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Jurassic rhynchonellide brachiopods from the Jordan Valley

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Jurassic rhynchonellide brachiopods from the Jordan Valley are herein revised and new taxa are added to the faunal list. In this study of Jurassic rhynchonellides from Wadi Zarqa, northwestern Jordan, we recognize the following taxa: *Eurysites rotundus*, *Cymatorhynchia quadriplicata*, *Daghanirhynchia triangulata*, *D. angulocostata*, *Pycnoria magna*, *Schizoria elongata*, and *Schizoria* cf. *intermedia*. The following new taxa are described: *Daghanirhynchia susanae* sp. nov. and *Amydroptychus markowitzi* sp. nov. The Middle Jurassic Mughanniyya Formation of northwest Jordan is dominated by limestone beds. The sedimentary environment is interpreted as neritic, light, and nutrient-rich resulting in high faunal diversity. The high rhynchonellide endemism of this fauna is yet another confirmation of pronounced Middle Jurassic endemism along the southern Tethyan margin of the Ethiopian Province. Brachiopods of the Jordanian Mughanniyya Formation can be correlated with the fauna of the Aroussiah Formation in Sinai and the Zohar and Matmor formations in Southern Israel.

Key words: Brachiopoda, Rhynchonellida, Mughanniyya Formation, Jurassic, Jordan.

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Introduction

During the Jurassic Period the Levant was a part of the Gondwanian Tethys platform shelf that extended from Morocco in the west to the Arabian Peninsula, in the east and southward to the Horn of Africa. The collecting area for this study (Fig. 1) is a part of the elevated platform terrain of the Arabian Nubian Shield, which is covered by intermittent Palaeozoic to Cenozoic sedimentary successions consisting mainly of clastic units with marine carbonates increasing upward (Rybakov and Segev 2005). The Late Triassic in the Levant consisted of an area that was covered by broad sea-marginal flats, analogous to modern sabkhas, in which evaporites and dolomite rocks were deposited, whereas at the beginning of the Jurassic, emergence led to subaerial exposure that was accompanied by extensive freshwater runoff and subaerial weathering (Goldberg and Friedman 1974). Subsequent subsidence allowed the formation of shallow and marginal shelf environments interrupted by lagoons resulting in the deposition of thick, partly calcareous sandstone beds that were overlain by thick, partly gypsiferous carbonate, marl, and sandy marl rocks (Basha 1980).

Cox (1925) and Muir-Wood's (1925) descriptions of brachiopods and molluscs provided the first reliable data on the age of the Jurassic formations of Jordan. Their faunas were collected in Wadi Zarqa by Bryce Kerr Nairn Wyllie, Keir Arthur Campbell, and George Martin Lees on behalf of the Turkish Petroleum Company, later known as the Anglo-Persian Oil Company (Picard and Hirsch 1987).

This paper is one of a series that was begun with an analysis of the megafossils of northern Sinai (Feldman et al. 1982, 1991; Feldman 1986, 1987; Feldman and Owen 1988, 1993) and Israel (Feldman et al. 2001) in order to systematically study the brachiopod faunas. These data will help establish the history of brachiopod species and their evolution within the Jurassic Ethiopian Province, that is the part of the Tethyan Realm that laid along the southern Tethyan margin. The taxonomic information recorded as a result of these studies will elucidate the biogeographic history of the Ethiopian Province and help to interpret the structure and palaeoecology of its marine communities. For example, in the Jurassic sequence exposed at Hamakhtesh Hagadol, southern Israel, Feldman and Brett (1998) recognised sclerobionts (epi- and endobiontic) organisms on crinoids. Wilson et al. (2008, 2010) further developed the invertebrate community palaeoecological framework.

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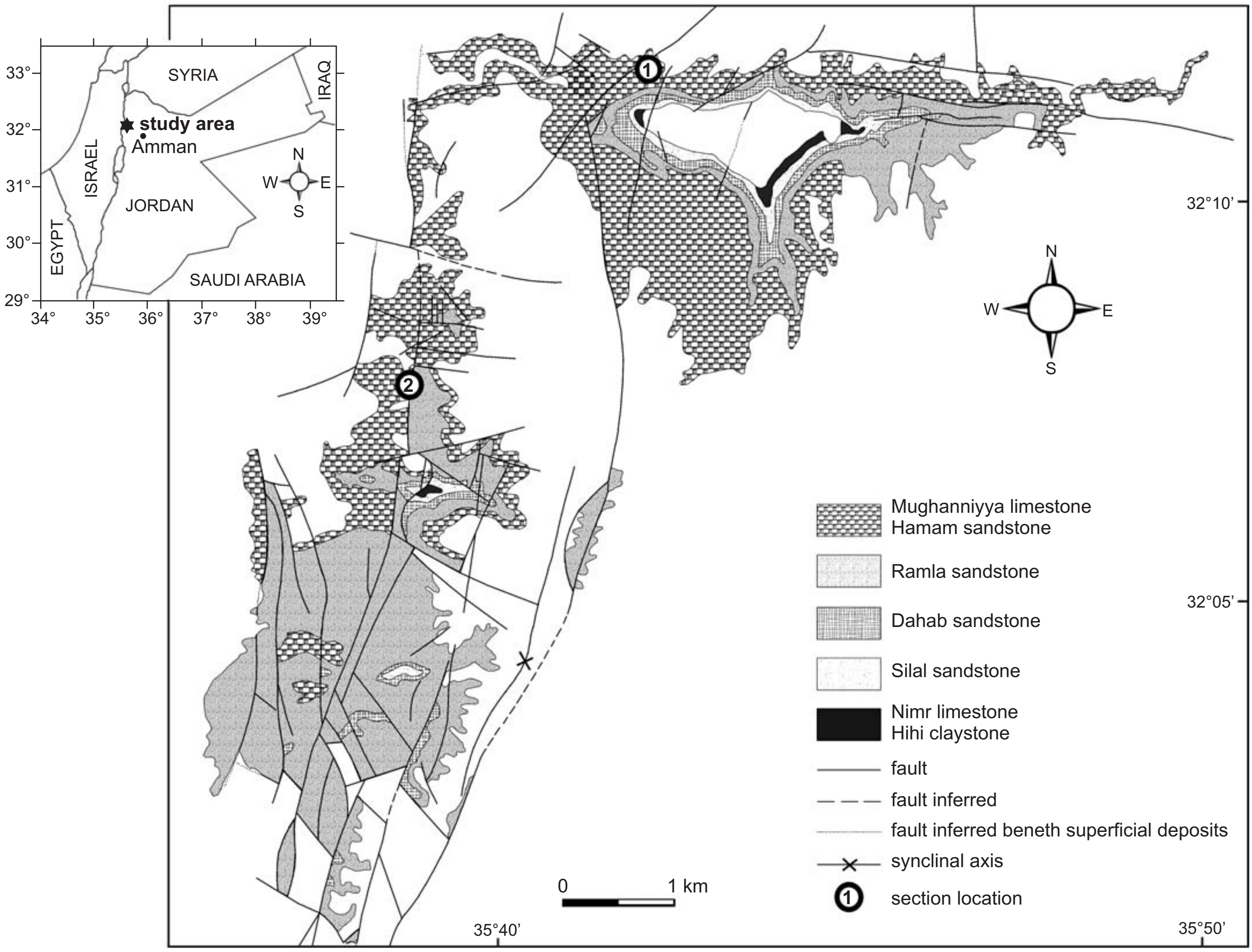

Fig. 1. Geographical map of the study area in northwestern Jordan. The collecting localities are indicated by circles: Locality 1, Tel el Dhahab section; Locality 2, Arda section. Modified from Muneizel and Khalil (1993) and Swarieh and Barjous (1993).

Previous studies of Ethiopian Province brachiopods from northern Sinai (Feldman et al. 1982, 1991a; Feldman 1987; Feldman and Owen 1988; Hegab 1988, 1989, 1991, 1992, 1993), along with Cooper's (1989) monograph and Alméras' (1987) work, complement the present paper on the brachiopods of the Jordan Valley. The Ethiopian Province has been recognised from the Early Jurassic until the mid and possibly end of the Cretaceous 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) recognised endemic faunas in the ammonoids and Kitchin (1912) in the trigoniacean and crassatellacean bivalves.

The Jurassic brachiopods of Saudi Arabia studied by Cooper (1989) were collected during the years 1933–1953 by field geologists of the Arabian-American Oil Company (Aramco). Cooper (1989) also used the Porter M. Kier-Earl G. Kauffman collections (1962) in his analyses (Gus Arthur Cooper, personal communication 1977). He noted that, whereas several rock types are recorded, some of the specimens cannot be assigned to specific parts of the column, but most have been referred to various ammonite zones. Consequently, it is not possible to determine the palaeoecological conditions under which they existed during the Jurassic. In Jordan, however, collecting was accomplished under strict stratigraphical control and an eventual palaeoecological study of the brachiopods and their communities and a comparison between the Negev communities can be accomplished.

Geographical and geological setting

In northwestern Jordan Jurassic outcrops can be found (Fig. 1) along the western part of Wadi Zarqa beginning near the old Jerash Bridge and extending westward to Deir-Alla, a distance of about 20 km; toward the south the outcrop belt

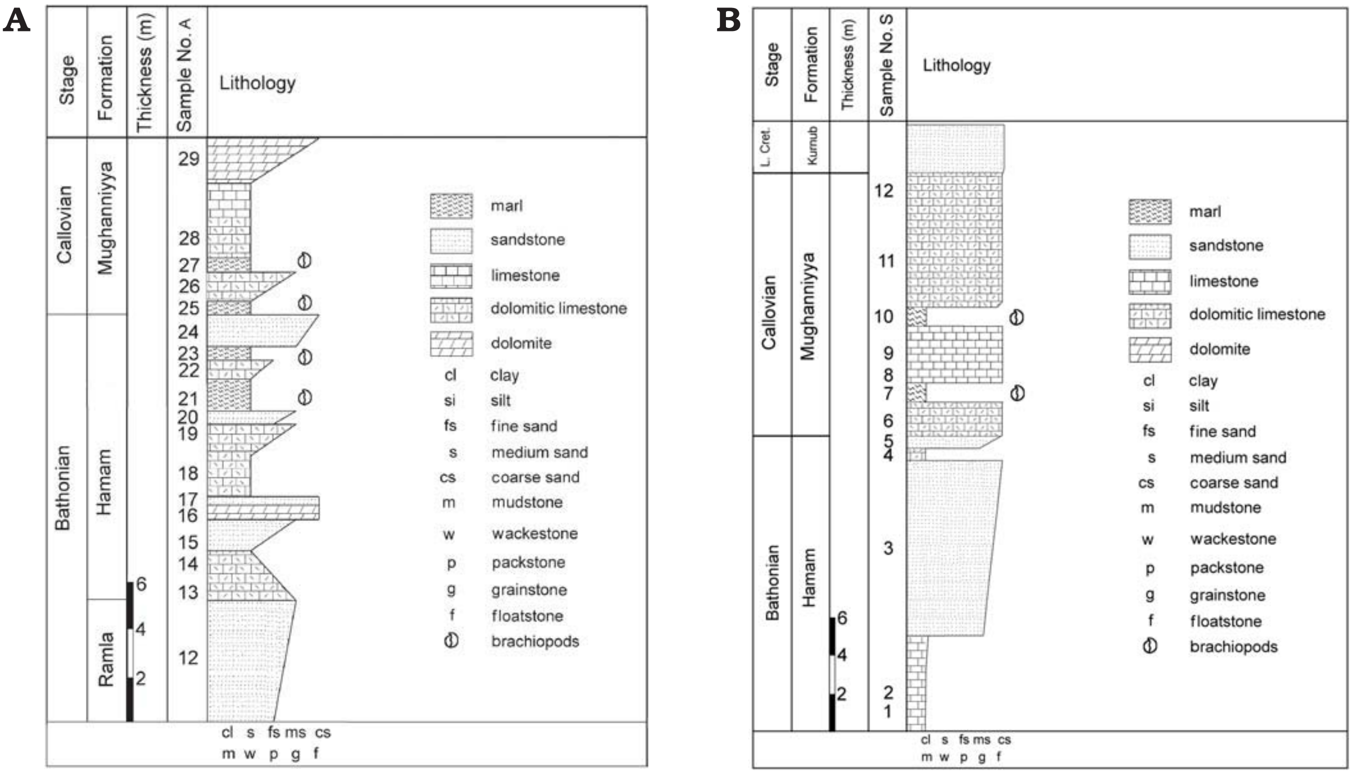

Fig. 2. Stratigraphical columns of the sections sampled showing lithology and brachiopod yielding beds. **A**. Arda section. **B**. Tel el Dhahab section. Abbreviation: L. Cret., Lower Cretaceous.

passes through Ain-Khuneizir, Subeihi, and Arda Road (Ahmad 2002). Two outcrops of dolomite and limestone can be found in the Baqa depression near the intersection of Wadi Mahis and Wadi Shueib. The Jurassic succession decreases in thickness from the Zarqa River and Wadi Huni eastward toward the Zarqa Bridge and from there southeast toward Suweileh-1 and Safra-1.

The Jurassic rocks of Jordan have been subdivided into seven formations: Hihi, Nimr, Silal, Dhahab, Ramla, Hamam, and Mughanniyya (Khalil and Muneizel 1992). The Mughanniyya Formation belongs to the Callovian, the Hamam and Ramla formations belong to the Bathonian and the Dhahab and Silal formations belong to the Bajocian Stage. Blake (1935, 1940) was the first to construct a geological cross section midway between the "Zerqa mouth" and the Jerash Crossing; however, detailed stratigraphic sections were only provided in 1959 by Wetzel and Morton (Picard and Hirsch 1987).

The Mughanniyya Formation (Fig. 2) represents the upper part of the Jurassic sequence in Jordan and outcrops consistently below the Kurnub Sandstone Group. The formation is composed of alternating claystone, siltstone, and marly limestone beds with minor dolomite, dolomitic limestone, and coquinas.

Ammonite zonation

The paucity of ammonites in the Jurassic sediments of Jordan makes the formations difficult to date. Three species of ammonites have been described from northwestern Jordan: *Ermoceras* cf. *coronatoides* Douvillé, 1916, *Teloceras labrum* Buckman, 1922, and *Normannites* gr. *braikenridgii* (Buckman, 1927). These taxa, collected from the Dhahab Formation of early middle to late Bajocian age, were described by Basha and Aqrabawi (1994). The closest Jurassic rocks to those in Jordan occur in southern Israel.

The Callovian ammonite biozonation of the sequence at Hamakhtesh Hagadol, southern Israel, was refined by Gill and Tintant (1975), Lewy (1983), Gill et al. (1985), and more recently by Cariou et al. (1997). The same authors and Hirsch et al. (1998) considered the section at Hamakhtesh Hagadol to be a nearly continuous middle to upper Callovian sequence, unique in the Levant, comprising the *Erymnoceras coronatum* Zone (middle Callovian), *Peltoceras athleta* Zone (upper Callovian), and *Orionoides* (*Poculisphinctes*) *poculum* Subzone (= lower part of the *Quenstedtoceras lamberti* Zone). The Callovian ammonite succession in Hamakhtesh Hagadol (Arabic Province) facilitates correlation with the standard scale stages of Submediterranean Europe. Elsewhere in the Middle East, coeval exposures of the Zohar Formation are found at Abu El Darag (Suez Gulf, Egypt), Gebel El-Maghara, and Gebel El-Minshera (northern Sinai, Egypt), in the Hermon Limestone Formation (Antilebanon), and in the Tuwaiq Mountain Limestone Formation (Saudi Arabia). Coeval sequences of the upper Callovian Matmor Formation (nearly 100 m thick) are only found in the Negev boreholes at Qeren, Sherif, Rehkme, Boqer, and the Hallal borehole in Sinai, Egypt, all of which are part of the platform of the Higher

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Negev (Picard and Hirsch 1987). In the Gebel El-Maghara section (Sinai Deep) and in the Hermon exposures of the Judean Embayment (Hirsch et al. 1998), the later Callovian is reduced to a few dm of section covered by Oxfordian shales (Cariou et al. 1997).

Goldberg (1963) subdivided the 206-m-thick section at Hamakhtesh Hagadol into 69 subunits (numbered 5–74). The sequence consists of the Ziyya and Madsus members of the Zohar Formation (Coates et al. 1963) and of the Matmor Formation (Goldberg 1963, emended Hirsch and Roded 1997).

Material and methods

All specimens are preserved as articulated shell material. The specimens are from the Hamam and Mughanniyya formations (Bathonian–Callovian) in northwest Jordan. Serial sections were prepared with a WOKO 50P grinding machine with slice-spacing of 100 to 200 μm. Drawings were made with the help of a camera lucida. Measurements were taken with digital caliper and rounded to 0.1 mm. Specimens were coated with ammonium chloride prior to photographing. All measurements are in millimetres (mm); the width of the dorsal fold is measured at the anterior commissure. Est. indicates the specimen was incomplete and the measurement was estimated. The systematics follows the revised *Treatise on Invertebrate Palaeontology* (Manceñido et al. 2002).

Institutional abbreviations.—AMNH, Division of Palaeontology, American Museum of Natural History, New York, NY, USA; GSI, Geological Survey of Israel, Jerusalem, Israel; USNM, United States National Museum, Smithsonian Institution, Washington, D.C., USA.

Other abbreviations.—L, length; T, thickness; W, width.

Systematic palaeontology

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 Rzhonsnitskaya, 1956

Family Cyclothyrididae Makridin, 1955

Subfamily Cardinirhynchiinae Makridin, 1964

Genus *Eurysites* Cooper, 1989

Type species: *Eurysites transversus* Cooper, 1989; Bajocian/Callovian, Saudi Arabia.

Eurysites rotundus Cooper, 1989

Fig. 3A.

1989 *Eurysites rotundus* sp. nov.; Cooper 1989: 32–33, pl. 8: 27–49, pl. 17: 1–11, fig. 17.

Material.—Three articulated specimens: AMNH FI-72366, AMNH FI-72367, AMNH FI-72368, bed S-7, Mughanniyya Formation, Tel el Dhahab section, Jordan.

Description.—Shell medium size (Table 1), somewhat worn, outline roundly triangular and almost pyriform but slightly rounded at margins, length almost equal to width; strongly dorsibiconvex; anterior commissure uniplicate, lateral commissure straight but rises slightly posteriorly. Ventral beak straight, long, and pointed; costae high, subangular, numbering about 14.

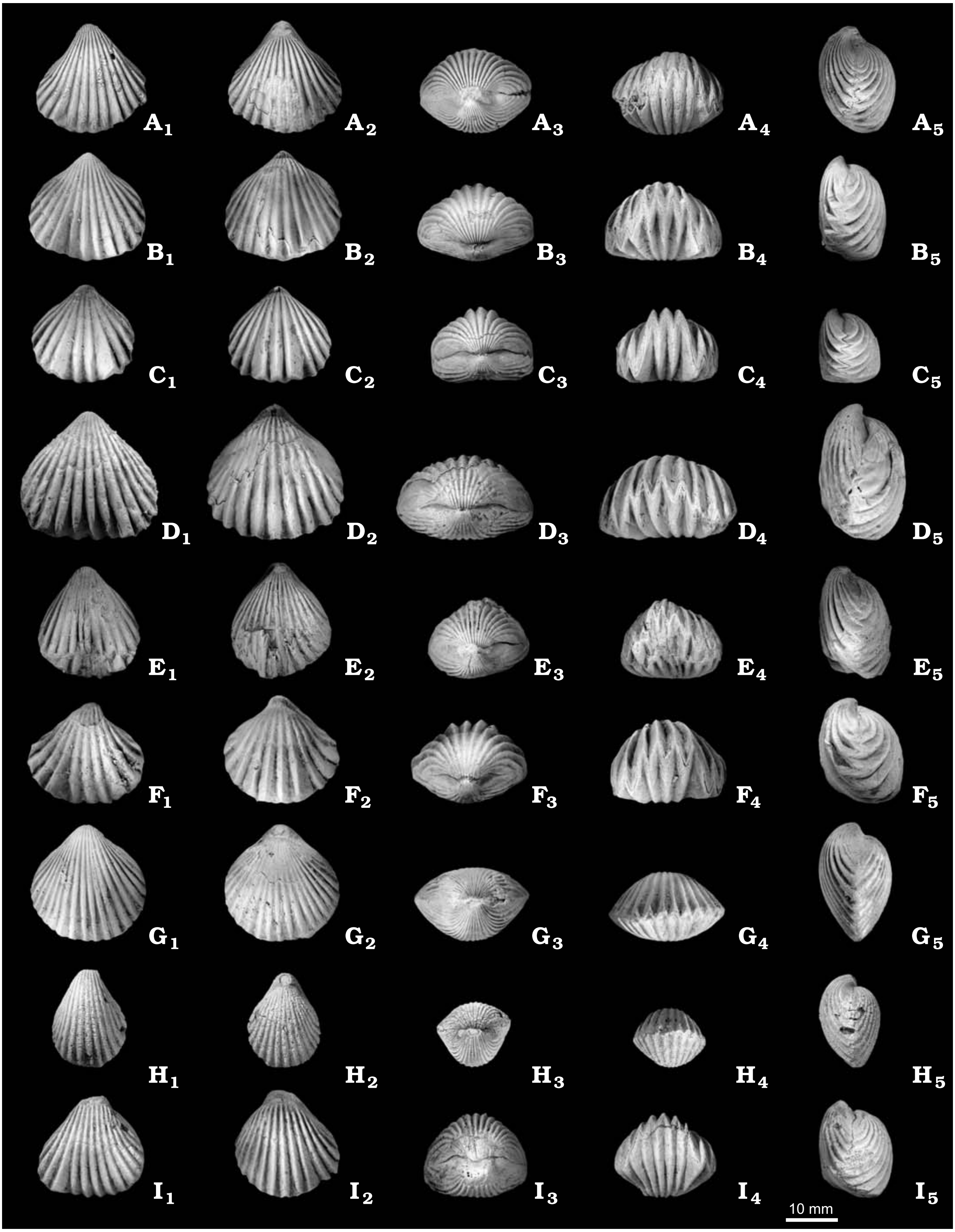
Ventral valve broadly convex in anterior view, less convex in lateral view. Ventral interarea appears high but partially obscured as is the pedicle foramen. Umbo convex, swollen, becoming flatter anteriorly; sulcus low bearing 4 costae, flanks slightly curved with 10 costae.

Dorsal valve with weakly defined fold rising slightly above flanks begins just past midlength becoming more distinct near anterior commissure. The fold bears 5 costae, with 8 costae on each dorsal flank; flanks rounded when viewed anteriorly. In lateral view convexity of dorsal valve is at maximum at midvalve; sides steep.

Table 1. Measurements (in mm) of *Eurysites rotundus* Cooper, 1989.

Specimen	Length	Dorsal valve length	Width	Thickness	Fold width
AMNH FI-72366	21.4	19.3	21.6	15.7	10.4
AMNH FI-72367	20.2	18.1	20.6	13.0	10.3
AMNH FI-72368	14.5	12.3	15.1	10.1	6.4

Fig. 3. Jurassic rhynchonellide brachiopods from Jordan. **A**. *Eurysites rotundus* Cooper, 1989. Articulated specimen (AMNH FI-72366), bed S-7, Mughanniyya Formation, Tel el Dhahab, Jordan, in ventral (A_1), dorsal (A_2), posterior (A_3), anterior (A_4), and lateral (A_5) views. **B**. *Cymatorhynchia quadriplicata* (Zieten, 1830). Articulated specimen (GSI M 2975), bed 21a, Hamam Formation, Arda, Jordan, in ventral (B_1), dorsal (B_2), posterior (B_3), anterior (B_4), and lateral (B_5) views. **C**. *Daghanirhynchia susanae* sp. nov. Articulated specimen, holotype (AMNH FI-72380), bed S-7, Mughanniyya Formation, Arda section, Jordan, in ventral (C_1), dorsal (C_2), posterior (C_3), anterior (C_4), and lateral (C_5) views. **D**. *Daghanirhynchia angulocostata* Cooper, 1989. Articulated specimen (AMNH FI-72395), bed S-7, Mughanniyya Formation, Tel el Dhahab, Jordan, in ventral (D_1), dorsal (D_2), posterior (D_3), anterior (D_4), and lateral (D_5) views. **E**. *Daghanirhynchia triangulata* Cooper, 1989. Articulated specimen (AMNH FI-72398), bed 21a, Hamam Formation, Arda, Jordan, in ventral (E_1), dorsal (E_2), posterior (E_3), anterior (E_4), and lateral (E_5) views. **F**. *Pycnoria magna* Cooper, 1989. Articulated specimen (AMNH FI-72399), bed 21a, Hamam Formation, Arda, Jordan, in ventral (F_1), dorsal (F_2), posterior (F_3), anterior (F_4), and lateral (F_5) views. **G**. *Amydroptychus markowitzi* sp. nov. AMNH FI-72405, holotype, bed S-7, Mugannhiyya Formation, Arda section, Jordan, in ventral (G_1), dorsal (G_2), posterior (G_3), anterior (G_4), and lateral (G_5) views. **H**. *Schizoria elongata* Cooper, 1989. Articulated specimen (AMNH FI-72408), bed S-7, Mughanniyya Formation, Tel el Dhahab section, Jordan, in ventral (H_1), dorsal (H_2), posterior (H_3), anterior (H_4), and lateral (H_5) views. **I**. *Schizoria* cf. *intermedia* Cooper, 1989. Articulated specimen (AMNH FI-72409), bed 21b, Hamam Formation, Arda section, Jordan, in ventral (I_1), dorsal (I_2), posterior (I_3), anterior (I_4), and lateral (I_5) views. →



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Due to a paucity of material we did not section any specimens. However, Cooper (1989) illustrates transverse serial sections which show relatively thick dental plates that disappear before midvalve. His dorsal valves have a very short median septum or ridge with thick outer hinge plates; the crura are raduliform with well developed bases.

Discussion.—*Eurysites rotundus* differs from *E. transversus* (see Cooper 1989: fig. 18; pl. 8: 50–59; pl. 9: 1–16; pl. 17: 12) in its triangular shape and more swollen dorsal valves that are distinctly more convex in lateral view and less elliptical outline. On our specimen of *E. rotundus* there are no fila visible possibly due to the somewhat weathered shell surface. Cooper (1989) noted that on his specimens of *E. rotundus* from Saudi Arabia (housed in the USNM) there were fine concentric fila in the interspaces between the costae. *E. rotundus* is similar to *Flabellirhynchia* Buckman, 1918 from the Bajocian of Great Britain in its elongated beak and outline. It resembles *Flabellirhynchia delicata* (Buckman 1918: pl. 19: a–c) in general outline but differs in its lower fold, thicker and stubbier anterior commissure and longer beak.

Remarks.—The genera *Cymatorhynchia* and *Flabellirhynchia* were introduced by Buckman (1918) in a paper that has been dated originally as 1917, however, the footnote to Corrigenda sheet from the Geological Survey of India states: "Print off orders regarding this memoir were given to the press in September, 1917, but owing to shortage of paper, copies were not actually issued till July, 1918"; Shi and Grant (1993: 144). As not all following authors noticed the actual publication date *Cymatorhynchia* and *Flabellirhynchia* are cited in some papers as 1918 and elsewhere as 1917.

Stratigraphic and geographic range.—Bajocian to Callovian; Saudi Arabia, Jordan.

Family Tetrarhynchiidae Ager, 1965

Subfamily Tetrarhynchiinae Ager, 1965

Genus *Cymatorhynchia* Buckman, 1918

Type species: *Rhynchonella cymatophorina* Buckman, 1910; Aalenian to upper Bajocian of Europe, Africa, Saudi Arabia, India, Burma, China, and Tibet.

Cymatorhynchia quadriplicata (Zieten, 1830)

Figs. 3B, 4.

1830 *Terebratula quadriplicata*; Zieten 1830: 55, pl. 41: 3.

1851 *Terebratula quadriplicata*; Quenstedt 1851: 453, pl. 36: 16; 1858: 423, pl. 58: 5–8; 1868–1871, pl. 38: 42.

1851–1852 *Rhynchonella quadriplicata* (Zieten); Davidson 1851–1852: appendix: 23, pl. A: 22; 201, pl. 29: 1–3.

1918 *Cymatorhynchia quadriplicata* (Zieten); Buckman 1918: 53–54.

1918 *Rhynchonella quadriplicata* (Zieten); Rollier 1918: 148.

1936 *Rhynchonella quadriplicata* (Zieten); Arcelin and Roche 1936: 59, pl. 2: 1–6, pl. 11: 1, 4, 5, pl. 12: 5, pl. 13: 3, 4.

1939 *Rhynchonella quadriplicata* (Zieten); Roche 1939: 268, pl. 4: 11.

1965 *Cymatorhynchia quadriplicata* (Zieten in Davidson); Rousselle 1965: 52, pl. 2: 11, 12.

1966 *Cymatorhynchia quadriplicata* (Zieten); Alméras 1966: 70–97, 73, pl. F–G, pl. 2: 5–8.

1966 *Cymatorhynchia quadriplicata* var. *vergissonensis*; Alméras 1966: 79, pl. D–E, pl. 2: 1–4.

1966 *Cymatorhynchia quadriplicata* var. *lata*; Alméras 1966: 88, pl. I, pl. 4: 6–8.

1966 *Cymatorhynchia quadriplicata* var. *depressa*; Alméras 1966: 95.

1966 *Cymatorhynchia quadriplicata* var. *trilobata*; Alméras 1966: 96.

1969 *Cymatorhynchia quadriplicata* (Zieten); Pevny 1969: 143, pl. 28: 1a–c.

1980 *Cymatorhynchia quadriplicata* (Zieten); Fischer 1980: 140, pl. 58: 1, 2.

1981 *Cymatorhynchia quadriplicata* (Zieten); Parnes 1981: 21, pl. 2: 5–13.

1987 *Cymatorhynchia quadriplicata* (Zieten); Shi 1987: 55, pl. 3: 12.

1993 *Cymatorhynchia quadriplicata* (Zieten, 1830); Shi and Grant 1993: 72–73, pl. 7: 17–19, pl. 8: 8–13, pl. 9: 1–7, 11–17, pl. 12: 1, 2, 6, 7.

1996 *Cymatorhynchia quadriplicata* (Zieten, 1830); Alméras and Elmi 1996: pl. 1: 21.

Material.—42 articulated specimens: AMNH FI-72369 (sectioned), AMNH FI-72370, bed S-7, AMNH FI-72371, AMNH FI-72372, AMNH FI-72373, AMNH FI-72374, AMNH FI-72375, bed S-10, Mughanniyya Formation, Tel el Dhahab section; AMNH FI-72376, bed 21a, AMNH FI-72377, bed 21b, AMNH FI-72378–79, bed 25, Hamam Formation, Arda section GSI M 2975, GSI M 742, GSI M 4510, GSI M 4522, GSI M 4539, GSI M 4553, GSI M 4556, GSI M 4565 (collected from the Tel el Dhahab section but beds not identified), Jordan.

Description.—Shells medium to large (Table 2), subpentagonal to subquadrate in outline, moderately dorsibiconvex, maximum width near midlength. Anterior commissure widely uniplicate. Ventral beak short, suberect to erect, deltidial plates disjunct to conjunct; costae subangular to sharp numbering about 16–17; growth lines barely visible near anterior commissure.

Ventral valve moderately to strongly convex posteriorly but less convex anteriorly; a broad, shallow sulcus originates just past one-third of valve length bearing 3–4 strong subangular costae, 5–6 costae on ventral flank; foramen round, small to medium sized, ventral interarea low.

Dorsal valve more globose posteriorly, flattened toward anterior commissure; moderately convex in lateral view; a broad, low fold originates just posterior to midlength bearing 4 costae with 6 costae on dorsal flank.

Table 2. Measurements (in mm) of *Cymatorhynchia quadriplicata* (Zieten, 1830).

Specimen	Length	Dorsal valve length	Width	Thickness	Fold width
AMNH FI-72372	27.3	21.6	25.9	15.3	12.5
AMNH FI-72373	20.0	19.0	23.5	14.7	9.0
AMNH FI-72374	26.6	21.6	29.0	20.8	13.3
AMNH FI-72375	19.1	17.5	21.6	11.0	8.4
GSI M 742	23.6	21.5	24.3	19.9	10.9
GSI M 2975	27.6	23.0	29.5	21.9	14.6
GSI M 4510	26.4	23.8	30.0	20.9	12.1
GSI M 4539	23.3	21.2	24.3	15.5	10.9
GSI M 4553	24.1	21.9	26.1	15.3	12.6
GSI M 4556	21.0	19.1	21.5	14.4	9.1
GSI M 4565	15.7	14.3	15.7	10.4	7.6

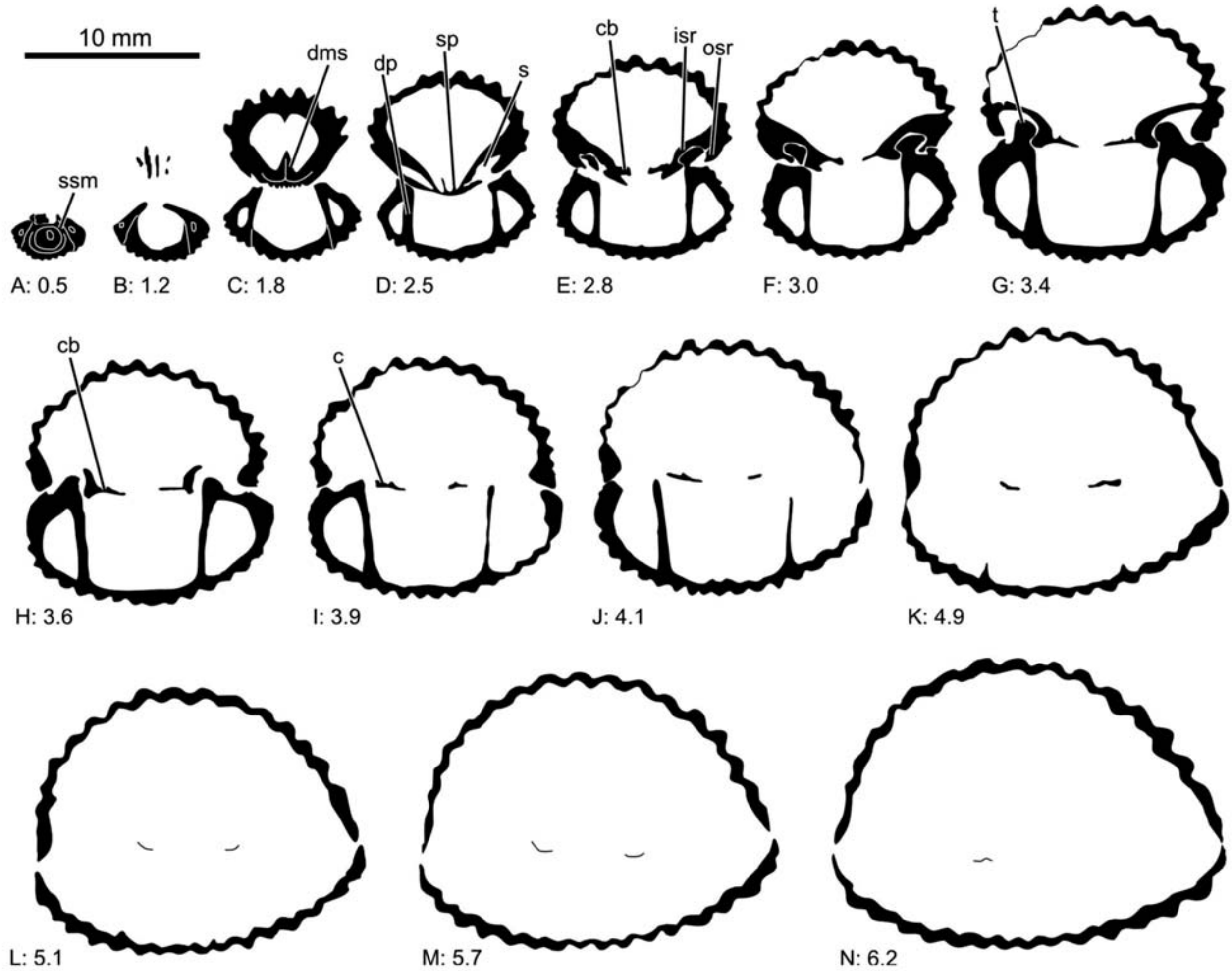

Fig. 4. Serial sections of the rhynchonellide brachiopod *Cymatorhynchia quadriplicata* (Zieten, 1830). AMNH FI-72369. Bed 21a, Hamam Formation, Arda, Jordan. Numbers describe sectional distance from apex. Abbreviations: c, crus; cb, crural base; dms, dorsal median septum; dp, dental plate; isr, inner socket ridge; osr, outer socket ridge; s, socket; sp, septalial plate; ssm, secondary shell material; t, tooth.

Interior. Very short, low dorsal median septum, strong dental plates parallel to subparallel anteriorly in one sectioned specimen, teeth short, somewhat bulbous; septalium not preserved, outer hinge plates subhorizontal arched slightly ventrally, sockets deep, asymmetrical, crura raduliform.

Discussion.—The shells differ from *Cymatorhynchia*? *singularis* (USNM 303631) of Cooper (1989) in possessing less costae, a more inflated dorsal valve and less tumid ventral posterior. Buckman's (1918: pl. 17: 15a, c) *C. cymatophorina* is wider and has finer and more numerous costae (about 26 on the dorsal valve). *Cymatorhynchia quadriplicata* var. *inflata* Alméras (USNM 319165) has a more subcircular outline, more inflated dorsal valve, finer and denser ribs as well as a less developed fold and sulcus as noted by Shi and Grant (1993). They also noted that the Tethyan form varies considerably in morphology and was split into seven variants by Alméras (1966). Five of the variants (except for *C. quadriplicata* var. *densecosta* and *C. quadriplicata* var. *inflata*) have the same basic characteristics namely, less tumid dorsal than ventral valve, slightly depressed shell, subpentagonal outline, and few but strong ribs. Shi and Grant therefore regard them as a single variable species: *C. quadriplicata* (Zieten, 1830). They suggest combining the varieties *C. quadriplicata denecosta* and *C. quadriplicata* var. *inflata* into a single species: *Cymatorhynchia denecosta* Alméras, 1966. Alméras and Elmi (1996) describe a specimen of *C. quadriplicata v*ar. *inflata* from Toulon, France, that is larger (USNM 541691: L, 30.3; W, 29.4 [est.]; T, 24.8), much more gibbous and has finer and more numerous costae (about 26). *C. quadriplicata v*ar. *inflata* from Württemberg, Germany, has similar dimensions (USNM 541692: L, 30.1; W, 33.0; T, 24.4) but the costae are less numerous (20) and sturdier.

Stratigraphic and geographic range.—Bathonain to Callovian; England, France, Jordan, Ethiopia.

Genus *Daghanirhynchia* Muir-Wood, 1935

Type species: *Daghanirhynchia daghaniensis* Muir-Wood, 1935; Callovian, Somalia.

Daghanirhynchia susanae sp. nov.

Figs. 3C, 5.

Etymology: Latinization of Susan after Susan Feldman.

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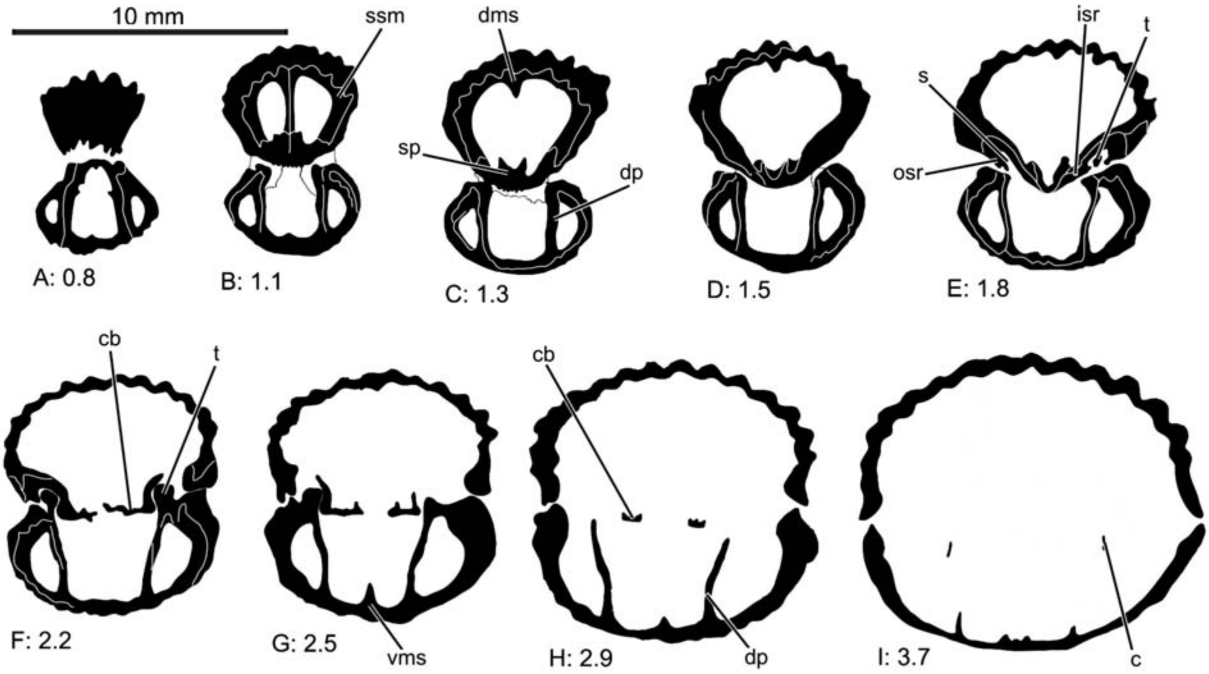

Fig. 5. Serial sections of rhynchonellide brachiopod *Daghanirhynchia susanae* sp. nov. AMNH FI-72410. Bed 21b, Hamam Formation, Arda, Jordan. Numbers describe sectional distance from apex. Abbreviations: c, crus; cb, crural base; dms, dorsal median septum; dp, dental plate; isr, inner socket ridge; osr, outer socket ridge; s, socket; sp, septalial plate; ssm, secondary shell material; t, tooth; vms, ventral median septum.

Holotype: Articulated specimen AMNH FI-72380.

Type locality: Wadi Zarqa, Arda Section, Jordan.

Type horizon: Bed S-7, Mughanniyya Formation, Callovian (upper Middle Jurassic).

Material.—45 articulated shells: AMNH FI-72380, AMNH FI-72381, AMNH FI-72386, AMNH FI-72388, AMNH FI-72393, AMNH FI-723410 (sectioned) bed S-7, AMNH FI-72394, bed S-10, AMNH FI-72383, AMNH FI-72387, AMNH FI-72391, AMNH FI-72392, Mughanniyya Formation, Arda section; AMNH FI-72382, AMNH FI-72384, bed 21a, AMNH FI-72389, bed 21b, AMNH FI-72385, Hamam Formation, Arda section; GSI M 731, GSI M 732, GSI M 741, GSI M 743, GSI M 4506, GSI M 4552, GSI M 4558 (collected from the Tel el Dhahab section but beds not identified), Jordan.

Diagnosis.—Coarsely plicated *Daghanirhynchia* with long, narrow fold bearing 3 costae.

Description.—The shells are medium size (Table 3), subpentagonal in outline, dorsibiconvex, maximum width at about midlength; strongly uniplicate anterior commissure, lateral commissure straight, beak suberect to erect, costae strong and coarse and narrow, numbering 12–16 but commonly 12–13, linguiform extension moderate. Anterior margin ends abruptly, stubby.

Ventral valve gently convex to almost flat in lateral view, concave in anterior profile. Sulcus originates just anterior to umbonal region, occupied by 2–3 costae. Foramen small, deltidial plates disjunct.

Dorsal valve moderately convex in lateral profile, fold originates just anterior to umbonal region, very narrow, highly elevated above flanks, occupied by 3 costae.

Dental plates parallel in posterior region of shell but diverge anteriorly from ventral floor. Teeth short, bulbous without crenulations; dorsal median septum short, reduced to low ridge, and finally disappearing at about one-third valve

Table 3. Measurements (in mm) of *Daghanirhynchia susanae* sp. nov.

Specimen	Length	Dorsal valve length	Width	Thickness	Fold width
Holotype AMNH FI-72380	19.0	17.9	19.5	15.4	6.9
AMNH FI-72381	21.5	19.6	22.8	16.9	6.5
AMNH FI-72382	22.0	19.7	22.7	16.5	6.5
AMNH FI-72383	21.9	18.8	22.4	12.1	7.9
AMNH FI-72384	20.1	17.3	19.9	15.9	6.7
AMNH FI-72385	21.0	20.0	21.6	16.5	8.2
AMNH FI-72386	21.5	19.4	23.9	15.4	7.4
AMNH FI-72387	20.7	18.1	20.8	14.6	7.1
AMNH FI-72388	24.1	21.6	25.3	20.6	8.1
GSI M 743	18.3	16.3	20.4	15.1	6.4

length. Hinge plates horizontal, very broad, and separated; septalium not preserved; crura raduliform. Secondary thickening in umbonal chambers.

Discussion.—*Daghanirhynchia susanae* sp. nov. differs from the type species *D. daghaniensis* Muir-Wood, 1935 in having coarser costae and a longer narrower fold. *D. macfadyeni* Muir-Wood, 1935 differs in that its fold is never raised above the level of the lateral slopes and bears a low, median fold. *D. elongata* Muir-Wood, 1935 is generally longer with finer costae and a shorter sulcus. The umbo in *D. elongata* extends further posteriorly than in *D. susanae. Daghanirhynchia macfadyeni* Muir-Wood, 1935 is characterised by a more convex ventral valve, a shallower shorter sulcus, and 4 costae on the fold. The costae of *D. macfadyeni* are finer than in *D. susanae* but may reach the same thickness in a few specimens. *D. platiloba* Muir-Wood, 1935 differs from the new species in having a less convex dorsal valve, a longer ventral umbo, and a shallower, shorter sulcus. *D. kabeitensis* Muir-Wood, 1935 is wider than *D. susanae* and has a longer ventral umbo. The size of costae and sulcus is the same as in *D. susanae*, *D. farquharsoni* Muir-Wood, 1935 is equibiconvex, whereas the specimens of *D. susanae* are clearly dorsibiconvex. The sulcus in *D. farquharsoni* is shallower than in *D. susanae* and sulcus and fold are rectangular in cross section, whereas in *D. susanae* the fold and sulcus are broadly rounded in cross section.

Stratigraphic and geographic range.—Bathonian to Callovian; Jordan.

Daghanirhynchia angulocostata Cooper, 1989

Fig. 3D.

1989 *Daghanirhynchia angulocostata* sp. nov.; Cooper 1989: 26–28, pl. 6: 1–19, pl. 7: 44–53, pl. 11: 16–21, figs. 13, 14.

Material.—Two articulated specimens: AMNH FI-72395, AMNH FI-72396, bed S-7, Mughanniyya Formation (Callovian, upper Middle Jurassic), Tel el Dhahab section, Jordan.

Description.—Shells large (Table 4), outline widely triangular with maximum width anterior to midlength. Anterior commissure strongly uniplicate; costae coarse and subangular in cross section, 14–15 in number; ventral beak narrow, suberect; ventral interarea low. Foramen medium to large, longitudinally oval to suboval. Deltidial plates disjunct.

Ventral valve almost flat in lateral view, umbonal region moderately swollen. Sulcus originates just posterior to midlength and deepens anteriorly with 3–4 costae. Linguiform extension moderate with narrow, slightly convex flanks adjacent to sulcus with 6–7 costae.

Dorsal valve moderately convex in lateral profile, moderately to gently domed in anterior view; fold originates just posterior to midvalve but in some shells at midvalve, elevating slightly with 4 costae, 6 costae on dorsal flank.

The internal structures of the shells are unknown due to a lack of sufficient material for serial sectioning.

Discussion.—The Jordanian specimens compare favourably with Cooper's (1989) shells in that they are large and widely

Table 4. Measurements (in mm) of *Daghanirhynchia angulocostata* Cooper, 1989.

Specimen	Length	Dorsal valve length	Width	Thickness	Fold width
AMNH FI- 72395	25.3	22.3	25.9	16.2	11.5
AMNH FI- 72396	20.2	17.8	23.5	12.7	7.5

triangular with maximum width anterior to midlength. Muir-Wood's (1935) description of the genus includes the presence of fine radial striae as a feature of the genus. Cooper (1989) did not observe these features on his shells from Saudi Arabia and found none on the specimens in the USNM collections from the type locality of *D. daghaniensis* Muir-Wood, 1935 (USNM 75665, 75666). The Jordanian shells are also lacking this feature as well as the thickened deltidial plates observed by Cooper (1989) in his Saudi Arabian shells.

Stratigraphic and geographic range.—Bathonian to Callovian, Saudi Arabia, Jordan.

Daghanirhynchia? *triangulata* Cooper, 1989

Fig. 3E.

1989 *Daghanirhynchia*? *triangulata* sp. nov.; Cooper 1989: 28–29, pl. 7: 6–21, pl. 11: 11–15.

Material.—Two articulated specimens: AMNH FI-72397, bed S-7, Mughanniyya Formation (Callovian, upper Middle Jurassic), Tel el Dhahab section; AMNH 72398, bed 21a, Hamam Formation, Arda section, Jordan.

Description.—There are two shells in the collection (Table 5) tentatively assigned to *Daghanirhynchia*? *triangulata* Cooper, 1989. The specimens are triangular with maximum width considerably past midlength; slightly dorsibiconvex, strongly uniplicate anterior commissure, lateral commissure straight, beak suberect, costae strong, coarse and narrow, numbering 16–17.

Ventral valve barely convex in lateral view, almost flat, concave in anterior profile. Sulcus originates just past umbonal region, occupied by three costae. Linguiform extension long and fairly narrow; ventral interarea low; 6–7 costae on flanks.

Dorsal valve slightly convex in lateral view, strongly domed in anterior view, sides becoming steeper as lateral margins approached. Fold begins at about midlength, occupied by 4 costae, slightly less than half the valve width; 6 costae on flanks.

The internal structures of the shells are unknown due to a lack of sufficient material for serial sectioning.

Discussion.—The shell closely resembles Cooper's (1989)

Table 5. Measurements (in mm) of *Daghanirhynchia*? *triangulata* Cooper, 1989.

Specimen	Length	Dorsal valve length	Width	Thickness	Fold width
AMNH FI- 72397	26.5	23.1	23.5	21.3	9.7
AMNH FI- 72398	22.7	20.2	22.4	13.6	7.6

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Daghanirhynchia? *triangulata* in its triangular outline and costation and is tentatively placed in that taxon until additional material can be studied.

Stratigraphic and geographic range.—Callovian, Jordan.

Genus *Pycnoria* Cooper, 1989

Type species: *Pycnoria magna* Cooper, 1989; Callovian, Saudi Arabia.

Pycnoria magna Cooper, 1989

Figs. 3F, 6.

1989 *Pycnoria magna* sp. nov.; Cooper 1989: 53–54, pl. 12: 11–36, pl. 18: 26–36, figs. 29, 30.

1991 *Pycnoria magna* Cooper; Feldman et al. 1991: 15, figs. 11A–C.

Material.—Six articulated specimens: AMNH FI-72402, AMNH FI-72404, AMNH FI-72403 (sectioned), bed S-7, AMNH FI-72400, bed S-20, Mughanniyya Formation (Callovian, upper Middle Jurassic), Tel el Dhahab section, AMNH FI-72401, bed 25, Mughanniyya Formation Formation (Callovian, upper Middle Jurassic), Arda section; AMNH FI-7299, bed 21, Hamam Formation (Bathonian, Middle Jurassic), Arda section, Jordan.

Description.—The shells are medium to large (Table 6) with rounded sides and an obtuse apical angle. Maximum width is at or slightly anterior to midvalve; outline subpentagonal, dorsal valve deeper and more convex than ventral valve. Lateral commissure straight, anterior commissure uniplicate. Beak short, erect to incurved; ventral interarea low, foramen

Table 6. Measurements (in mm) of *Pycnoria magna* Cooper, 1989. *, sectioned.

Specimen	Length	Dorsal valve length	Width	Thick-ness	Fold width
AMNH FI-72399	20.9	17.3	22.2	16.1	10.4
AMNH FI-72400	20.9	17.9	20.0	17.4	8.3
AMNH FI-72401	21.9	19.6	22.0	18.9	10.5
AMNH FI-72401	15.4	13.5	14.8	13.5	5.5
AMNH FI-72402	18.2	16.4	16.0	16.0	6.9
AMNH FI-72403*	21.8	20.8	21.6	15.2	9.5

hypothyrid, deltidial plates small, conjunct. Costae coarse and angular in cross-section numbering about 13–17. Some shells (AMNH FI-72399, AMNH FI-72400, AMNH FI-72401) have a relatively long linguiform extension.

Ventral valve flat in lateral profile but slightly convex in umbonal region; in anterior profile valve is shallowly concave. Low sulcus originates about one-third of distance from beak, deepening anteriorly; sulcus generally bears 3 costae and widens narrowly in some specimens but widely in others. Flanks narrow, steep bearing 4 costae.

Dorsal valve evenly convex in lateral profile, strongly to moderately domed in anterior view, with a well-defined arcuate median fold somewhat to strongly elevated above steep flanks. Fold narrow, originating at about midlength bearing 3–4 costae, usually 4. Flanks bear 5 costae.

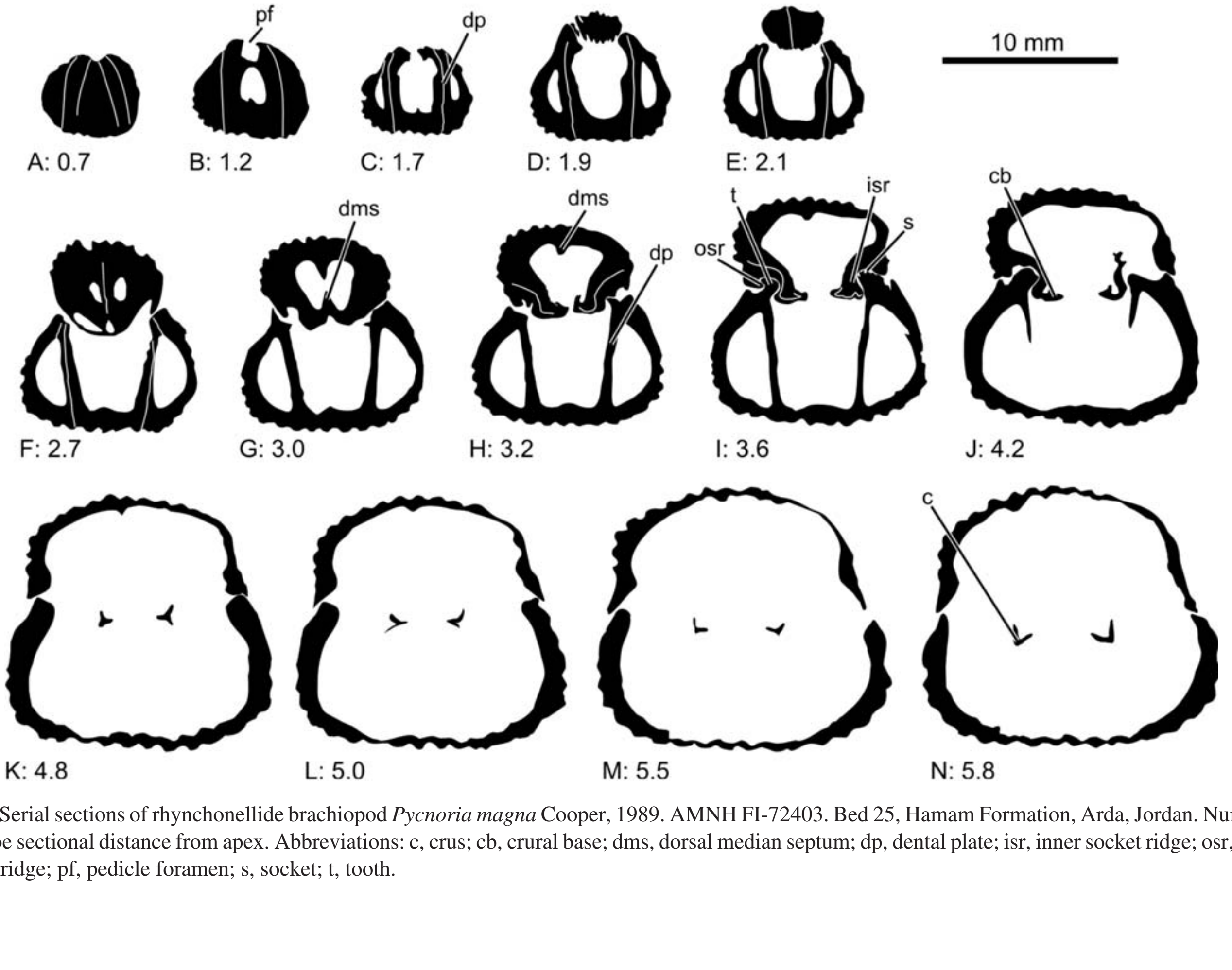

Fig. 6. Serial sections of rhynchonellide brachiopod *Pycnoria magna* Cooper, 1989. AMNH FI-72403. Bed 25, Hamam Formation, Arda, Jordan. Numbers describe sectional distance from apex. Abbreviations: c, crus; cb, crural base; dms, dorsal median septum; dp, dental plate; isr, inner socket ridge; osr, outer socket ridge; pf, pedicle foramen; s, socket; t, tooth.

Dental plates thick, long, and slightly divergent (less than 5°) from valve floor, shell relatively thin, median septum low, very weak. Strong, swollen slightly subquadrate hinge teeth fit into large sockets, crura raduliform, septalium appears to be narrow and short; crural bases weak. One tooth is somewhat corrugated. The general transverse outlines of Cooper's (1989) shells are similar to the Jordanian shells, the height of which is similar as is the presence of the median septum.

Discussion.—These specimens of *Pycnoria magna* compare favourably with the specimens described by Feldman et al. (1991) in that they also have 13 strong, angular, deeply incised costae with a well-defined arcuate median dorsal fold and a comparatively narrow sulcus. The Jordanian shells display more variability in that some have a more highly developed median dorsal fold and a slightly wider and more broadly arcuate anterior commissure, similar to that of *Strongyloria circularis* Cooper, 1989. Cooper's (1989) species of *Pycnoria magna* (USNM 303631; 243375) differs in that they have very fine concentric lines crossing the costae, a feature that may well have been removed here by exfoliation. *Pycnoria* differs from common rhynchonellides such as *Somalirhynchia* and *Daghanirhynchia* in its more solid and compact form as noted by Cooper (1989). We are in agreement with him that it differs from *Globirhynchia triangulata* in its stronger costation, narrower fold and deeper sulcus. *Burmirhynchia* is generally smaller with fewer costae (see Buckman 1918).

Stratigraphic and geographic range.—Bathonian to Callovian; Saudi Arabia, Jordan.

Subfamily Gibbirhynchiinae Manceñido, Owen, Dongli, and Dagys, 2002

Genus *Amydroptychus* Cooper, 1989

Type species: *Amydroptychus formosus* Cooper, 1989; Bajocian of Saudi Arabia.

Amydroptychus markowitzi sp. nov.

Fig. 3G.

Etymology: Named in memory of Alfred Markowitz (1926–2000), scientist, Renaissance Man, and healer.

Holotype: AMNH FI-72405.

Type locality: Arda section, Wadi Zarqa, Jordan.

Type horizon: Bed 27, Mughanniyya Formation (Callovian, upper Middle Jurassic).

Material.—Two articulated specimens: AMNH FI-72405 (holotype), AMNH FI-72406, bed 27, Mughanniyya Formation (Callovian, upper Middle Jurassic); Arda section, Jordan.

Diagnosis.—*Amydroptychus* with subcircular outline, equibiconvex, medium to large foramen, and rectimarginate anterior commissure with no indication of fold or sulcus.

Description.—Medium-sized shells (Table 7), outline subcircular and equibiconvex in longitudinal section without any indication of fold or sulcus. Ventral valve covered by 20 simple costae, dorsal valve by 21 costae. Furrows and costae are angular to rounded in cross section. Equibiconvex, apical angle acute, deltidial plates obscured, foramen medium, tubular. Anterior commissure rectimarginate; lateral commissure straight. Ventral beak erect in adults but suberect in juveniles. Twenty-one angular costae on adults and 25 on juveniles. Intercalations and bifurcations observed on juveniles but rare on adult specimens.

Table 7. Measurements (in mm) of *Amydropthychus markowitzi* sp. nov. *, rectimarginate anterior commissure.

Specimen	Length	Dorsal valve length	Width	Thick-ness	Fold width
Holotype AMNH FI-72405	22.7	20.4	22.2	13.7	*
AMNH FI-72406	14.8	13.2	15.0	8.4	*

The ventral valve is convex in lateral profile with the apex of the convexity occurring at one-third the distance from the beak; in anterior profile the valve is more sharply domed with the flanks sloping somewhat steeply until the commissure is reached.

The dorsal valve is convex in lateral view bulging more posteriorly and sloping gently toward the anterior commissure. In the juvenile specimens the bulge is less developed.

The internal structures of the shells are unknown due to a lack of sufficient material for serial sectioning.

Discussion.—The gentle folding that Cooper (1989) noted as being a conspicuous feature of *Amydroptychus formosus* is absent here. These specimens resemble *Strongyloria circularis* Cooper, 1989 but are less globose, lack an arcuately uniplicate anterior commissure, and have a narrower beak. In addition, these shells are more triangular than circular in outline as are *Strongyloria circularis* and *S. subelliptica* Cooper, 1989. Hegab (2005) described *Amydroptychus galaensis* from the Jurassic of the western side of the Gulf of Suez, Egypt, that differs from the Jordanian shells in their slightly sulcate anterior commissure (2005: 740, figs. 3, 6) and smaller number of costae (16).

Stratigraphic and geographic range.—Callovian; Jordan.

Genus *Schizoria* Cooper, 1989

Type species: *Schizoria elongata* Cooper, 1989; Bajocian of Saudi Arabia.

Schizoria elongata Cooper, 1989

Fig. 3H.

1989 *Schizoria elongata* sp. nov.; Cooper 1989: 55–56, fig. 31: 14, figs. 17–27.

Material.—Three articulated specimens: AMNH FI-72407, AMNH FI-72408, AMNH FI-72411, bed S-7, Mughanniyya Formation (Callovian, upper Middle Jurassic); Tel el Dhahab section, Jordan.

Description.—Shells small (Table 8), elongate but slightly oval, maximum width just anterior to midvalve. Dorsal valve deeper and asymmetrically more convex than ventral valve with the convexity more pronounced posteriorly; apical angle acute; anterior commissure on larger shell barely uniplicate

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Table 8. Measurements (in mm) of *Schizoria elongata* Cooper, 1989. *, rectimarginate anterior commissure.

Specimen	Length	Dorsal valve length	Width	Thickness	Fold width
AMNH FI- 72407	20.5	17.3	14.0 est.	12.5	*
AMNH FI- 72408	15.5	13.7	12.4	10.1	*

but on smaller shell not preserved well enough to determine morphology; lateral commissure straight. Beak narrow, long; foramen medium, mesothyrid, tubular; deltidial plates disjunct, ventral interarea low. Costae moderate and angular in cross section but subangular and rounded on smaller shell due to weathering and exfoliation; bifurcated and intercalated mostly on umbos ranging from 24–25 in number.

Ventral valve moderately convex in lateral profile and highly domed in anterior view. Umbonal region swollen, more so in large shell. Fold with 5 costae; 6 to 7 costae on flank of ventral valve.

Dorsal valve swollen posteriorly but less so in smaller specimen; highly domed in anterior view on the larger shell. Sulcus with 4 costae; 5 to 7 costae on flank.

The internal structures of our shells are unknown due to a lack of sufficient material for serial sectioning.

Discussion.—The shells closely resemble Cooper's (1989) *Schizoria elongata* in many respects but differ in that the pedicle foramen here is mesothyrid and is slightly larger than in his specimens. *Schizoria intermedia* Cooper, 1989 has more widely spaced costae on the flanks, fold, and sulcus with no bifurcations and rare intercalations; it also has a strongly uniplicate anterior commissure. *Sphenorhynchia plicatella* differs from *Schizoria elongata* in its less elongate-oval general outline, more evenly biconvex valves, shorter and more massive umbo, and less numerous costellae.

Stratigraphic and geographic range.—Bajocian to Callovian; Saudi Arabia, Jordan.

Schizoria cf. *intermedia* Cooper, 1989

Fig. 3I.

Material.—One articulated specimen, AMNH FI-72409, bed 21b, Hamam Formation (Bathonian, middle Middle Jurassic); Arda section, Jordan.

Description.—Shell small (L = 21.6; W = 20.0; T = 15.4), elongate oval in longitudinal direction, maximum width anterior of midvalve, dorsal valve more globose than ventral valve; sides rounded, anterior commissure strongly uniplicate; ventral beak and foramen damaged; lateral commissure straight; about 17 angular to subangular costae with no bifurcations or intercalations.

Ventral valve slightly convex in lateral view, gently domed and almost flat on top, umbonal region barely swollen; sulcus broad and shallow, originating at midvalve, bearing 4 costae.

Dorsal valve moderately convex in lateral profile, and evenly but narrowly domed in anterior view; fold beginning almost at midvalve, bearing 5 costae.

The internal structures are unknown due to a lack of sufficient material for serial sectioning.

Discussion.—The shell resembles *Schizoria intermedia* Cooper, 1989 but a definite taxonomic assignment cannot be made at this time due to inadequate material for serial sectioning and a damaged beak on the single specimen in the collection.

Stratigraphic and geographic range.—Bathonian, Jordan.

Paleobiogeography

Limestone beds dominate the Middle Jurassic Mughanniyya Formation of northwest Jordan with minor admixture of marl and claystone. Most of the Jurassic rocks of Jordan were deposited in shallow water, nearshore environments where food supply and light were not likely to have been limiting factors (Wolff 1973) which explains the high and diverse faunal content. The environment of deposition appears to have been neritic. We hope to provide data that will enable a more precise stratigraphic correlation between the strata in northwestern Jordan and southern Israel (e.g., Hamakhtesh Hagadol or Kurnub Anticline). Lewy (1983) noted that the lithostratigraphic correlation of the strata in the Zarqa River area with those in Israel lacks the necessary biostratigraphic data for the recognition of the equivalents to the Upper Callovian Zohar and Kidod formations in Jordan. During the Callovian there was a continuous platform sedimentation regime and a regional sea level high during Middle and Upper Callovian times that inundated most of the Arabian Platform with carbonates. In Sinai (Gebel el-Maghara) these limestone rocks built up the Aroussiah Formation. In the southern Negev the sequence appears to contain more marls (Hamahktesh Hagadol) and is known as the Zohar and Matmor formations (Hirsch et al. 1998; Hirsch 2005). In Jordan, the Mughanniyya Formation represents only the lowermost part of the Zohar Formation, as the youngest portion of the interval was eroded in infra-Cretaceous times (see Goldberg and Friedman 1974). It is of utmost interest as it represents a lower interval that is not exposed in the Jurassic of southern Israel (Hamahktesh Hagadol). These rocks yielded a fauna that is related to Ethiopian-Somali taxa (brachiopods, bivalves [e.g., *Eligmus* Eudes-Deslongchampes, 1856], gastropods and foraminiferans [e.g., *Kurnubia* lineage]). The northeastern Ethiopian Province was part of a broad shelf surrounding the Arabo-Nubian craton in the Middle Jurassic (Lewy 1983). Shelf and marginal marine flats with mostly carbonates and evaporites dominated the broad platform of northern Gondwana, whereas southern Tethyan Seaway deep water basinal limestone, radiolarian chert, and ophiolites (Goldberg and Friedman 1974) characterise obstructed terranes to the north along the Cyprus Arc and Assyrian Suture (Krashennikov et al. 2005).

A high degree of endemism characterises the rhynchonellide brachiopod faunas of the Jurassic Ethiopian Province. In the Sinai Peninsula (Gebel el-Maghara), southern Israel (Hamahktesh Hagadol), and in Saudi Arabia (Dhruma, Tuwaiq Mountain, and Hanifa formations) *Somalirhynchia* is relatively widespread but absent in correlative rocks in Jordan. In Hamahktesh Hagadol *Somalirhynchia* and *Burmirhynchia* occur in the Late Callovian Matmor Formation that are missing in Wadi Zarqa, Jordan. However, we have identified *Eurysites*, *Cymatorhynchia*, *Daghanirhynchia*, *Pycnoria*, *Schizoria*, and *Amydroptyhcus* from the early–middle Callovian Mughanniya Formation in Jordan. Cooper (1989) noted the high degree of endemism in a Saudi Arabian brachiopod fauna in which he described 13 new rhynchonellide genera (Dhruma, Tuwaiq Mountain, and Hanifa formations). Kier (1972) noted an extremely high degree of endemism in his study of Jurassic echinoids of Saudi Arabia; 24 out of 27 taxa were new. Muir-Wood's (1925) Jordan Valley fauna and Weir's (1925) Somalia fauna were not included here due to the lack of reliable identification since interior sections of these taxa are not available.

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