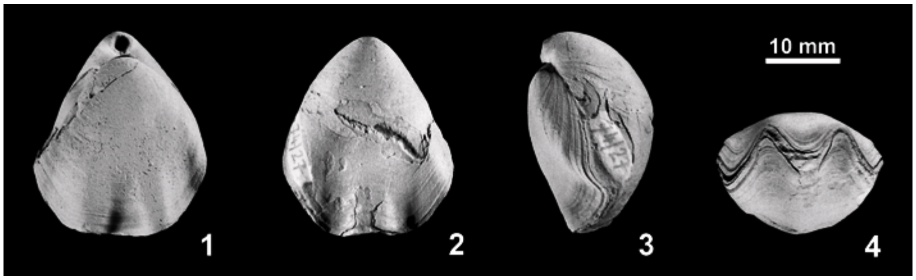

FIGURE *13*—*Ptyctothyris* species A, late Bathonian, Gebel Engabashi, northern Sinai. *1–4*, RGF VR 74/28, dorsal, ventral, lateral, and anterior views.

Externally the species is similar in dimensions, outline and the shape of folding to *Avonothyris*? species in Cooper, 1989, from the Bajocian–early Callovian (the precise age not placed) of Saudi Arabia. It differs only in having parallel carinae on the dorsal fold, a median ventral elevation, and a lateral commissure sharply curved ventrally and anteriorly. In all the described species the internal characters are unknown.

Occurrence.—Late Bathonian of Gebel Engabashi within the breached anticline of Gebel El-Maghara, northern Sinai (N 30°41′25″; E 33°25′07″).

Genus PTYCTOTHYRIS Buckman, 1918

Type species.—*Terebratula stephani* Davidson, 1877, p. 75, pl. 1, fig. 3.

PTYCTOTHYRIS species A
Figure 13

Material.—One specimen, RGF VR 74/28.

Description.—External characters: medium sized (see Appendix), elongate subpentagonal outline, longer than wide, maximum width in anterior third of shell, maximum thickness at midlength, slightly ventribiconvex; beak strong, erect, in close contact with dorsal umbo totally obscuring symphytium, mesothyrid foramen, circular, relatively large, slightly labiate, beak ridges poorly developed, rounded; fold strongly elevated anteriorly, originating at midlength, bounded by two subangular carinae separated by a shallow and broad sulcus; dorsal sulcus wide, shallow, developed in anterior half, formed by two rounded carinae, with widely rounded, median carina; anterior commissure strongly biplicate; shell surface marked by numerous, well developed growth lines. Internal characters: since there is only one specimen in the collection the interior of this species is unknown.

Discussion.—The specimen studied herein is very similar in the shape of its beak, strongly biplicate anterior commissure and folding of the shell to *Ptyctothyris quillyensis* (Bayle, 1878, pl. 7, fig. 9; refigured in Alméras and Fauré, 2008, pl. 11, fig. 7), from the early Bathonian (*Zigzag* Zone) of France (type locality Quilly, Calvados), northern Sinai (Moghara Massif, Gebel Aroussieh), Somalia and Kenya. It differs from Bayle's species only in having maximum width in the anterior third (W/L=0.85 instead of 0.65 in the holotype of *P. quillyensis*).

Another two representatives of the genus from northern Sinai (Gebel El-Maghara) are the late Bajocian *P. sinaiensis*, Feldman et al., 1991 and the late Callovian *P.*? *daghaniensis* Muir-Wood, 1935, the latter also known from Somalia. In contrast to the new species *P. sinaiensis* much weaker folding and a narrower shell. *P.*? *daghaniensis* has a more rounded subpentagonal outline with maximum width slightly anterior to midlength as well as weaker folding of the shell. All the species share the characteristic shape of the beak.

Occurrence.—Late Bathonian of Gebel Engabashi within the breached anticline of Gebel El-Maghara, northern Sinai (N 30°41′25″; E 33°25′07″).

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APPENDIX *1*—All measurements in mm. Abbreviations: L=length; W=width; T=thickness; NRDV=number of ribs on the dorsal valve; >=damage in that oriention.

Measurements of *Globirhynchia sphaerica.*

No RGF VR	L	W	T	W/L	T/L	T/W	NRDV	Remarks
74/1	16.8	16.5	12.5	0.98	0.74	0.76	11	Figs. 3.1–3.4, 4.1–4.4
74/2	20.2	20.2	16.7	1.00	0.83	0.83	17	Figs. 3.5–3.8, 4.5–4.8
74/3	21.9	23.7	19.1	1.08	0.87	0.80	17	Figs. 3.9–3.12, 4.9–4.12
74/4	23.4	20.6	18.1	0.88	0.77	0.88	17	sectioned, Figs. 3.13–3.16, 4.13–4.16
74/5	25.8	23.5	21.9	0.91	0.85	0.93	17	Figs. 3.17–3.20, 4.17–4.20

Measurements of *Daghanirhynchia angulocostata*.

No RGF VR	L	W	T	W/L	T/L	T/W	NRDV	Remarks
74/6	21.2	21.8	14.1	1.03	0.66	0.65	20	Figs. 5.1–5.4, 6.1–6.4
74/7	23.9	24.8	14.6	1.04	0.43	0.59	24	sectioned, Figs. 5.5–5.8, 6.5–6.8

Measurements of *Ectiphoria sinaiensis* n. sp.

No RGF VR	L	W	T	W/L	T/L	T/W	Remarks
74/8	22.2	20.0	15.2	0.90	0.68	0.76	paratype,
74/9	22.3	20.0	17.1	0.90	0.77	0.85	paratype
74/10	24.2	20.5	18.0	0.85	0.74	0.88	paratype, Figs. 1–4, 8.1–8.4
74/11	24.3	20.5	17.1	0.84	0.70	0.83	paratype
74/12	26.0	20.6	16.4	0.79	0.63	0.80	paratype
74/13	26.2	21.0	19.7	0.80	0.75	0.94	paratype, Figs. 5–8, 8.5–8.8
74/14	26.6	22.5	19.0	0.84	0.71	0.84	paratype, Figs. 9–12, 8.9–8.12
74/15	27.3	22.1	20.5	0.81	0.76	0.93	paratype, Figs. 13–16, 8.13–8.16
74/16	27.4	24.6	18.7	0.90	0.68	0.76	paratype
74/17	>27.4	24.4	18.0	-	-	0.74	paratype
74/18	28.4	22.8	22.0	0.80	0.77	0.96	paratype, sectioned, Figs. 17–20, 8.17–8.20
74/19	29.1	24.4	22.0	0.84	0.76	0.90	paratype
74/20	29.2	23.6	21.4	0.81	0.73	0.91	paratype
74/21	29.6	22.2	20.9	0.75	0.71	0.94	paratype
74/22	29.6	23.8	21.2	0.80	0.72	0.89	holotype, Figs. 21–24, 8.21–8.24

Measurements of *Cooperithyris circularis* n. gen, n. sp.

No RGF VR	L	W	T	W/L	T/L	T/W	Remarks
74/23	17.2	15.8	12.2	0.92	0.71	0.71	paratype, Figs. 1–4, 10.1–10.4
74/24	20.1	19.4	14.0	0.96	0.70	0.72	paratype, Figs. 5–8, 10.5–10.8
74/25	>25.0	25.0	19.5	-	-	0.78	paratype, sectioned, Figs. 9–12, 10.9–10.12
74/26	29.0	27.8	19.3	0.96	0.66	0.70	holotype, Figs. 13–16, 10.13–10.16

Measurements of *Avonothyris* species A.

No RGF VR	L	W	T	W/L	T/L	T/W	Remark
74/28	>40.0	31.9	>21.5	-	-	-	Fig. 12.1–12.4

Measurements of *Ptyctothyris* species A.

No RGF VR	L	W	T	W/L	T/L	T/W	Remarks
74/27	26.6	22.7	17.0	0.85	0.64	0.75	Figs. 12.1–12.4, 13.1–13.4